Global distribution of volcanism: Regional and country profiles

Report IV of the GVM/IAVCEI contribution to the UN-ISDR Global Assessment Report on Disaster Risk Reduction 2015

A report by Global Volcano Model[1] and the
International Association of Volcanology and Chemistry of the Earth's Interior[2]

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1. The Global Volcano Model (GVM; http://globalvolcanomodel.org/) was launched in 2011 and has grown to include 31 partner institutes collaborating from across the globe representing scientists from disciplines including volcanology, engineering and social science as well as private sector institutions. GVM is an international collaborative platform to integrate information on volcanoes from the perspective of forecasting, hazard assessment and risk mapping. The network aims to provide open access systematic evidence, data and analysis of volcanic hazards and risk on global and regional scales, and to support Volcano Observatories at a local scale.
2. The International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI; http://www.iavcei.org/) is an association of the International Union of Geodesy and Geophysics (IUGG). IAVCEI is the international association for volcanology with about 2000 members. The Association represents the primary international focus for: (1) research in volcanology, (2) efforts to mitigate volcanic disasters, and (3) research into closely related disciplines. There are 22 topic focussed Commissions of IAVCEI covering all aspects of volcanology, including hazards and risk.

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Cover image: The incandescent lava dome at the summit of Soufriere Hills Volcano, Montserrat. Photograph by Paul Cole.

Contents

1 Introduction

This background paper provides a resource for the relative analysis of volcanic hazard and risk around the world on the basis of regions and individual countries with volcanoes that have been active in the last 10,000 years. Global information can mask the fact that there are great variations between countries with active volcanoes in terms of the number of volcanoes, knowledge about these volcanoes and their hazards, and current capacity to monitor them. Volcanic hazards are, with the exception of ash hazard and gas, localised to the vicinity of a volcano and thus dedicated volcano observatories play an important role in disaster risk reduction. Country profiles enable the volcanic threat to be evaluated for each country independently. In many respects these profiles reconfigure existing information from diverse sources in a single place as a portrait of volcanic hazard and risk in each country. Knowledge gaps are identified, and current monitoring arrangements described.

Global and regional perspective

Active volcanoes are distributed widely though 86 countries and additional overseas territories worldwide. Globally, the numbers of volcanoes, their eruption styles and proximity to populations vary considerably. Here, we provide profiles illustrating the distribution of volcanoes through the 19 volcanic regions of the world, as described by Siebert et al. (2010) (Figure 1) and for the constituent countries, permitting national and regional analyses of volcanism.

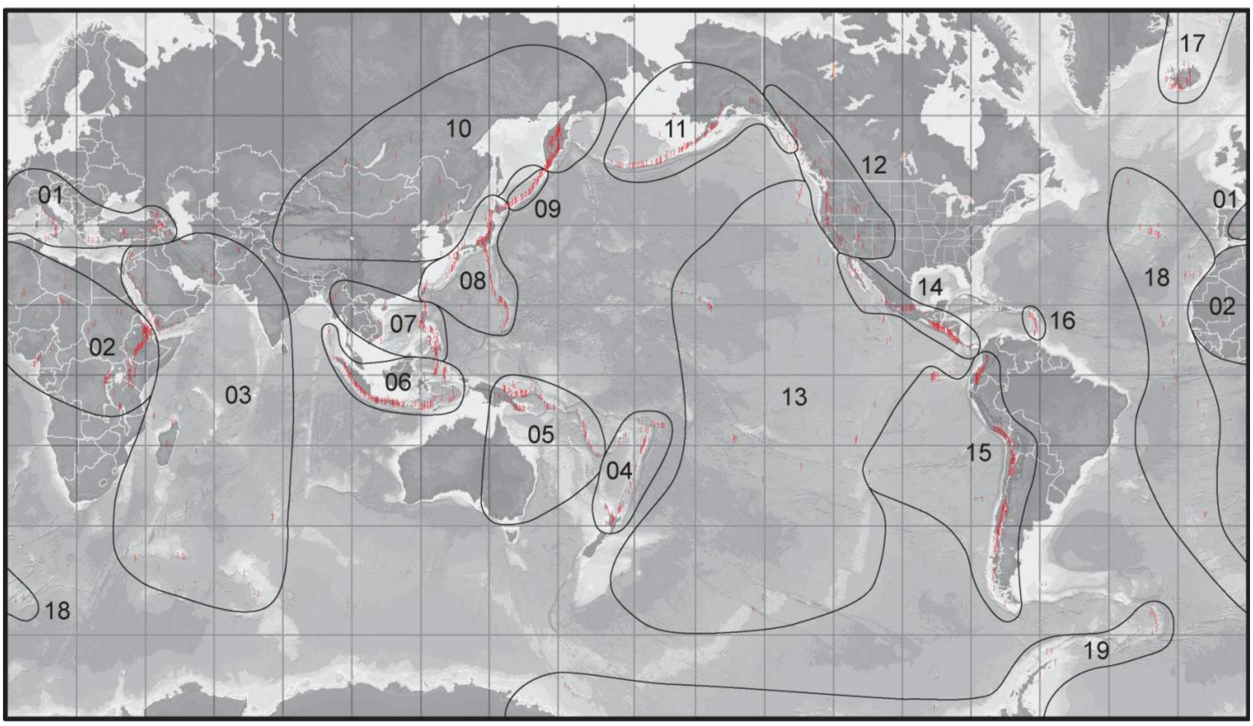

Figure 1: The 19 regions in Siebert et al. (2010) in which all Holocene volcanoes are located. The location of volcanoes is given in VOTW4.0 (2013) to include region, sub-region and country.

Methods, data collection and uncertainty

For each country we have compiled existing and available information on the number of volcanoes, their location, eruption history and character. The Global Volcanism Program of the Smithsonian Institution (VOTW4.0, 2013; Siebert et al. 2010) provides a detailed record for all Holocene volcanoes. VOTW4.22 (downloaded January 2013 for compilation and analysis in this report) is the database version used to provide the known eruption records for these volcanoes.

In addition, we sought the input from WOVO members (World Organisation of Volcano Observatories), and non-WOVO affiliated observatories institutions. A questionnaire was circulated in late 2013 to gather additional information, specifically on current monitoring arrangements for all volcanoes. We received additional corroboration through circulating the final profiles for verification. These contacts resulted in in-country collaboration on about 40% of the profiles. As a result, all the information in this report is to the best of our knowledge up to date and accurate. These profiles have benefited greatly from the collaboration of the international observatory and research institution community.

Despite the variability in data at both national and regional levels, we have developed a series of indices to enable relative global comparison of volcanic hazards and risk. We have applied a Volcano Hazard Index (VHI; described in CS19). From this assessment, three hazard level categories are defined: I to III, with increasing hazard. The country profiles also identify some basic assets at risk, including essential transport infrastructure. Notably, populations at risk are assessed and characterised by the Population Exposure Index (PEI; described in CS1) which provides an indication of population density close to the volcano. These hazard levels are combined with PEI to identify high-risk volcanoes.

The data presented are primarily complicated by data availability and complexities of under-recording, whereby the detail within the eruption record varies both spatially and with time. Data completeness and highly variable data quality are complex issues, and here we cannot fully address the implications of these complexities on the analyses. This knowledge gap prevents over-simplistic interpretation of basic data on numbers of eruptions and volcanoes in each region and country. Comparisons of, for example, numbers of eruptions in different regions could indicate more frequent activity in one region compared with another, when this could be an artefact of the quality of the eruption record rather than a true reflection of volcanic activity.

The monitoring methods, resources and research available vary considerably country-by-country. Identification of knowledge and monitoring gaps highlight significant areas which national governments and the global volcanological community can come together to address, ultimately to share knowledge and expertise, and to make resources available.

Report structure

First, we present a brief synopsis of the findings of both the national and regional data analyses. We then provide brief explanations of the data included in both the regional and country profiles, including description of the data sources and methods used. Note that the profiles should be read with this as an accompanying text: no explanations of the methodologies are given within the profiles themselves.

The profiles are then given for all 19 regions. A summary profile is provided for the region, in which the data for all constituent volcanoes is collated and briefly discussed. Individual profiles are provided for all countries within each region.

2 Synopsis

2.1 Number of Volcanoes

There are 1,551 volcanoes with known or suspected Holocene activity. These are spread unequally across the 19 regions (Table 1). These variations mostly reflect large differences in land area between the different regions as well as uneven distributions of regions in relation to tectonic plate boundaries where most (about 86%) of the world's volcanoes are located.

2.2 Number of eruptions

Eruptions are recorded in VOTW4.22 as confirmed, uncertain and discredited. Uncertain and discredited eruptions are not included in this analysis. There are 9,444 confirmed eruptions from 866 volcanoes during the Holocene. Note that the number of volcanoes with recorded eruptions is fewer than the 1,551 Holocene volcanoes: the remaining volcanoes are suspected to have had activity of Holocene age, but this activity has not been confirmed.

There are two main types of data on volcanic eruptions, namely those that are observed and recorded *historic events* and those that are based only on *geological studies* of deposits. Analysis of historic data indicates that there is a marked decrease in historically recorded eruptions before 1500 AD (Furlan, 2010). Most of the data prior to 1500 AD are from geological studies where deposits have been dated. Indeed, just 9% of eruptions (288 out of 3,321 events) prior to 1500 AD are dated based on recorded human observations. Since 1500 AD, 6,123 eruptions are recorded, of which 95% (5,838) are dated based on historical observations. This combination of data types together with the marked under-recording in the data make basic data on numbers of eruptions, types of eruption and impact hard to interpret.

There are significant variations in the number of eruptions per volcano in the different regions (Table 1). This variation might reflect differences in the frequency of eruptions between regions, but differences in recording are more likely to contribute significantly to these regional variations. Japan (with Taiwan and Marianas) and Iceland, for example, are countries with very good historic and geological records (Table 3) and have high numbers of eruptions per volcano. The global average is 6.1 recorded eruptions per volcano.

Region	Number of confirmed eruptions	Number of volcanoes	Number of eruptions per volcano
Mediterranean and West Asia	446	46	9.7
Africa and Red Sea	196	141	1.4
Middle East and Indian Ocean	252	56	4.5
New Zealand to Fiji	437	56	7.8
Melanesia and Australia	449	83	5.4
Indonesia	1,277	145	8.8
Philippines and SE Asia	203	59	3.4
Japan, Taiwan, Marianas	1481	143	10.4
Kuril Islands	165	49	3.4
Kamchatka and Mainland Asia	781	140	5.6
Alaska	526	92	5.7
Canada and Western USA	245	77	3.2
Hawaii and Pacific	348	34	10.2
Mexico and Central America	781	118	6.6
South America	976	197	5.0
West Indies	132	16	8.3
Iceland and Arctic	503	33	15.2
Atlantic Ocean	166	37	4.5
Antarctica	80	32	2.5

Table 1: The number of confirmed Holocene eruptions and number of volcanoes per region and the ratio of the two.

2.3 Age of eruptions and recording

The median age of eruptions in each region can be used as a metric to provide an approximation of record completeness (the median age is that at which half of the recorded eruptions are older). Since the VOTW4.22 database is for the Holocene, the mid-point is 5,000 BP. Assuming that rates of eruptive activity were uniform and all events were recorded over this period then half of the eruptions would fall either side of 5,000 BP if the record were complete. The record is however, known to be incomplete. There is evidence of increased explosive volcanism in the early Holocene (Brown et al. 2014), but this is a small signal. Under-recording has such a strong effect on the data that the approximation of uniformity is considered valid for using the difference between the median age in the data and the 5,000 BP value as a measure of under-recording. This is an especially important factor in considering the extent to which current assessments and analyses are representative of past activity and the potential to under- or over-estimate hazard and risk.

Table 2 shows the median age for small eruptions (VEI ≤3) and large explosive eruptions (VEI ≥4) by region. There are large variations, but the observation that the median age is so much younger than 5,000 years BP indicates the very strong influence of under-recording.

Region	Number of small eruptions (VEI ≤3)	Median age small eruptions (VEI ≤3) (Year BP)	Number of large eruptions (VEI ≥4)	Median age large eruptions (VEI ≥4) (Year BP)
Mediterranean and west Asia	278	204	27	2894
Africa and Red Sea	143	98	12	5614
Middle East and Indian Ocean	230	115	1	4714
New Zealand to Fiji	323	84	41	3764
Melanesia and Australia	364	52	30	689
Indonesia	1,170	103	34	200
Philippines and SE Asia	162	112	16	336
Japan, Taiwan, Marianas	1,038	130	117	1884
Kuril Islands	124	65.5	15	142
Kamchatka and Mainland Asia	456	118	107	4214
Alaska	275	54	35	2114
Canada and Western USA	104	2814	23	1814
Hawaii and Pacific	294	219	1	224
Mexico and Central America	584	112	70	1589
South America	655	117	89	2214
West Indies	37	71	28	2109
Iceland and Arctic	221	714	51	652
Atlantic Ocean	58	223	13	1634
Antarctica	51	99	1	2224
Global	**6,567**	**110**	**711**	**1884**

Table 2: The number of small (VEI ≤3) and large (VEI≥4) eruptions in each region and the median age (year BP, where present is taken as 2014 AD) of the eruptions.

The median age of small eruptions in almost all regions is close to the present, with most being less than 200 years BP. The median ages of eruptions of VEI ≥4 are generally considerably older than for small eruptions. This likely reflects both the increased geological preservation potential for larger eruptions, which produce thicker and more widespread deposits and the greater impact of larger eruptions which are more likely to have been recorded in historic times. Indonesia has a consistently low median age, reflecting the early stages of the geological studies in this region and the thorough modern eruption record. On average the median age of eruptions is low in Hawaii and the Pacific, Melanesia and Australia, Antarctica and the West Indies. Canada and the Western USA and Kamchatka and Mainland Asia have consistently high median ages, indicative of a more complete Holocene eruption record. Only Canada and Western USA has a median age of VEI ≤3 eruptions approaching the mid-point of the Holocene: this results from a very short historic record and many detailed geological studies in this region, which preferentially identify larger magnitude eruptions.

The proportion of eruptions recorded geologically and historically per region also serves to indicate spatial and temporal variation in the eruption record, whilst also accounting for the eruptions which are recorded without a VEI. Over 70% of eruptions recorded in seven regions are recorded post-1500 AD (Table 3). It is clear that eruptions are normally less frequent with increasing magnitude and as such a longer eruption record is required to capture these large events adequately. Small eruptions in Table 3 can be seen to be dominantly recorded in historical times, whilst the record of large events extends much further back due to geological preservation.

Short eruption records represent knowledge gaps where further investigation is required to complete a more comprehensive eruptive history that captures low-frequency and large-magnitude events, and in many regions efforts are ongoing to improve on the geological record and to improve the catalogue of historical activity. Notwithstanding these efforts it is unlikely that a complete record can ever be constructed before about 1900 AD in any region. Thus future efforts will need to develop statistical and process models to understand the full implications of uncertainty and help to fill this knowledge gap.

Region	Geological: Total number of eruptions pre-1500 AD (% of total)	Historical: Total number of eruptions post-1500 AD (% of total)	Number of small eruptions (VEI≤3)		Number of large eruptions (VEI≥4)	
			Geological	Historical	Geological	Historical
Mediterranean & West Asia	226 (51%)	220 (49%)	73	205	23	4
Africa & Red Sea	47 (24%)	149 (76%)	10	133	11	1
Middle East & Indian Ocean	27 (11%)	225 (89%)	15	214	2	0
New Zealand to Fiji	141 (32%)	296 (68%)	49	274	35	6
Melanesia & Australia	49 (11%)	400 (89%)	1	363	15	15
Indonesia	74 (6%)	1203 (94%)	21	1149	5	29
Philippines & SE Asia	25 (12%)	178 (88%)	0	162	7	9
Japan, Taiwan, Marianas	607 (41%)	874 (59%)	221	817	92	25
Kuril Islands	17 (10%)	148 (90%)	0	124	3	12
Kamchatka & Mainland Asia	444 (57%)	337 (43%)	147	309	92	15
Alaska	193 (37%)	333 (63%)	5	270	22	13
Canada & Western USA	205 (84%)	40 (16%)	76	28	21	2
Hawaii and Pacific	176 (51%)	172 (49%)	125	169	0	1
Mexico & Cent. America	203 (26%)	578 (74%)	43	541	49	21
South America	304 (31%)	672 (69%)	47	608	66	23
West Indies	90 (68%)	42 (32%)	4	33	25	3
Iceland & Arctic	357 (71%)	146 (29%)	122	99	29	22
Atlantic Ocean	108 (65%)	58 (35%)	7	51	11	2
Antarctica	28 (35%)	52 (65%)	8	43	1	0

Table 3: The total number of eruptions recorded geologically (pre-1500 AD) and historically (post 1500 AD). This total includes eruptions of unknown VEI. The number of small and large eruptions in each period and region are also given.

2.4 *Explosive Eruption size*

The modal VEI calculated across the regions does not vary much from VEI 2, with eruptions of this size dominating the record. In part this will be due to the default assignment in VOTW of VEI 2 to eruption records for those eruptions known to have been explosive, but lacking sufficient detail for VEI classification (Siebert et al., 2010). The largest eruption in each region has been identified, and all regions have one or more large explosive Holocene eruptions of VEI ≥4. This demonstrates that large explosive activity has occurred in each region in the past and can be used to indicate that there is the potential for explosive volcanism in all 19 regions. No eruptions of VEI ≥8 have been recorded in the Holocene, though five regions have eruptions of VEI 7: Kamchatka and Mainland Asia, Mediterranean and West Asia, Canada and Western USA, Japan, Taiwan and the Marianas, and Indonesia. The maximum eruption size recorded in the West Indies, Antarctica and Hawaii and the Pacific is VEI 4. Explosive eruptions of high magnitude have the potential for the greatest impact, with large hazard footprints and the potential for catastrophic loss of life and economic losses. These are, however, relatively infrequent: whilst all regions have hosted explosive eruptions, eruptions of VEI ≥4 account for just 10% of all eruptions (with an attributed VEI). Of course, eruptions do not have to be large explosive events to result in large losses: small eruptions may have significant impact in heavily populated areas, and long duration eruptions of low VEI may have widespread consequences.

2.5 Hazard and uncertainty assessments

Hazard scores have been calculated for individual Holocene volcanoes, based on the known historical eruption record and weighted for volcanic hazards that are known to have been associated with greater losses in past eruptions (the VHI, CS19 for full details). Just 328 volcanoes are "classified" having sufficiently well constrained hazard scores based on reasonably detailed eruptive histories. As a result of this index, each classified volcano can be assigned a hazard level. Hazard Levels of I, II and III are assigned based on the distribution of classified hazard scores. Globally, 134 volcanoes are thus classed at Hazard Level I, 106 at Hazard Level II and 88 at Hazard Level III.

Table 4 shows the proportion of volcanoes with valid hazard scores by region, ordered by rank. Of the total number of volcanoes, the Iceland and Arctic Ocean region has the highest proportion of classified volcanoes with assigned hazard levels of any region, at 48%. 40% of volcanoes in Indonesia are classified. These regions have reasonably comprehensive historical eruptive histories for nearly half of their volcanoes. This reflects in part the number of recent eruptions that have occurred while monitoring institutions have been active. When taken with the median age of events in these regions, it is clear that the very recent histories are well known and it is these informing the Hazard score. In three of the regions 10% or fewer volcanoes have assigned hazard levels.

Region	Number of volcanoes with classified Hazard Scores (%)	Region	Number of volcanoes with classified Hazard Scores (%)
Iceland and Arctic	16 (48%)	Mexico and Central America	23 (19%)
Indonesia	58 (40%)	Atlantic Ocean	7 (19%)
Japan, Taiwan, Marianas	46 (32%)	Mediterranean and West Asia	8 (17%)
West Indies	5 (31%)	Canada and Western USA	10 (14%)
Kuril Islands	13 (27%)	Philippines and SE Asia	8 (14%)
New Zealand to Fiji	15 (26%)	Antarctica	4 (13%)
Alaska	22 (24%)	Kamchatka and West Asia	14 (10%)
Hawaii and Pacific	8 (24%)	Middle East and Indian Ocean	4 (7%)
Melanesia and Australia	19 (23%)	Africa and Red Sea	8 (6%)
South America	40 (20%)		

Table 4: The number of classified volcanoes per region and percentage of volcanoes in each region, shown in order of decreasing percentage.

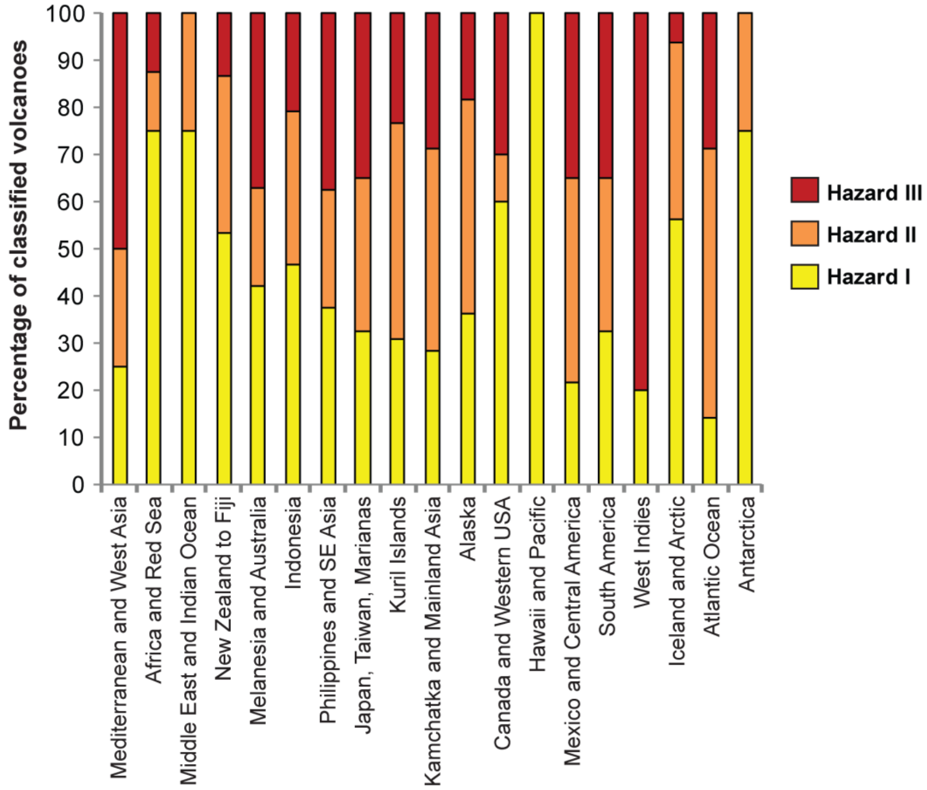

Figure 2: The percentage of volcanoes in each region with a classified score categorised into Hazard Levels.

The Japan, Taiwan and Marianas, South America and Indonesia regions have the highest numbers of Hazard Level III volcanoes (16, 14 and 12 respectively).

However, as a percentage of the valid volcanoes in the region, the West Indies is highest, with 4 out of 5 classified volcanoes here classed at Hazard Level III (Figure 2). This reflects the predominant explosive style of the historical eruptive activity. The volcanoes of Hawaii and the Pacific and Antarctica are classed with the lowest hazard levels.

2.6 Population Exposure Index

The population distribution around volcanoes is the most basic indicator of risk associated with volcanic hazards. The calculation of a Population Exposure Index (PEI) is discussed in detail in CS1. The population residing within 100 km of one or more Holocene volcanoes ranges considerably across the regions, from Antarctica with no permanent population to the Indonesia region with over 180 million people living within this distance. The regions are ranked in Table 5 by the population within 100 km. High populations close to active volcanoes generate inherent issues with risk to life, livelihoods and infrastructure. Globally, over 800 million people live within 100 km of one or more Holocene volcanoes (see CS1 for further discussion of population and volcano distribution).

Region	Population within 100 km
Indonesia	>180 million
Africa and Red Sea	>120 million
Philippines and SE Asia	>116 million
Mexico and Central America	>96 million
Japan, Taiwan, Marianas	>72 million
Middle East and Indian Ocean	>67 million
Mediterranean and West Asia	>61 million
South America	>35 million
Kamchatka and Mainland Asia	>32 million
Melanesia and Australia	>5 million
Canada and Western USA	>4 million
New Zealand to Fiji	>2 million
Hawaii and Pacific	>1 million
West Indies	>1 million
Iceland and Arctic	<300,000
Alaska	<300,000
Atlantic Ocean	<300,000
Kuril Islands	?
Antarctica	0

Table 5: The population residing within 100 km of one or more Holocene volcano per region, in descending order of rank.

2.7 Risk Levels

Risk is defined in a variety of ways through a combination of hazard, exposure and vulnerability. Here, hazard is derived from the Volcano Hazard Index (VHI), and exposure from the Population Exposure Index (PEI). These both are presented here in a semi-quantitative manner, described as relative levels rather than absolute values. We base our approach to assessment of risk on these relative indices given the number and variety of volcanic hazards and the complexities of exposure. Quantification of vulnerability to volcanic hazards has not been attempted as part of this study.

All volcanoes have a PEI value, though only a small percentage have a classified VHI. These classified volcanoes are assigned a Risk Level of I to III derived from the product of exposure and hazard. The distribution of the Risk Levels considers the importance of the presence of an element at risk: e.g. a 'low' hazard in a highly populated area may have a considerable impact. Here, risk to life is based on the population distribution around volcanoes. Unclassified volcanoes (with no VHI) are not assigned a risk level, instead these are tabulated within the profiles by their PEI and Holocene eruptive record to indicate recent activity and exposure.

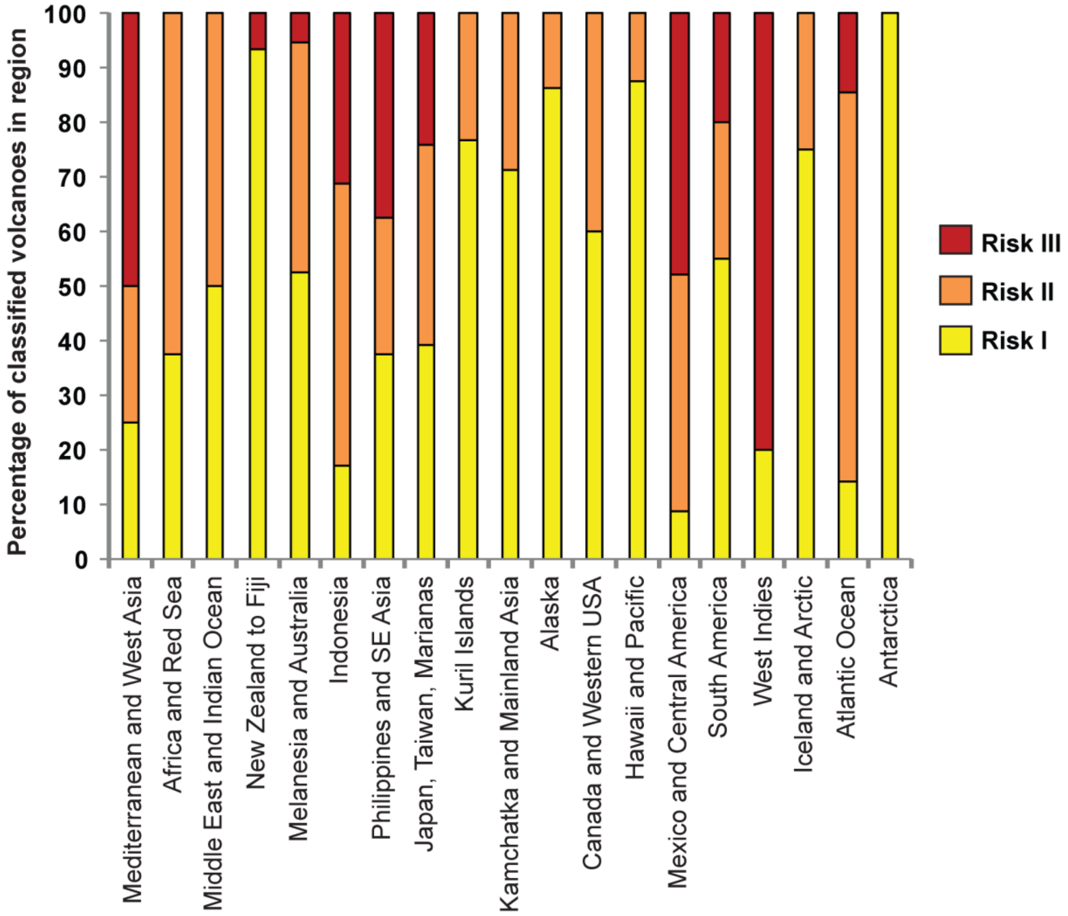

Figure 3: Percentage of classified volcanoes in regions at each Risk Level category.

Most volcanoes in the world are assigned to Risk Levels I and II (Figure 3). Ten regions host Risk Level III volcanoes, with the highest numbers of such volcanoes being in the Indonesia region, and indeed Indonesia itself. About a third of the classified volcanoes in this region are Risk Level III. A similar proportion of volcanoes in the Philippines and SE Asia are Risk Level III. About half of the classified volcanoes in the Mediterranean and West Asia and Mexico and Central America regions are Risk level III, whilst four out of five classified volcanoes in the West Indies are Risk Level III.

Antarctica is the only region where 100% of the volcanoes are Risk Level I, due to the absence of a permanent population on the continent. About 90% of volcanoes in Hawaii and the Pacific, Alaska and New Zealand to Fiji are Risk Level I, due to a combination of low proximal populations in these regions and low hazard scores in Hawaii.

In addition to individual risk levels for volcanoes, the overall volcanic threat level within each country is derived from a combination of the VHI, population exposed and total population. This is discussed in detail in CS20.

2.8 Fatalities and Property Damage

The human impact of eruptive activity can be partially described by the occurrence of fatalities, reported property damage, evacuations and displaced populations. 397 confirmed historical eruptions are recorded with associated fatalities in VOTW4.22. These fatalities are due to a variety of factors, such as pyroclastic density currents, lahars and tsunamis. All regions except Antarctica have historic records of fatal eruptions. Typically, fewer than 10% of eruptions per region have records of associated fatalities. Property damage is more frequent, which in part demonstrates the positive impact of evacuations on reducing lives lost. Auker et al. (2013) examined the global historical volcanic fatalities record and found that the fatality count is dominated by a few large disasters, with most fatal eruptions resulting in small numbers of lives lost. The occurrence of fatalities was found to have a good correlation with the size of the eruption (VEI), but, as expected, was strongly influenced by the population density and the occurrence of pyroclastic flows and lahars. The VEI range and occurrence of these two hazardous phenomena are given within the country profiles, along with the PEI giving an indication of the population around the volcanoes.

2.9 Volcano monitoring capacity

The degree of monitoring undertaken at volcanoes is highly variable. We include basic information on the monitoring situation in each country profile. This information has been gathered through collaboration with the monitoring institutions, the World Organisation of Volcano Observatories (WOVO, CS12) and through online resources. Although there are many remote and satellite methods that can be used in the monitoring of volcanoes, here we report on ground-based systems which are dedicated to the monitoring of volcanoes.

Given the sometimes sparse availability of data, the assessment of 'monitored' volcanoes here is fairly basic, designed to enable an estimation of the numbers of: volcanoes without dedicated monitoring systems; those with some monitoring; and those that have adequate monitoring for basic assessments of magma movements and some quantitative assessments of the probability of future volcanic events. This has been achieved where possible through the determination of the number of seismometers on a volcano. Volcanic earthquakes often form the first sign of volcanic unrest. These earthquakes occur at shallow depths, are typically low magnitude and are usually located immediately below a volcanic edifice. These earthquakes differ from tectonic events and require seismometers dedicated to the detection of events of this style. National and regional seismic networks are designed largely to detect tectonic earthquakes, though these systems are often used to provide alerts of unusual activity on or near volcanoes, which may then instigate the deployment of dedicated monitoring systems in countries where such equipment and expertise is available. Single dedicated seismometers are of limited use in determining the location of earthquakes and for forecasts of volcanic activity, though in countries where resources are prioritised at recently active or high hazard or risk volcanoes a single seismometer can be used, often in combination with the larger regional network, to alert the relevant authorities and commence the deployment of further monitoring systems. Ideally, a multi-station network of four or more seismometers is required to accurately establish the location and size of seismic events beneath a volcano, allowing for swarms of micro-quakes to be detected and for the establishment of the cause of earthquakes - volcano-magmatic, glacier movements, rockfalls and others. Three monitoring levels have been devised to provide a basic indication of the monitoring systems in place at volcanoes:

- Level 1: No known dedicated volcano monitoring equipment. No dedicated seismometers.
- Level 2: Three or fewer seismometers dedicated to volcano monitoring, coupled with an institution that is responsible for monitoring. Additional monitoring techniques such as deformation or gas analysis may also be in place.
- Level 3: Four or more seismometers dedicated to volcano monitoring, couple with an institution that is responsible for monitoring. Additional monitoring techniques may also be in place.

These monitoring levels are coupled with the volcanic risk levels allowing observations of prioritisation of monitoring resources or indication of volcanoes where the risk level suggests monitoring resources could be particularly beneficial.

A correlation is frequently seen between those volcanoes with a high risk level and the monitoring level showing that most institutions focus monitoring efforts on historically active volcanoes and those located near or in populated areas. Seismic networks are the most common form of dedicated ground-based monitoring instrumentation utilised around the world. Around 55% of historically active volcanoes have dedicated ground-based monitoring in place at least on a rudimentary level. About 14% of historically active volcanoes are described with three or fewer seismometers and the majority of these volcanoes have this seismic monitoring alone. About 35% of historically active volcanoes are considered adequately monitored, with four or more seismometers within 20 km distance and most of these volcanoes have further monitoring systems in place, most commonly comprising deformation monitoring through the use of GPS stations and tilt meters.

Of the historically active volcanoes between 25 and 45% are unmonitored. The uncertainty exists due to an absence of information for about a quarter of historical volcanoes. Further research is being undertaken to better understand monitoring levels around the world. At least a quarter of volcanoes are recognised as unmonitored, and some of these are located in densely populated areas and have records including large magnitude eruptions. As monitoring resources and funding are limited, it is to be expected that monitoring systems are often found to be dedicated to frequently active, or recently active, volcanoes. The absence of monitoring at other volcanoes does not mean that these have been assessed to pose little risk. Without regular monitoring, the background activity levels of a volcanic system cannot be determined, making identification and assessment of unusual activity problematic, which could result in signals indicative of magma movement being missed. Observatories and research institutions must be supported in their monitoring efforts.

2.10 Discussion

Volcanism is highly variable around the world, however the completeness of the eruption record is also variable. Past records of eruption age, magnitude and style are vital to understand volcanic activity and such records are commonly missing. Issues of under-recording must be understood and accounted for in the analysis of volcanic activity, hazard and risk at all volcanoes. Monitoring institutions play a vital role in the understanding of the current activity of volcanoes, and for establishing baselines for background levels of activity. These are crucial to the recognition of increased unrest leading up to eruptions. However with limited resources many volcanoes are un- or under-monitored. The hazard and risk levels provided in the regional and country profiles are designed to provide relative rankings, and could be used to suggest prioritisation of resources, but they do not substitute for focussed local assessments for individual volcanoes or areas, where factors such as volcano morphology will exert significant effects on population exposure and hazard footprint. Such local focussed hazard and risk assessments are critical for disaster preparedness and emergency management.

The regional and country profiles here are intended to provide a general description of the volcanoes, volcanic hazards and risk for each area.

3 Profile data

Here we present brief descriptions of the data provided within the region and country profiles.

Regional profiles

A map is provided showing the distribution of volcanoes throughout the region and the capitals of the constituent countries. These countries are detailed in a table with the number of Holocene volcanoes listed. Data is derived from VOTW4.0.

Eruption Frequency

The average return periods between small (VEI <4) and large (VEI >3) eruptions in each region are given. These were determined by Mead et al., (2014) by running a Monte Carlo Markov Chain 'break in slope' model, with minor revisions using the May 2013 dataset from VOTW4.22 and are shown here rounded to the nearest 1, 10 or 100 years. This method accounts for differences in the quality of the eruption records to determine average recurrence intervals based on size of the eruptions. This is intended to provide an approximation of regional frequency. It cannot be used as a forecasting tool.

Eruption Size

As large magnitude eruptions of VEI or magnitude 4 and above on average have the greatest potential for causing losses at increased distances from volcanoes, the percentage of eruptions of VEI ≥ 4 in the region is given.

A graph showing the percentage of eruptions in the region classified at each VEI level is provided for those eruptions where the VEI is known. The number of eruptions is shown above each column. Data is derived from VOTW4.22.

Country profiles

A profile is provided for all countries which are represented within the regions. Some countries have territories in more than one region: the reader will be alerted to the appropriate section.

Description

A summary description is provided detailing the volcanoes in the country. This includes the distribution and number of volcanoes, a discussion of the eruption styles recorded during the Holocene, relation to population and infrastructure, monitoring efforts and historical experience of eruptions. This description draws on the data provided throughout the profile, data within VOTW4.22 (2013) and additional references where given. Questionnaires were sent to volcano observatories and other institutions responsible for monitoring. Where a response was received, data from these questionnaires are incorporated.

A map illustrating the distribution of volcanoes through each country is provided, which also shows the location of the capital and largest cities and a 200 km buffer zone. Eruptions from volcanoes located within this buffer zone may affect the country under consideration although impact from eruptions at greater distances cannot be discounted.

Volcano Facts

Number of Holocene volcanoes: This is the number of volcanoes with known or suspected activity during the Holocene (the last 10,000 years) as listed in VOTW4.22.

Number of Pleistocene volcanoes with M≥4 eruptions: The number of volcanoes with explosive eruptions of magnitude (M) 4 and above recorded during the Pleistocene (10 ka to 2.588 Ma), as listed in LaMEVE (Crosweller et al., 2012). This is included because large magnitude eruptions normally occur infrequently, and the Holocene does not always provide enough time to be statistically representative of large magnitude eruptions (Deligne et al., 2010).

Number of volcanoes generating pyroclastic flows: The number of volcanoes with pyroclastic flows recorded during the Holocene, as recorded in VOTW4.22.

Number of volcanoes generating lahars: The number of volcanoes with lahars recorded during the Holocene, as recorded in VOTW4.22.

Number of volcanoes generating lava flows: The number of volcanoes with lava flows recorded during the Holocene, as recorded in VOTW4.22.

Number of fatalities caused by volcanic eruptions: The number of fatalities during the Holocene, as listed in VOTW4.22. This is the sum of the given fatality numbers. Where fatalities are listed with qualitative descriptors we adopt the method of Simkin et al. (2001) to account for these (as in Table 6) and include '?' before the value:

Descriptor	Value
Few	3
Some	3
Several	5
Unknown or ?	15
Many	100
Hundreds	300

Table 6: Qualitative descriptors and their assigned quantitative value, as in Simkin et al. (2001).

Tectonic setting: This is the tectonic setting as given in VOTW4.0. Three categories are used: subduction zone or compressional settings; rift zone or tensional settings – for example mid-ocean or continental rifts; and intra-plate settings related to mantle plumes for volcanoes such as Yellowstone or in Hawaii.

Largest recorded Pleistocene eruption: This is the largest recorded eruption from 10 ka to 2.588 Ma as listed in the LaMEVE database (LaMEVE Version 2; Crosweller et al., 2012), based on the magnitude recorded there. Where no Pleistocene eruption is recorded in LaMEVE, this is left blank. Note that LaMEVE only contains data on eruptions of M≥4.

Largest recorded Holocene eruption: This is the largest recorded eruption during the Holocene (the last 10,000 years) as found in the LaMEVE database. Where no Holocene eruption is recorded in LaMEVE, then the eruption with the greatest VEI is given from the VOTW4.22 dataset.

Number of Holocene eruptions: Here the number of eruptions is given from VOTW4.22. These eruptions are described as 'confirmed' where the eruption is certain and 'uncertain' where further research is needed to confirm the age and occurrence of the eruption.

Recorded Holocene VEI range: This is the range of VEI (Volcanic Explosivity Index) values attributed to Holocene eruptions in VOTW4.22 for each country. The VEI ranges from 0 to 8 in whole numbers, describing the size of the eruption. The size of many eruptions is not known, and hence described as 'Unknown'.

Number of historically active volcanoes: The number of volcanoes with confirmed eruptions recorded from 1500 AD to the present day in VOTW4.22.

Number of historical eruptions: The number of eruptions within the country that are recorded and confirmed from 1500 AD to the present day in VOTW4.22.

Primary volcano type and dominant rock type: A table is provided including the number of Holocene volcanoes in each volcano type group and breaks this down further into dominant rock type groups. This is based on data from VOTW4.0, which categorises volcanoes into over 20 volcano types. These VOTW4.0 volcano types are grouped into a classification scheme modified after Jenkins et al. (2012) (Table 7).

Volcano type group	**Includes VOTW4.0 volcano types**
Caldera(s)	Caldera, Caldera(s), Pyroclastic shield
Large cone(s)	Complex, Compound, Somma, Stratovolcano, Stratovolcano(es), Volcanic Complex
Shield(s)	Shield, Shield(s)
Lava dome(s)	Lava dome, Lava dome(s)
Small cone(s)	Cinder cone, Cinder cones, Cones, Cone, Crater rows, Explosion craters, Fissure vent(s), Lava cone, Maar, Maar(s), Pyroclastic cone(s), Scoria cones, Tuff cones, Tuff rings, Volcanic field
Hydrothermal field	Hydrothermal field, Hydrothermal field(fumarolic)
Submarine	Submarine
Subglacial	Subglacial

Table 7: Volcano type classification modified after Jenkins et al. (2012) and the VOTW4.0 volcano types in each category.

The dominant rock type is based on that given in VOTW4.0 and grouped following the definitions given in Siebert et al. (2010) as in Table 8.

Rock type group	Includes VOTW4.0 rock types
Basaltic	Basalt, Picro-basalt, Tephrite, Basanite, Trachybasalt
Andesitic	Andesite, Basaltic-andesite, Trachyandesite, Basaltic trachyandesite
Dacitic	Dacite
Rhyolitic	Rhyolite
Trachytic	Trachyte
Trachytic/Andesitic	Trachyte/Trachyandesite
Phonolitic	Phonolite, Phonotephrite, Tephriphonolite
Foiditic	Foidite

Table 8: Dominant rock type classification grouping the Dominant Rock Type as given in VOTW4.0 following the system described in Siebert et al. (2010).

Socio-Economic Facts

Total population: The total population of each country reported in the year given (normally 2012). Data is derived from the United Nations Population Division.

GDP, GNI and HDI: The Gross Domestic Product per capita for each country reported in 2011 (or the year given); the Gross National Income per capita, and the Human Development Index reported in 2012. Data derived from the United Nations Development Programme 2013.

Population Exposure

Capital city: The capital of the given country.

Distance from capital to nearest Holocene volcano: The distance (km) from the capital city to the nearest Holocene volcano. Note that this volcano may be located in a neighbouring country. Distance determined using the coordinates given in VOTW4.0.

Total population (2011): Although the most recent total population is given under Socio-Economic Facts, the 2011 data is provided here as the 2011 LandScan dataset is used to provide population information within given radii of volcanoes.

Number (percentage) of people living within 10/30/100 km of a Holocene volcano: The number of people within a country living within the given distance of Holocene volcanoes. Note that these volcanoes may be located in bordering countries. This was calculated using the 2011 Landscan dataset provided by UNEP/GRID. The percentage is the number of people as a percentage of the 2011 population.

Largest cities: A list of the largest cities, as measured by population and the population size. The top ten cities are provided where the data is available. See "Map sources" for source details.

Infrastructure Exposure

The number of airports and ports, and the total length of roads and railroads located within the 100 km radii of volcanoes in the country. This does not count infrastructure beyond the border of the country and counts infrastructure only once where located in overlapping radii. See "Map sources" for source details.

A map of the country is provided showing the location of the volcanoes with 100 km radius circles surrounding them. This radius is used to provide an indication of the area in which direct hazards may be distributed and the infrastructure within these radii. The map also shows the location of the capital and major cities, and ports and airports.

A brief discussion of the infrastructure is given, discussing the location of the cities and infrastructure in relation to the volcanoes. Where volcanoes lie close to the country's borders, a description is given when the 100 km radii of border volcanoes extend into neighbouring countries.

Hazard and Exposure Assessments

The frequency of eruptions, occurrence of pyroclastic flows, lahars and lava flows, the maximum recorded and modal VEI are used as a system of hazard indicators to determine hazard scores for Holocene volcanoes (the Volcano Hazard Index, VHI; CS19). Many volcanoes lack a detailed eruption history and hence only 328 volcanoes are classified with a VHI. See CS19 for further details on the methodology. Here, the hazard scores are assigned to Hazard Levels of I to III, with increasing hazard, for the classified volcanoes. The unclassified volcanoes do not have a hazard level assigned.

The Population Exposure Index (PEI; CS1) has been calculated through weighting the total population within radii of 10, 30 and 100 km surrounding Holocene volcanoes by a ration of the area and the occurrence of historical fatalities within the given distances. The PEI is designed to rank volcanoes by the population distribution within 100 km radii and to provide a preliminary measure of population exposure to volcanic hazards. PEI is assigned at levels 1 to 7, with increasing PEI and hence population density. See CS1 for further details.

Ultimately, the Hazard Levels must be combined with measures of exposure in order to make statements about risk. For example, VHI Level I volcanoes may cause huge impacts if located sufficiently close to vulnerable populations or infrastructures. At this stage both the VHI and PEI are semi-quantitative, being presented as levels based upon numerical values, and risk cannot therefore be calculated as a strict product of hazard and exposure. However, plots of hazard levels against the Population Exposure Index for each volcano in each country provide a useful visualisation of a risk matrix. This matrix is derived using a qualitative assessment of the product of the VHI and PEI, amended to consider the potential impact of hazardous phenomena within highly populated areas regardless of the hazard level (i.e. volcanoes of PEI 7 are all considered Risk Level III). Risk is defined at three levels, I, II and III with increasing risk, shown by the warming of the colours (Figure 4).

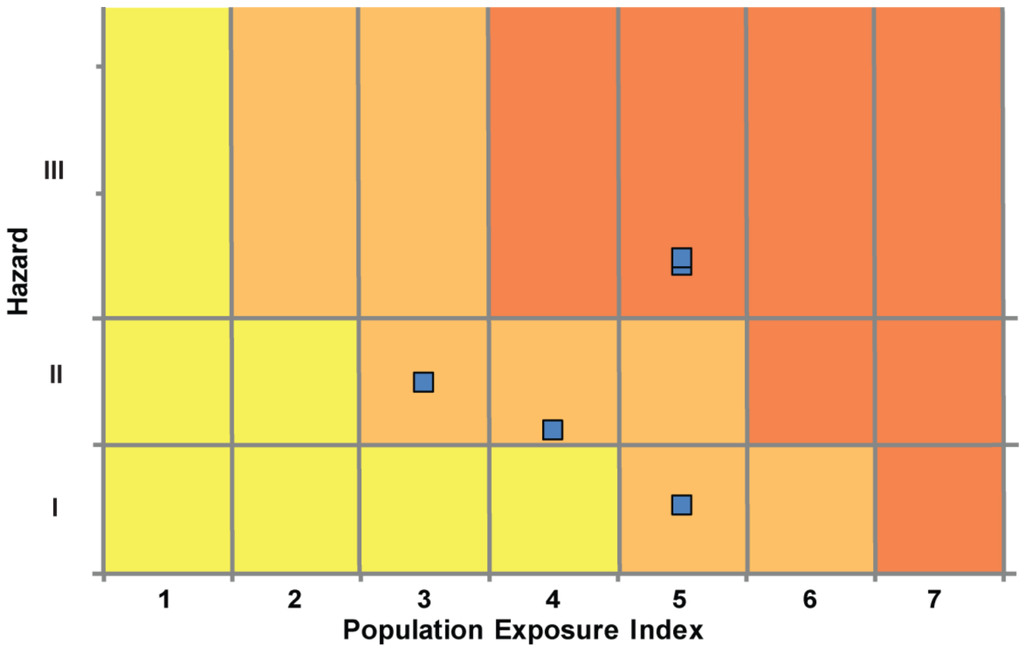

Figure 4: An example matrix combining VHI and PEI levels to indicate level of risk. Each volcano is represented by a point plotted using its hazard score and PEI level. The warming of the colouring of the matrix squares represents increasing risk (Risk Level I is yellow; Risk Level II is orange; Risk Level III is red).

The granularity within the matrix prevents detailed assessment and the matrix is therefore intended as a tool for the relative ranking of volcanoes. It should not be seen as a quantitative tool, as it comprises two ordinal rating scales which could be considered qualitative descriptors. This should not be used to undertake further calculations.

This globally applied assessment of VHI, PEI and ultimately risk does not substitute for focussed, local assessments. The PEI, for example, considers the population within concentric circles around a volcano, though in reality the exposed population will be governed by a number of factors (e.g. topography, which can shield a population on one side of the volcano and channel hazardous flows towards populations on the other). The impact on the human population is also determined by vulnerability, which is not considered here. The assessment of risk is based on these broad hazard and exposure assessments and therefore does not capture the full complexity of the situation. However, the ranking of volcanoes using this method can help identify volcanoes where monitoring and mitigation resources may need to be focussed and where localised hazard and risk assessments may be a priority.

A table is given identifying the volcanoes in each Hazard-PEI group. Another table ranks the volcanoes by their PEI, in descending order of PEI, also giving the Risk Level for each volcano.

A table is given showing the PEI of all volcanoes, the Hazard level of classified volcanoes and an indication of the eruption record for unclassified volcanoes (Table 9). Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption. As activity and eruption size is incorporated in the determination of the hazard level, the classified volcanoes are not distinguished in this manner.

CLASSIFIED	**Hazard III**							
	Hazard II						Volcano D	
	Hazard I		Volcano A					
UNCLASSIFIED	**U – HHR**		**Volcano B**					
	U- HR					Volcano C		
	U- NHHR							Volcano E
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 9: Table identifying volcanoes in each Hazard-PEI group.

National Capacity for Coping with Volcanic Risk

A global database of monitoring institutions and monitoring instrumentation is in development (GLOVOREMID; CS16). At present, this database is populated for Latin America and efforts to expand this to a global dataset are ongoing but not complete.

A preliminary investigation and appraisal of global monitoring has been undertaken for this study to permit a first order assessment of the number of historically active volcanoes with dedicated ground-based monitoring systems in place. Institutions were approached to aid this understanding and information from those that responded has been combined with the Latin American dataset from GLOVOREMID, information from the World Organisation of Volcano Observatories (WOVO, see CS12) and data available online.

For each country where historical eruptions (those since 1500 AD) are recorded in VOTW4.22 we provide a brief description of the monitoring efforts coupled with an understanding of the Risk Levels. A graph is provided showing the number of historically active volcanoes by monitoring level, colour-coded to represent the Risk Levels of the volcanoes. Monitoring levels are given as 1 to 3. Level 1 indicates no known ground-based monitoring. This may be because no systems are in place at the volcanoes or that the state of monitoring is unknown to this author at this time. These two criteria are grouped to account for the uncertainty in the description of "no monitoring". Monitoring Level 2 indicates the presence of some dedicated ground-based monitoring systems at the volcanoes, including three or fewer seismic stations. Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including four or more seismic stations and often multiple monitoring systems.

Map Sources

The overview maps and infrastructure maps were compiled using the following sources:

1. Base maps

   1.1. Relief map – World Shaded Relief map, downloaded from ESRI ArcGIS Online (available within ESRI ArcGIS software), 2014. Further information:

   http://www.arcgis.com/home/item.html?id=9c5370d0b54f4de1b48a3792d7377ff2

   1.2. Country boundaries - World Countries map, downloaded from ESRI ArcGIS Online (within ArcGIS software), 2012. Further information: http://www.esri.com/software/arcgis/arcgisonline/maps/maps-and-map-layers

   Some additional country outline maps were required:

   1.3. Antarctica relief map – Antarctic Bathymetry Basemap by NOAA_NDGC, map downloaded from ESRI ArcGIS Online (available within ESRI ArcGIS software), 2013. Further information: http://www.esri.com/software/arcgis/arcgisonline/maps/maps-and-map-layers

   1.4. Alaska boundary map – Free GIS boundary maps from Department of Labor and Workforce Development, 2012 Boroughs and Census areas, available from: http://labor.alaska.gov/research/census/maps.htm#gis

   1.5. Outline of French Polynesia – Available from DIVA_GIS, free GIS data by country. Further information: http://www.diva-gis.org/gdata

2. Cities and populations

   2.1. World cities – ESRI World Cities, downloaded from ESRI ArcGIS Online (available within ESRI ArcGIS software), 2012. Further information:

   http://www.esri.com/software/arcgis/arcgisonline/maps/maps-and-map-layers

   2.2. Alaska and USA towns/cities - USA City Populations, downloaded from ESRI ArcGIS Online (available within ESRI ArcGIS software), 2012, based on US Cencus 2000. Further information: http://www.esri.com/software/arcgis/arcgisonline/maps/maps-and-map-layers.

3. Airports – World Airports downloaded from ESRI ArcGIS Online (available within ESRI ArcGIS Online software), 2011. Further information: http://www.esri.com/software/arcgis/arcgisonline/maps/maps-and-map-layers

4. Ports

   4.1. National Geospatial-Intelligence Agency, Ports, version 2010. Further information:

   http://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_pageLabel=msi_portal_page_62&pubCode=0015

5. Roads

   5.1. All roads and Major roads – World Roads map downloaded from ESRI ArcGIS Online (available within ESRI ArcGIS software), 2011. Further information: http://www.esri.com/software/arcgis/arcgisonline/maps/maps-and-map-layers

6. Railways

   6.1. World Railroads map downloaded from ESRI ArcGIS Online (available within ESRI ArcGIS software), 2011. Further info: http://www.esri.com/software/arcgis/arcgisonline/maps/maps-and-map-layers

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Volcanoes of the World 4.0 and 4.22 (2013) Smithsonian Institution, Washington DC. http://www.volcano.si.edu. VOTW4.22 was accessed and downloaded January 13th 2014.

5 Regional and country profiles

Region	Region name, Country
Region 1	**Mediterranean and West Asia**
	Armenia
	Azerbaijan
	France (Mainland)
	Georgia
	Germany
	Greece
	Italy
	Spain (Mainland)
	Turkey
Region 2	**Africa and Red Sea**
	Algeria
	Cameroon
	Chad
	Democratic Republic of Congo
	Djibouti
	Equatorial Guinea
	Eritrea
	Ethiopia
	Kenya
	Libya
	Mali
	Niger
	Nigeria
	Rwanda
	Sao Tome and Principe
	Sudan
	Tanzania
	Uganda
Region 3	**Middle East and Indian Ocean**
	Afghanistan
	Comoros
	France
	Iran
	Madagascar
	Pakistan
	Saudi Arabia
	South Africa
	Syria
	Yemen
Region 4	**New Zealand to Fiji**

	Fiji
	New Zealand
	Samoa
	USA – American Samoa
	Tonga
Region 5	**Melanesia and Australia**
	Australia
	Papua New Guinea
	Solomon Islands
	Vanuatu
Region 6	**Indonesia**
	India
	Indonesia
	Malaysia
Region 7	**Philippines and SE Asia**
	Myanmar (Burma)
	Philippines
	Vietnam
Region 8	**Japan, Taiwan, Marianas**
	Japan
	Taiwan
	USA – Marianas Islands
Region 9	**Kuril Islands**
	Russia/Japan – Kuril Islands
Region 10	**Kamchatka and Mainland Asia**
	China
	Democratic People's Republic of Korea
	Mongolia
	Republic of Korea
	Russia
Region 11	**Alaska**
	USA – Alaska
Region 12	**Canada and Western USA**
	Canada
	USA – contiguous states
Region 13	**Hawaii and Pacific Ocean**
	France
	USA – Hawaii
	USA – Pacific – Other
Region 14	**Mexico and Central America**
	Costa Rica
	El Salvador
	Guatemala
	Honduras

	Mexico
	Nicaragua
	Panama
Region 15	**South America**
	Argentina
	Bolivia
	Chile
	Colombia
	Ecuador – mainland
	Galapagos Islands
	Peru
Region 16	**West Indies**
	Dominica
	France – Guadeloupe and Martinique
	Grenada
	Netherlands – Dutch Antilles
	St. Kitts and Nevis
	St. Lucia
	St. Vincent and the Grenadines
	UK – Montserrat
Region 17	**Iceland and Arctic Ocean**
	Iceland
	Norway
Region 18	**Atlantic Ocean**
	Brazil
	Cape Verde
	Portugal – Azores
	Spain – Canary Islands
	UK
Region 19	**Antarctica**
	Antarctica and UK

Region 1: Mediterranean and West Asia

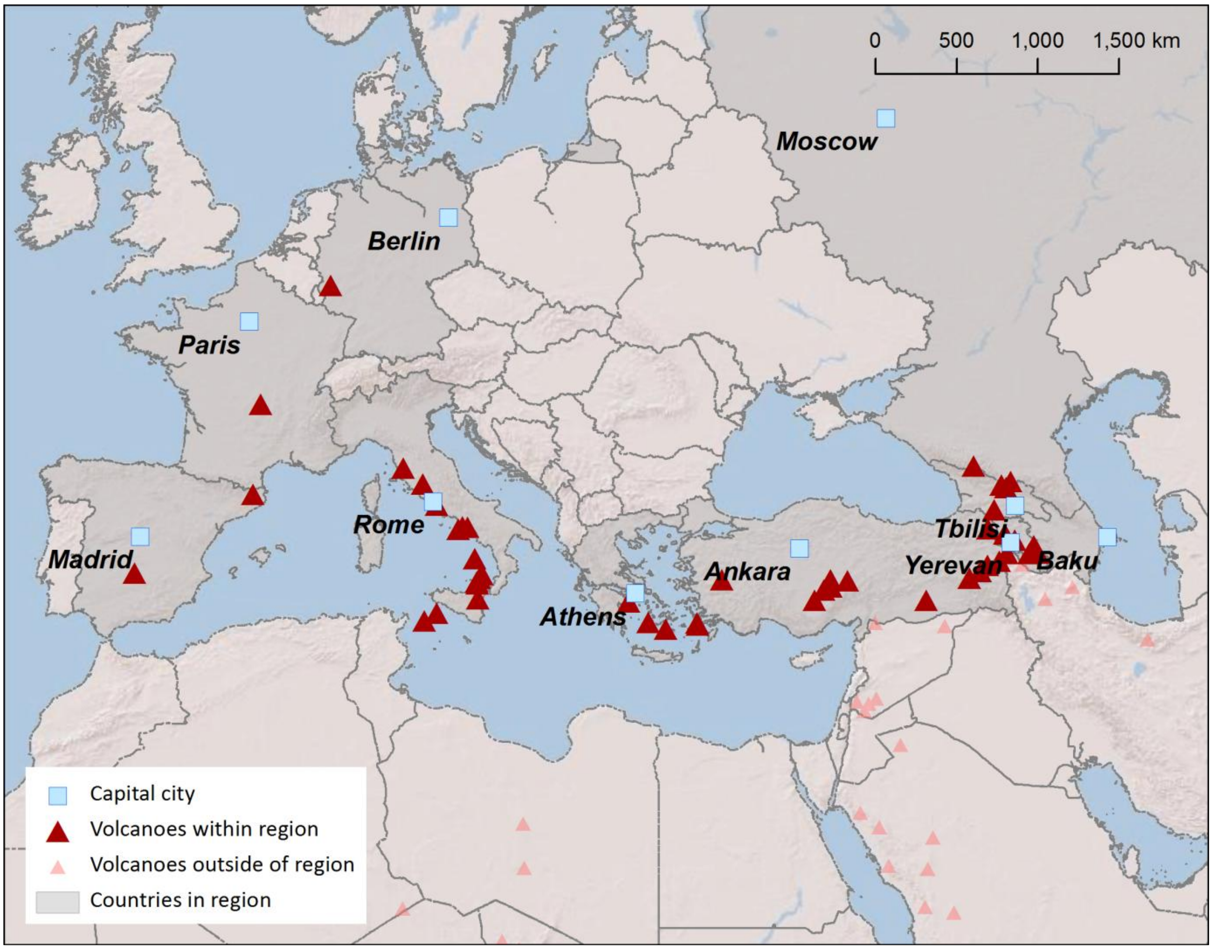

Figure 5: The distribution of Holocene volcanoes through the Mediterranean and West Asia region. The capital cities of the constituent countries are shown.

Description

Country	Number of volcanoes
Armenia	5
Azerbaijan	2
France	1
Georgia	4
Germany	1
Greece	5
Italy	14
Russia (see Region 10)	1
Spain	2
Turkey	13

Table 10: The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

Region 1: The Mediterranean and West Asia comprises volcanoes in ten countries from the westernmost Calatrava Volcanic Field in central Spain, to Tskhouk-Karckar on the border of Armenia and Azerbaijan in the east. All of Region 1's volcanoes are included in this regional profile, however for the country profile for Russia see Region 10: Kamchatka and Mainland Asia.

Forty-six volcanoes are located in the Mediterranean and West Asia region. Most of these volcanoes are in Italy. Volcanism here is largely due to the subduction of the African Plate beneath the Eurasian Plate.

A range of volcano morphologies is present throughout this region, however most volcanoes (72%) here are stratovolcanoes and small cones (volcanic fields). A range of rock types are also present, from mafic basalts to felsic rhyolites and a range of alkalis, although the majority of volcanoes (17, 37%) have a dominantly andesitic composition.

As would be expected with such a range of compositions and volcano types, the activity styles throughout the Holocene have varied considerably with eruption magnitudes of VEI 0 to 7 indicating mild activity to very large explosive events. About 60% of eruptions have been small at VEI 0 – 2, however about 9% of eruptions have been large explosive VEI ≥4 events. These VEI ≥4 eruptions have occurred at just five volcanoes in Italy and Greece. 24 of 27 eruptions occurred in Italy, although pyroclastic flows have also occurred in 55 Holocene eruptions throughout France, Spain, Italy, Greece and Turkey. The largest Holocene eruption was the VEI 7 1610 BC Minoan eruption of Santorini in Greece, as recorded in VOTW4.22. This is commonly associated with the downfall of the Minoan civilisation.

Twelve volcanoes have historical records of 220 eruptions, all of which were recorded through direct observations. 92 eruptions (40% of the geological record) were recorded through historical observations prior to 1500 AD, dating back to 1500 BC, demonstrating the effect of a large population on the eruption record. 6% of historical events have involved the production of pyroclastic flows, and 9% have resulted in lahars. Lava flows are recorded in 65% of historical eruptions, one of the highest proportions in all regions.

12% of historical eruptions have resulted in loss of life. The population of this region is high, and most volcanoes have moderate to high local populations. 19 volcanoes (41%) have a high PEI, indicating high local populations. Most classified volcanoes are classed at Risk Level III, however 83% of volcanoes in this region are unclassified with insufficient records to calculate VHI without large uncertainties.

All historical eruptions in this region occurred in Italy, Greece and Turkey. It is these volcanoes where monitoring is focussed by national groups, however not all historically active volcanoes are monitored. The four historically active Risk Level III volcanoes in Italy and Greece are monitored using multi-system monitoring networks.

Volcano facts

Number of Holocene volcanoes	46

Number of Pleistocene volcanoes with M≥4 eruptions	22
Number of volcanoes generating pyroclastic flows	12 (55 eruptions)
Number of volcanoes generating lahars	9 (29 eruptions)
Number of volcanoes generating lava flows	20 (225 eruptions)
Number of eruptions with fatalities	32
Number of fatalities attributed to eruptions	9,294
Largest recorded Pleistocene eruption	The largest Quaternary eruption in region 1 occurred at Vulsini in Italy, with the M7.7 Bolsena eruption of 300 ka.
Largest recorded Holocene eruption	The M6.6 Protohistoric First (AP1) eruption of Vesuvius, Italy at 3.5 ka is the largest recorded Holocene eruption in region 1. The Minoan eruption of Santorini in Greece at 3.56 ka is the second largest eruption in this region during the Holocene, at M6.5.
Number of Holocene eruptions	446 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 7 and unknown.
Number of historically active volcanoes	12
Number of historical eruptions	220

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
4	Caldera(s)	Foiditic (1), Rhyolitic (1), Trachytic/Andesitic (2)
18	Large cone(s)	Andesitic (8), Basaltic (2), Dacitic (3), Phonolitic (1), Rhyolitic (3), Trachytic/Andesitic (1)
4	Lava dome(s)	Andesitic (1), Basaltic (1), Rhyolitic (2)
5	Shield(s)	Andesitic (1), Basaltic (2), Dacitic (1), Rhyolitic (1)
15	Small cone(s)	Andesitic (9), Basaltic (3), Foiditic (1), Unknown (2)
2	Submarine	Basaltic (1), Phonolitic (1)

*Table **11:** The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.*

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	2
Large (> VEI 3)	200

*Table **12:** Average recurrence interval (years between eruptions) for small and large eruptions in the Mediterranean and West Asia.*

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about 2 years, whilst the ARI for large eruptions is longer, at about 200 years.

Eruption Size

Eruptions are recorded through the Mediterranean and West Asia region of VEI 0 to 7, representing a range of eruption styles from gentle effusive events, to very large explosive eruptions (Figure 6). VEI 2 events dominate the record, with nearly 45% of all Holocene eruptions classed as such. 9% of eruptions here are explosive at VEI≥4.

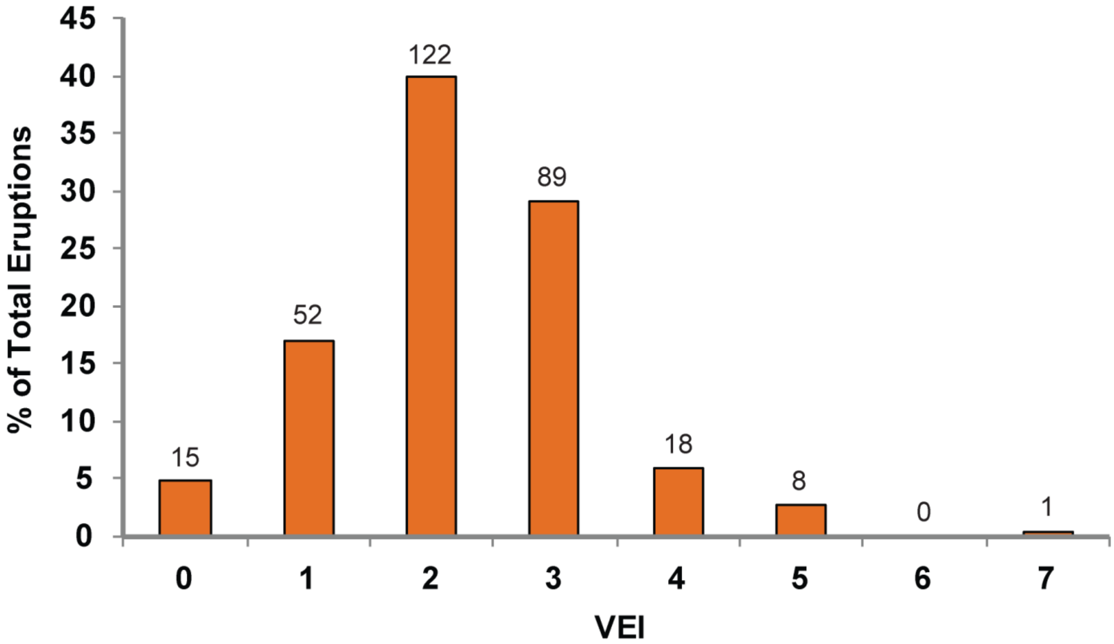

Figure 6: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 141 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	359,039,884
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,826 – 34,437
	(Mean 19,249)
Gross National Income (GNI) per capita (2005 PPP $)	5,005 – 35,431

	(Mean 18,970)
Human Development Index (HDI) (2012)	0.722 – 0.920 (High to Very High)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	2,082,785 (0.58%)
Number (percentage) of people living within 30 km of a Holocene volcano	15,313,847 (4.27%)
Number (percentage) of people living within 100 km of a Holocene volcano	61,703,936 (17.19%)

CLASSIFIED	**Hazard III**				Vulcano; Santorini			Campi Flegrei; Vesuvius
	Hazard II		Nisyros			Etna		
	Hazard I			Stromboli			Campi Flegrei Mar Sicilia	
UNCLASSIFIED	**U – HHR**				Pantelleria; Nemrut Dagi; Tendürek Dagi; Ararat			
	U- HR		Palinuro	Mílos; Elbrus; Kasbek; Porak; Tskhouk-Karckar	Larderello; Methana; Süphan Dagi	Vulsini; Ischia; Lipari; Erciyes Dagi; Dar-Alages	West Eifel Volcanic Field; Calatrava Volcanic Field; Acigöl-Nevsehir	Chaîne des Puys; Ghegam Ridge
	U- NHHR		Yali	**Panarea**; Kabargin Oth Group; Unnamed	Hasan Dagi; Göllü Dag; Karaca Dag; Girekol Tepe; Unnamed; Aragats	Olot Volcanic Field; Kula; Karapinar Field		**Alban Hills**; Kars Plateau
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 13: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of volcanoes	Population Exposure Index
6	7
4	6
9	5
15	4
9	3
3	2
0	1

Table 14: The number of volcanoes in the Mediterranean and West Asia region classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
4	III
2	II
2	I
38	Unclassified

Table 15: The number of volcanoes in the Mediterranean and West Asia region classified at each Risk Level.

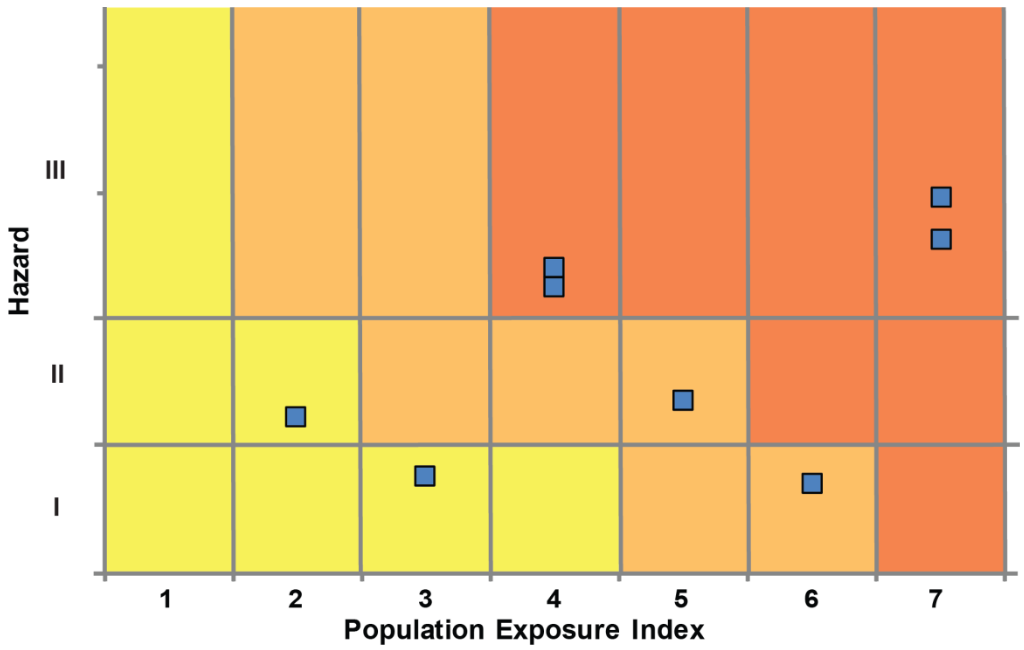

Figure 7: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

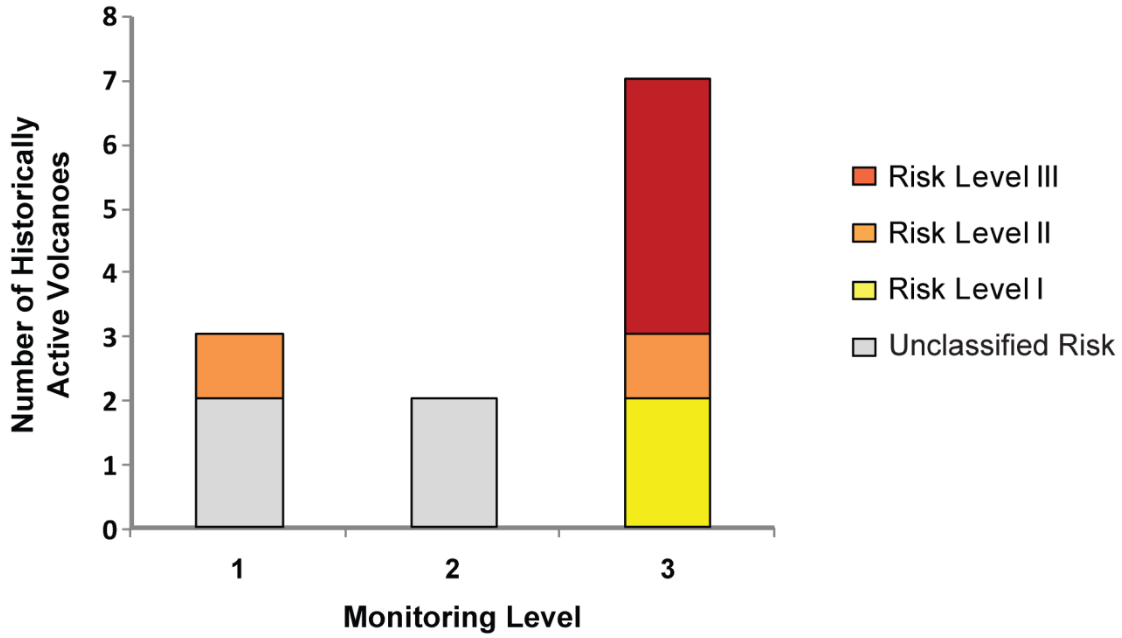

Figure 8: The monitoring and risk levels of the historically active volcanoes in the Mediterranean and West Asia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Armenia

Description

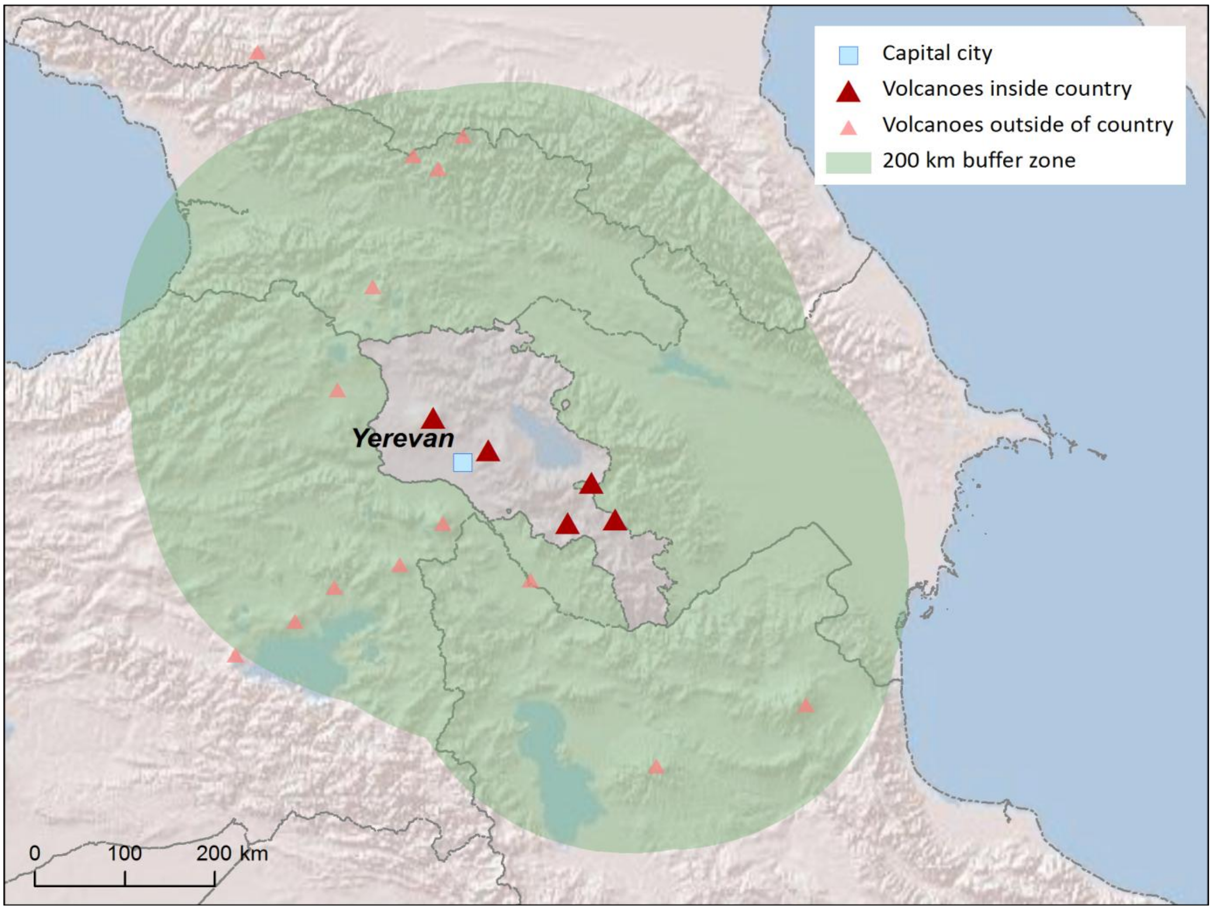

Figure 9: Location of Armenia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Armenia.

Armenia is situated in a region of copious Quaternary-Holocene-Historical volcanism. Yerevan, the capital of Armenia, a city with a population of more than 1 million people, is located between three volcanic systems – Aragats stratovolcano, Ghegam volcanic upland and Ararat stratovolcano in eastern Turkey (just 40 km from the southern suburbs of Yerevan). There are three Holocene volcanoes or groups of volcanoes located wholly in Armenia: Dar-Alages (Vayots-Sar), Smbatasar and other monogenetic centres of Ghegam volcanic ridge and Aragats. Aragats stratovolcano is one of the largest stratovolcanoes in the entire region, and produced central vent (including Plinian eruptions) and monogenetic flank eruptions. Aragats is included here as it is considered in VOTW4.0, however, recent research and K-Ar and Ar-Ar dating indicates that the latest flank and summit activity is mid-Pleistocene at 0.48-0.52 Ma (Meliksetian et al. 2014). A further two volcanoes are located on the border: Porak (a group of cones and fissures) and Tskhouk-Karckar (a group of 8 cinder cones) (Figure 9).

The volcanism in Armenia is associated with the ongoing collision of the Eurasian and Arabian tectonic plates. Volcano locations are closely linked to major fault locations and small pull-apart basins related to regional tectonic movements. Holocene volcanoes comprise andesite to basaltic andesitic cinder cones (Tskhouk-Karckar group on Syunik volcanic upland, Dar-Alages (Vayots-Sar), Smbatasar, Porak on Vardenis volcanic upland), a volcanic field (Ghegam Ridge comprising 127 Quaternary cinder cones, some of which are presumably Holocene in age, as Holocene lava flows exist within Ghegham volcanic upland) and the stratovolcano Aragats.

With the exception of Aragats, all of the above listed volcanoes have recorded Holocene eruptions of Strombolian type producing lava flows. The dominant formation of pyroclastic cinder cones suggests that explosive volcanic activity. Fatalities and property damage were reported for the explosive 778 BC eruption of Porak and reports exist of evacuations during the 3000 BC eruption of Tskhouk-Karckar.

Of Armenia's population, more than 99% (nearly 3 million people) live within 100 km of the five Holocene volcanoes. The capital, Yerevan, lies just 23 km from Ghegam Ridge volcanic upland. The 100 km radii of these volcanoes also extend into the surrounding countries of Iran, Turkey, Georgia and Azerbaijan (Figure 10).

No eruptions are recorded since AD 1500 and there is no current knowledge of active volcano monitoring in Armenia. There is however an extensive National Observation Network of seismometers used for monitoring earthquake activity by the Armenian National Survey for Seismic Protection (NSSP).

The Asian Disaster Reduction Center (ADRC) produced a report on the hazards in Armenia in 2012, with a further six such reports dating back to 2001. In this they do not consider volcanic hazards, but list earthquakes as the most common disasters in Armenia. They describe how Armenia has moved from a system of 'reactive relief' efforts to proactive risk reduction, particularly in relation to the seismic hazard. The Ministry of Emergency Situations (MES-Armenia) are described by the ADRC as having developed a national disaster risk reduction strategy based on the Hyogo Framework for Action, and are responsible for national level disaster management. MES-Armenia, however, again do not consider volcanic hazards except for describing these as a potential cause of landslides.

See also:

Armenian National Survey for Seismic Protection: http://www.nssp-gov.am/index_eng.htm

Ministry of Emergency Situations: http://www.mes.am/en/

Asian Disaster Reduction Center: Armenia: http://www.adrc.asia/nationinformation.php?NationCode=51&Lang=en&NationNum=01

Meliksetian, K. Et al. (2014) Aragats stratovolcano in Armenia – volcano-stratigraphy and petrology, Geophysical Research Abstracts, Vol. 16, EGU2014-567-2.

Volcano Facts

Number of Holocene volcanoes (or volcano groups)	5, inclusive of two on the border
Number of Pleistocene volcanoes with M≥4 eruptions	None are currently listed in LaMEVE, however large

	magnitude eruptions are indicated by the presence of large volume ignimbrites.
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	4
Number of fatalities caused by volcanic eruptions	Unknown number of fatalities
Tectonic setting	Intra-plate (Post-Collisional)
Largest recorded Pleistocene eruption:	-
Largest recorded Holocene eruption	One eruption of VEI 0. Remainder are unknown.
Number of Holocene eruptions	5 confirmed eruptions. 2 uncertain eruptions.
Recorded Holocene VEI range	Unknown – 0
Number of historically active volcanoes	0
Number of historical eruptions	0

Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Andesitic (2)
3	Small cone(s)	Andesitic (3)

Table 16: The number of volcanoes in Armenia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	2,969,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	5,112
Gross National Income (GNI) per capita (2005 PPP $)	5,540
Human Development Index (HDI) (2012)	0.729 (High)

Population Exposure

Capital city	Yerevan

Distance from capital city to nearest Holocene volcano	23.7 km
Total population (2011)	2,967,975
Number (percentage) of people living within 10 km of a Holocene volcano	31,897 (1.1%)
Number (percentage) of people living within 30 km of a Holocene volcano	1,482,611 (50%)
Number (percentage) of people living within 100 km of a Holocene volcano	2,942,003 (99.1%)

Largest cities, as measured by population, and populations:

Yerevan	1,093,485
Gyumri	121,976

Infrastructure Exposure

Number of airports within 100 km of a volcano	3
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	2,301
Total length of railroads within 100 km of a volcano	206

The volcanoes in Armenia are widespread across the country, which measures less than 400 km across, thus, with the exception of a very small area in the north-east, the country in its entirety lies within 100 km of Holocene volcanoes. This places all critical infrastructure including airports and an extensive road and rail network within 100 km of volcanoes. The capital, Yerevan, lies just 23 km from Ghegham Ridge volcano and within 60 km of Ararat, a large stratovolcano in Turkey. The Armenian nuclear power plant (ANPP) is also exposed and volcanic hazard here was quantitatively assessed according to the IAEA SSG-21 safety guide. This report, by Connor, Connor, Meliksetian and Savov is due for publication soon. Connor et al. (2012) conducted a lava flow hazard analysis for the ANPP and found that lavas from Aragats would be diverted, but that lavas from the Shamiram Plateau could inundate the site (the annual probability is approximately 1.0×10^{-7} to 8.8×10^{-7} considering the low recurrence rate of volcanism).

The 100 km radii of the volcanoes in Armenia also extend into the surrounding countries of Iran, Turkey, Georgia and Azerbaijan.

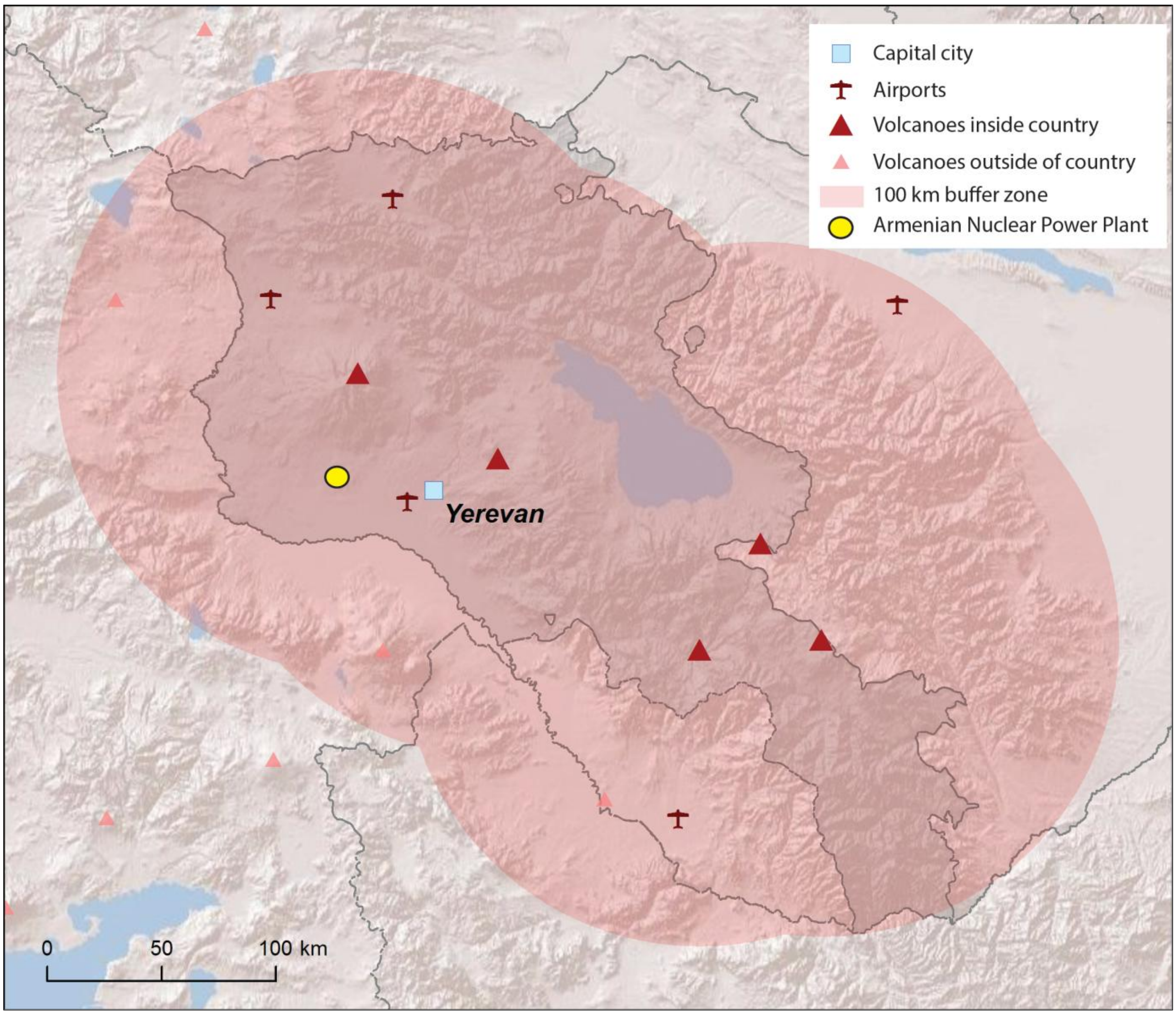

Figure 10: The location of Armenia's volcanoes and the extent of the 100 km zone surrounding them. Airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

No volcanoes in Armenia have eruption records comprising sufficient data (four or more eruptions of known size) for hazard classification. These are therefore unclassified. Of these volcanoes, none have records of unrest above background levels or eruption since 1900, and none have historical (post 1500 AD) eruptions recorded. Aragats volcano has no Holocene eruption record, with recent research indicating the most recent activity here was mid-Pleistocene in age.

The PEI in Armenia ranges from PEI 3 to PEI 7, indicative of moderate to large population sizes in close proximity to the volcanoes. Ghegam Ridge in west-central Armenia lies within 30 km of Yerevan, the nation's capital, and thus has a very high proximal population.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR			Porak; Tskhouk-Karckar		Dar-Alages		Ghegam Ridge
	U- NHHR				Aragats			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 17: Identity of Armenia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption. Note that recent research indicates that most recent activity of Aragats was mid-Pleistocene in age.*

National Capacity for Coping with Volcanic Risk

Four volcanoes in Armenia have evidence of Holocene eruptions but no eruptions are reported in the historical record. No regular ground-based monitoring is undertaken at any Holocene volcanoes in Armenia, however some work to study volcanic hazards and minor seismicity in volcanic regions is being undertaken by the Institute of Geological Sciences of the Armenian National Academy of Sciences.

Azerbaijan

Description

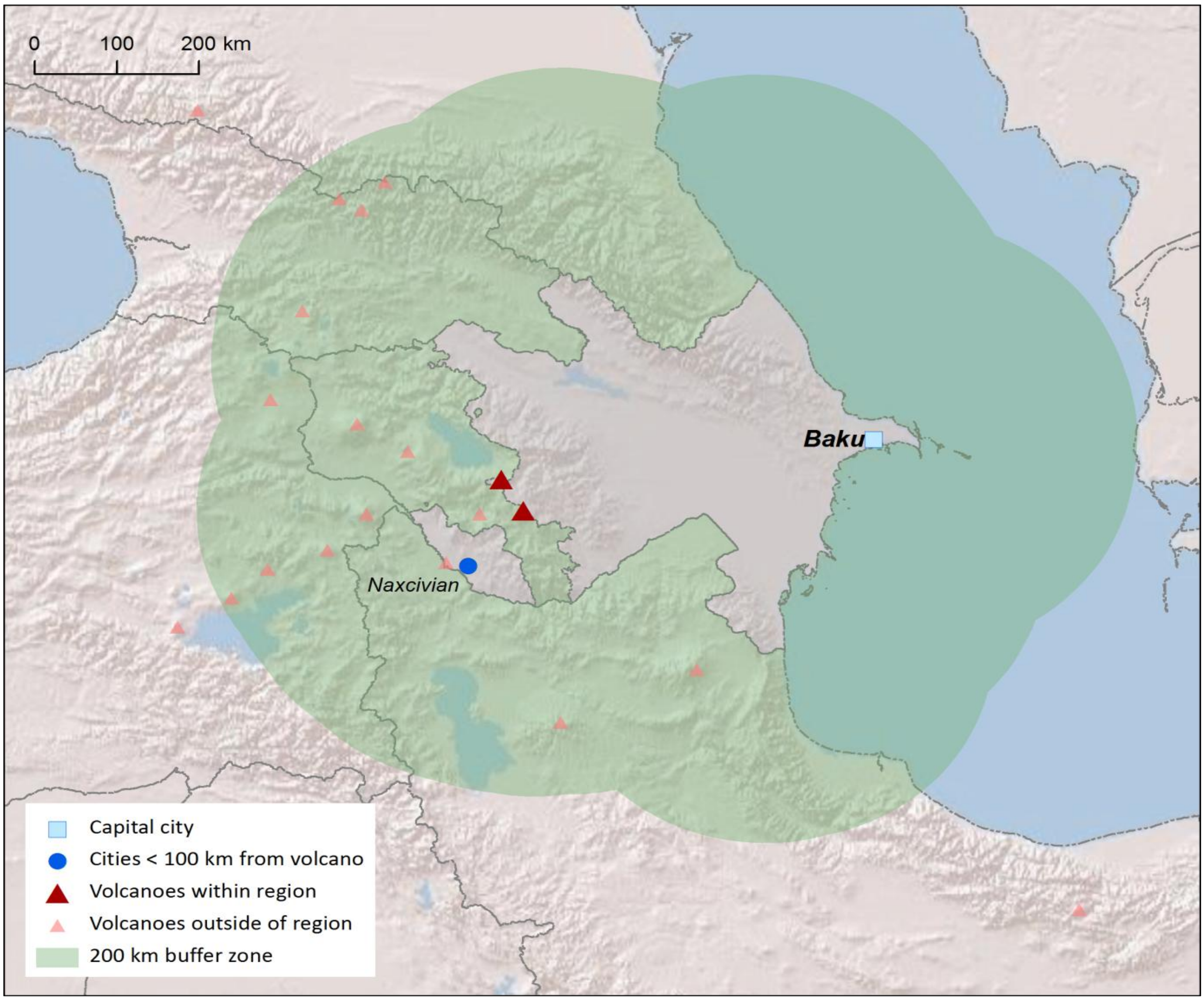

Figure 11: Location of Azerbaijan's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Azerbaijan.

There are two Holocene volcanoes partly located in Azerbaijan: Porak and Tskhouk-Karckar, which are also on the border with Armenia (Figure 11). These volcanoes are associated with the ongoing collision of the Eurasian, Arabian and African tectonic plates and their locations are closely linked to major fault locations. Porak is a stratocone and Tskhouk-Karckar a pyroclastic cone. Both produce andesite to basaltic andesite.

Both volcanoes have eruptions recorded in the Holocene: Porak in ~4510 BC and ~778 BC, with an uncertain eruption in ~740 BC, and Tskhouk-Karckar in ~3000 BC. The eruptions produced lava flows and are also described as explosive. There are no records for eruption size. Fatalities and property damage were reported for the explosive 778 BC eruption of Porak and reports exist of evacuations during the 3000 BC eruption of Tskhouk-Karckar.

The capital of Azerbaijan lies nearly 300 km to the east of the volcanoes, however a large city, Naxcivian, lies less than 100 km southwest of Tskhouk-Karckar. Just over 20% of Azerbaijan's population (more than 2 million people) live within 100 km of these Holocene volcanoes and the 100 km radii extends into the surrounding countries of Armenia and Iran.

No eruptions are recorded since AD 1500 and there is no current knowledge of active volcano monitoring in Azerbaijan. There is however an extensive national network of seismometers used for monitoring earthquake activity by the Azerbaijan National Academy of Sciences – Republican Seismological Service Centre.

The Asian Disaster Reduction Center (ADRC) produced a report on the hazards in Azerbaijan in 2011. In this they do not consider volcanic hazards, with the exception of mud volcanoes. They describe how there are over 220 mud volcanoes throughout the country and offshore, and these have had eruptions of mud and gas explosions and related fires. The Ministry of Emergency Situations for the Republic of Azerbaijan (MES-Azerbaijan) are described by the ADRC as the organisation responsible for emergency planning and are addressing the Hyogo Framework for Action (HFA).

See also:

Asian Disaster Reduction Center: Azerbaijan:
http://www.adrc.asia/nationinformation.php?NationCode=31&Lang=en&NationNum=35

Ministry for Emergency Situations: http://www.fhn.gov.az/

Republic Seismic Survey Centre: www.seismology.az

Volcano Facts

Number of Holocene volcanoes	3, inclusive of two on the border with Armenia and one on the border with Iran
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	2
Number of fatalities caused by volcanic eruptions	Fatalities?
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	
Largest recorded Holocene eruption	All eruptions recorded are of unknown VEI.
Number of Holocene eruptions	3 confirmed eruptions. 1

	uncertain eruption.
Recorded Holocene VEI range	Unknown
Number of historically active volcanoes	0
Number of historical eruptions	0

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Andesitic (1)
2	Small cone(s)	Andesitic (1), Unknown (1)

Table 18: The number of volcanoes in Azerbaijan, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	9,316,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	8,890
Gross National Income (GNI) per capita (2005 PPP $)	8,153
Human Development Index (HDI) (2012)	0.734 (High)

Population Exposure

Capital city	Baku
Distance from capital city to nearest Holocene volcano	290.6 km
Total population (2011)	9,397,279
Number (percentage) of people living within 10 km of a Holocene volcano	5,975 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	251,943 (2.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	2,068,272 (22%)

Largest cities, as measured by population, and populations:

Baku	1,116,513
Naxcivian	64,754

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	2,107
Total length of railroads within 100 km of a volcano (km)	95

The volcanoes of Azerbaijan are located on the western border with Armenia. The 100 km radii of these volcanoes therefore extend into Armenia and Iran. The capital, Baku, lies nearly 300 km to the east, however one of the largest cities in Azerbaijan, Naxcivian, lies within the 100 km radii, exposing significant infrastructure here including an extensive road network and airports. Being inland volcanoes, no ports are exposed.

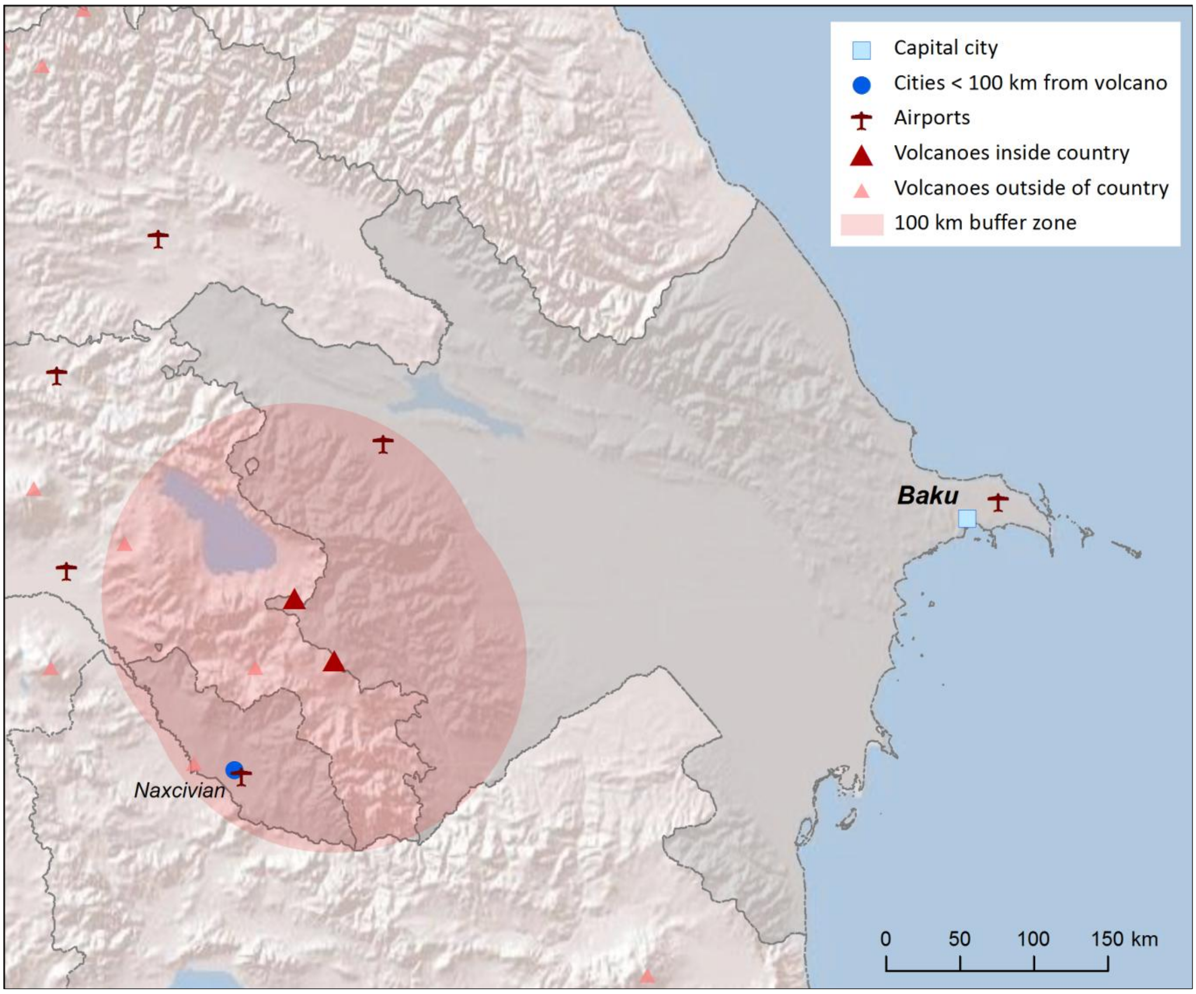

Figure 12: The location of Azerbaijan's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The volcanoes of Azerbaijan have insufficient numbers of eruptions in their eruptive records to classify the hazard without large uncertainties. Therefore, the volcanoes here are unclassified. No volcanoes have post 1500 AD eruptions or post 1900 AD unrest above background levels recorded, and the Unnamed volcano has no Holocene eruptions recorded at all.

With no hazard levels attributed, the risk cannot be derived. However the PEI indicates moderate to large local populations, with the Unnamed lava field on the border of Azerbaijan-Iran lying about 20 km from the city of Nakhchivan, of population around 75,000.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR			Porak; Tskhouk-Karckar				
	U- NHHR					Unnamed		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 191: Identity of Azerbaijan's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Azerbaijan have recorded historical eruptions, although there are records of Holocene activity. No information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Azerbaijan.

France – Mainland

Description

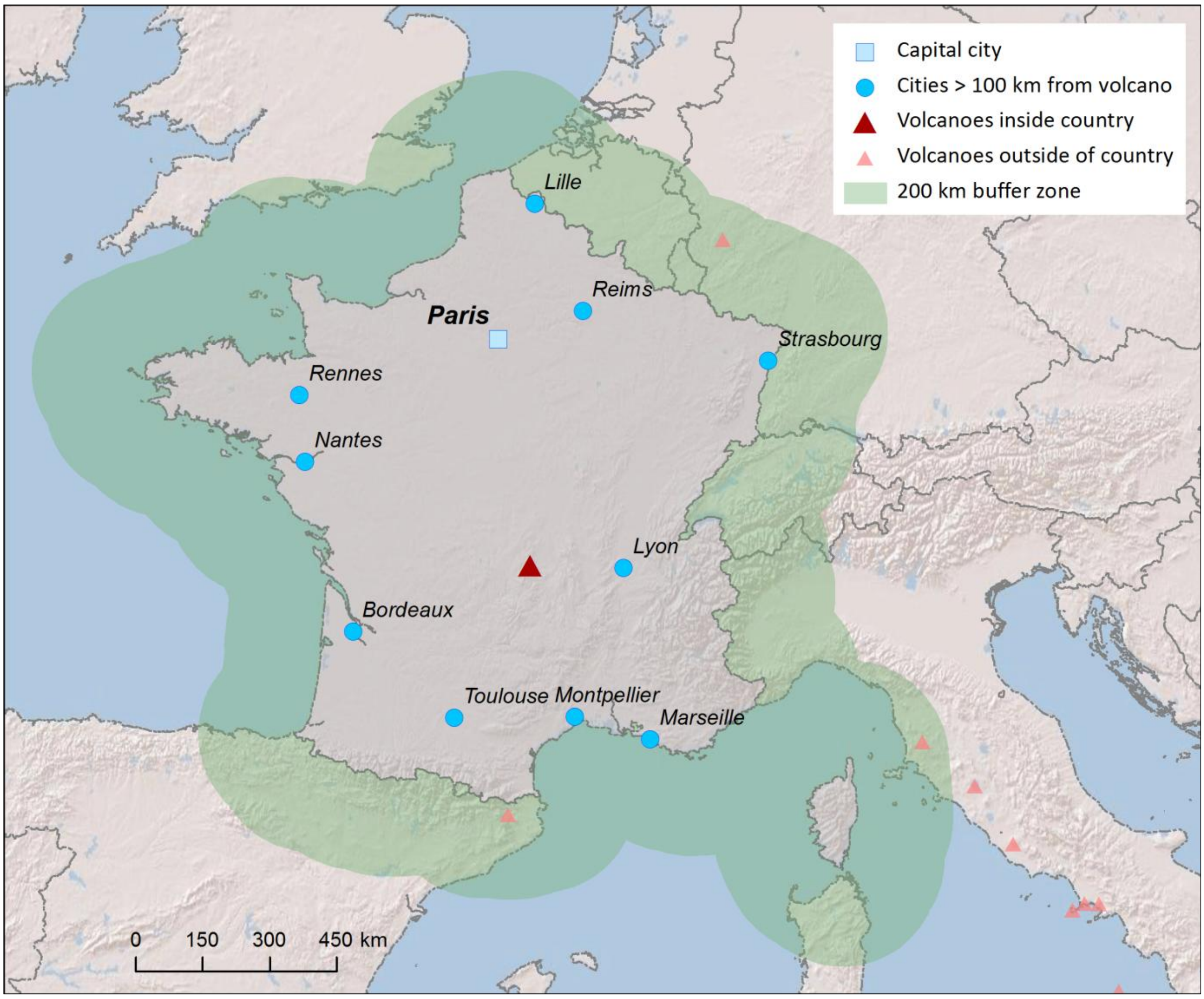

Figure 13: Location of Mainland France's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect France.

Only one Holocene volcano is located in mainland France: the Chaîne des Puys volcano in central France. The Chaîne des Puys form an ~40 km N-S trending chain of monogenetic basaltic and trachytic cinder cones, basaltic maars, and trachytic lava domes. The chain is ~ 4 km wide and runs parallel to the Limagne fault; volcanism is related to a rift zone. Construction of the present-day Chaîne des Puys began about 70,000 years ago, and was largely complete by the beginning of the Holocene.

There are eight recorded eruptions in the Holocene but no eruption sizes are recorded. A M4 eruption was recorded prior to the Holocene at about 14,000 years ago. Construction of Holocene lava domes has been accompanied by pyroclastic flows and the formation of explosion craters (maars) and cinder cones that fed lengthy lava flows. The most recent eruption (~4040 BC) included powerful explosions and the formation of the Lac Pavin maar. The dating of younger tephras has not yet been confirmed, and reports of historical eruptions as late as 1000 years before present have been discredited.

Chaîne des Puys lies nearly 350 km to the south of the capital, Paris, and more than 100 km from the major cities of mainland France. However, nearly two million people (3% of mainland France's population) live within 100 km, including the city of Clermont-Ferrand, an extensive road and rail network and two airports.

Volcano Facts

Number of Holocene volcanoes	1 in mainland France
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	The M4 eruption of Les Roches Tephra at Chaîne des Puys at 13,872 BP.
Largest recorded Holocene eruption	All recorded eruptions were of unknown VEI.
Number of Holocene eruptions	8 confirmed eruptions.
Recorded Holocene VEI range	0
Number of historically active volcanoes	0
Number of historical eruptions	0

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
1	Lava dome(s)	Basaltic (1)

Table 20: The number of volcanoes in Mainland France, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	63,933,000

Gross Domestic Product (GDP) per capita (2005 PPP $)	29,819
Gross National Income (GNI) per capita (2005 PPP $)	30,277
Human Development Index (HDI) (2012)	0.893 (Very High)

Population Exposure

Capital city	Paris
Distance from capital city to nearest Holocene volcano	347.5 km
Total population (2011)	63,299,650
Number (percentage) of people living within 10 km of a Holocene volcano	52,764 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	427,957 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	1,864,864 (3%)

Ten largest cities, as measured by population, and their populations (2012):

Paris	2,138,551
Marseille	794,811
Lyon	472,317
Toulouse	433,055
Nantes	277,269
Strasbourg	274,845
Montpellier	248,252
Bordeaux	231,844
Lille	228,328
Rennes	209,375

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	2,747
Total length of railroads within 100 km of a volcano (km)	546

Chaine des Puys volcano is located in the Auvergne region of central France, distal to the capital, Paris, which lies nearly 350 km to the north, and the other largest cities in France. However, the city of Clermont-Ferrand lies within 10 km, exposing significant infrastructure here, including an extensive road and rail network and two airports.

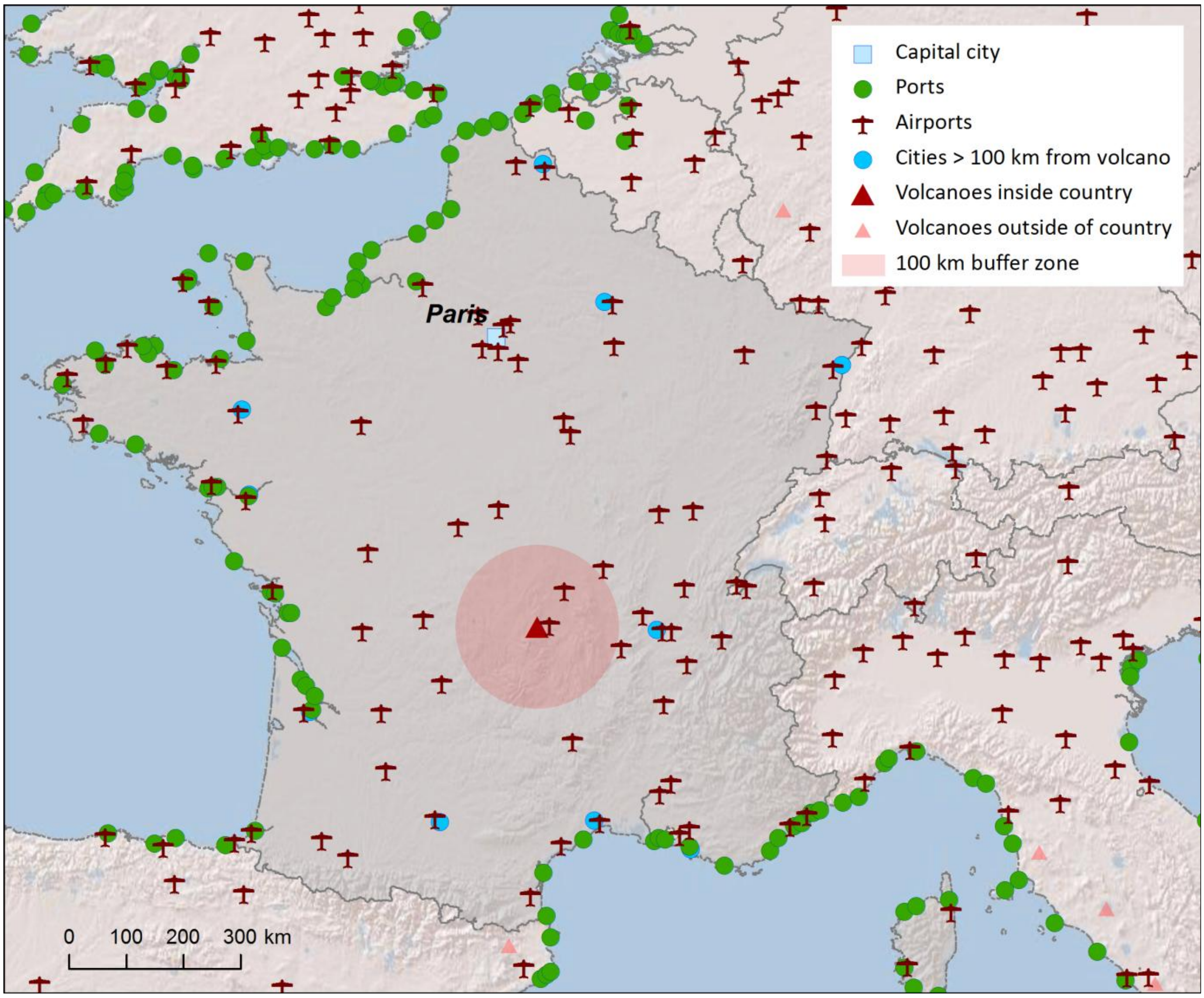

Figure 14: The location of Mainland France's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The Chaine des Puys volcano has eight confirmed Holocene eruptions in the VOTW4.22 record, however as none of these has an attributed size the hazard level cannot be determined and this volcano is therefore unclassified.

Although the hazard level is undetermined which means risk cannot be constrained, this volcano classifies with the highest PEI of 7, with a high local population including the city of Clermont-Ferrand lying within 10 km. This high population would indicate a high level of risk even if the hazard is low.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR							Chaîne des Puys
	U- NHHR							
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 21: Identity of Mainland France's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

The Chaîne des Puys volcanoes have had eight recorded Holocene eruptions but no recorded historical eruptions. Continuous seismic monitoring is undertaken in the region, by the Observatoire de Physique du Globe de Clermont-Ferrand.

Georgia

Description

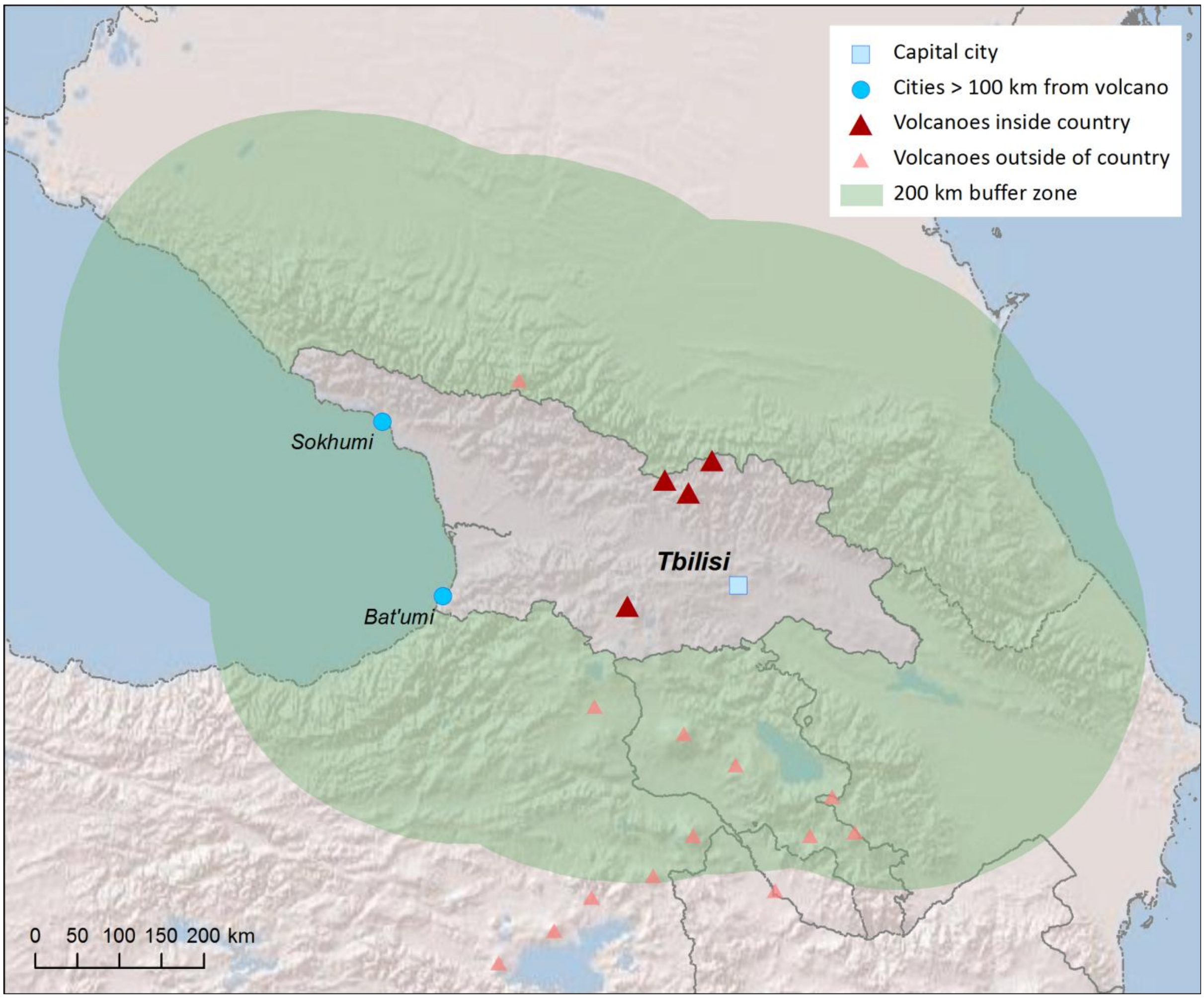

Figure 15: Location of Georgia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Georgia.

Four Holocene volcanoes are located in Georgia: Kasbek, the Karbargin Oth Group, an unnamed volcano in the north of the country, and a further unnamed volcano in the south. Georgia is located on the Eurasian Plate near the collision zone between the Eurasian, Arabic and Anatolian Plates, however the volcanism here is described as intra-plate. These volcanoes comprise andesitic cinder and lava cones, in addition to the andesitic stratovolcano, Kasbek.

Although all four volcanoes are suspected to have had Holocene age activity, only Kasbek has recorded Holocene eruptions. The size of these eruptions is unknown however lava flows are recorded from one eruption. No historical eruptions are recorded. The absence of a detailed eruption history for the volcanoes in Georgia makes assessment of hazard difficult and associated with large uncertainties.

A small population resides within 10 km of the volcanoes in Georgia, however nearly 40% of the population live within 100 km of one or more Holocene volcanoes. The 100 km radii of the Georgian volcanoes extend beyond the country's borders into Russia, Armenia and Turkey.

Volcano Facts

Number of Holocene volcanoes	4
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Unknown
Number of Holocene eruptions	2 confirmed eruptions.
Recorded Holocene VEI range	Both are of unknown VEI.
Number of historically active volcanoes	0
Number of historical eruptions	0

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Andesitic (1)
3	Small cone(s)	Andesitic (3)

Table 22: The number of volcanoes in Georgia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	4,358,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,826
Gross National Income (GNI) per capita (2005 PPP $)	5,005
Human Development Index (HDI) (2012)	0.745 (High)

Population Exposure

Capital city	Tbilisi
Distance from capital city to nearest Holocene volcano	92.2 km
Total population (2011)	4,585,874
Number (percentage) of people living within 10 km of a Holocene volcano	7,896 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	96,329 (2.1%)
Number (percentage) of people living within 100 km of a Holocene volcano	1,831,569 (39.9%)

Largest cities, as measured by population, and populations:

T'Bilisi	1,049,498
Bat'umi	121,806
Sokhumi	81,546

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	1,646
Total length of railroads within 100 km of a volcano (km)	294

The volcanoes in Georgia are distributed to the north and south of the country, where they are located near the borders; their 100 km radii therefore extend into Russia, Armenia and Turkey. There are no airports located within the 100 km radii in Georgia itself, however three airports beyond its borders are exposed. The capital of Georgia, Tbilisi, lies at just over 90 km from the nearest Holocene volcano (an unnamed volcano in the north), exposing significant critical infrastructure, including an extensive road and rail network.

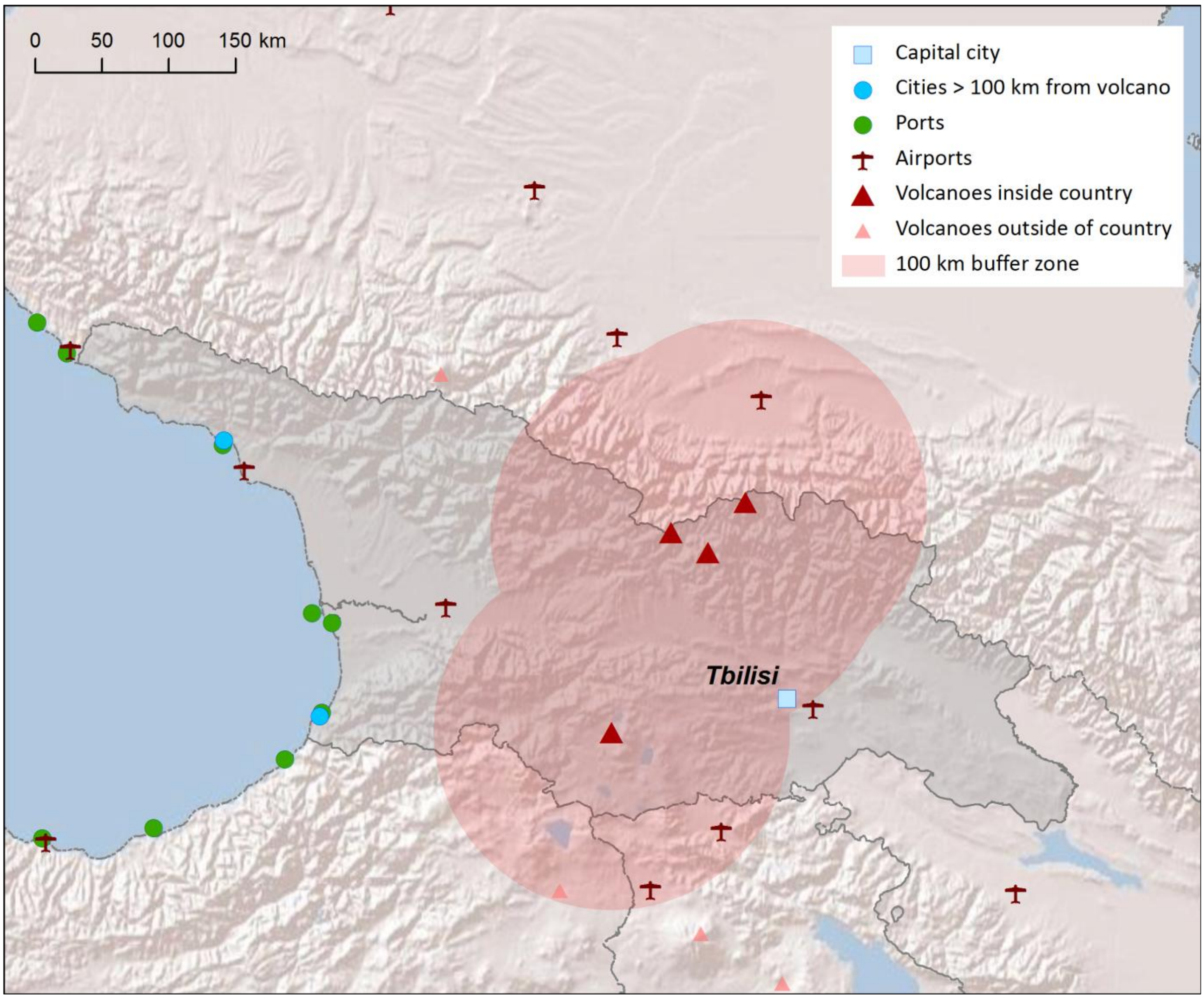

Figure 16: The location of Georgia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Of the four Georgian volcanoes, only Kasbek has a Holocene record of confirmed eruptions, and these events were of unknown size. No historical eruptions or post-1900 AD unrest above background levels are recorded at any volcanoes. The absence of a detailed eruptive history means that the hazard levels at these volcanoes cannot be determined without large uncertainties and these volcanoes are therefore unclassified. The risk levels therefore cannot be derived, though from the PEI (of 3 to 4), moderate local populations are indicated.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR			Kasbek				
	U- NHHR			Kabargin Oth Group; Unnamed	Unnamed			
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 23: Identity of Georgia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Georgia have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Georgia.

Germany

Description

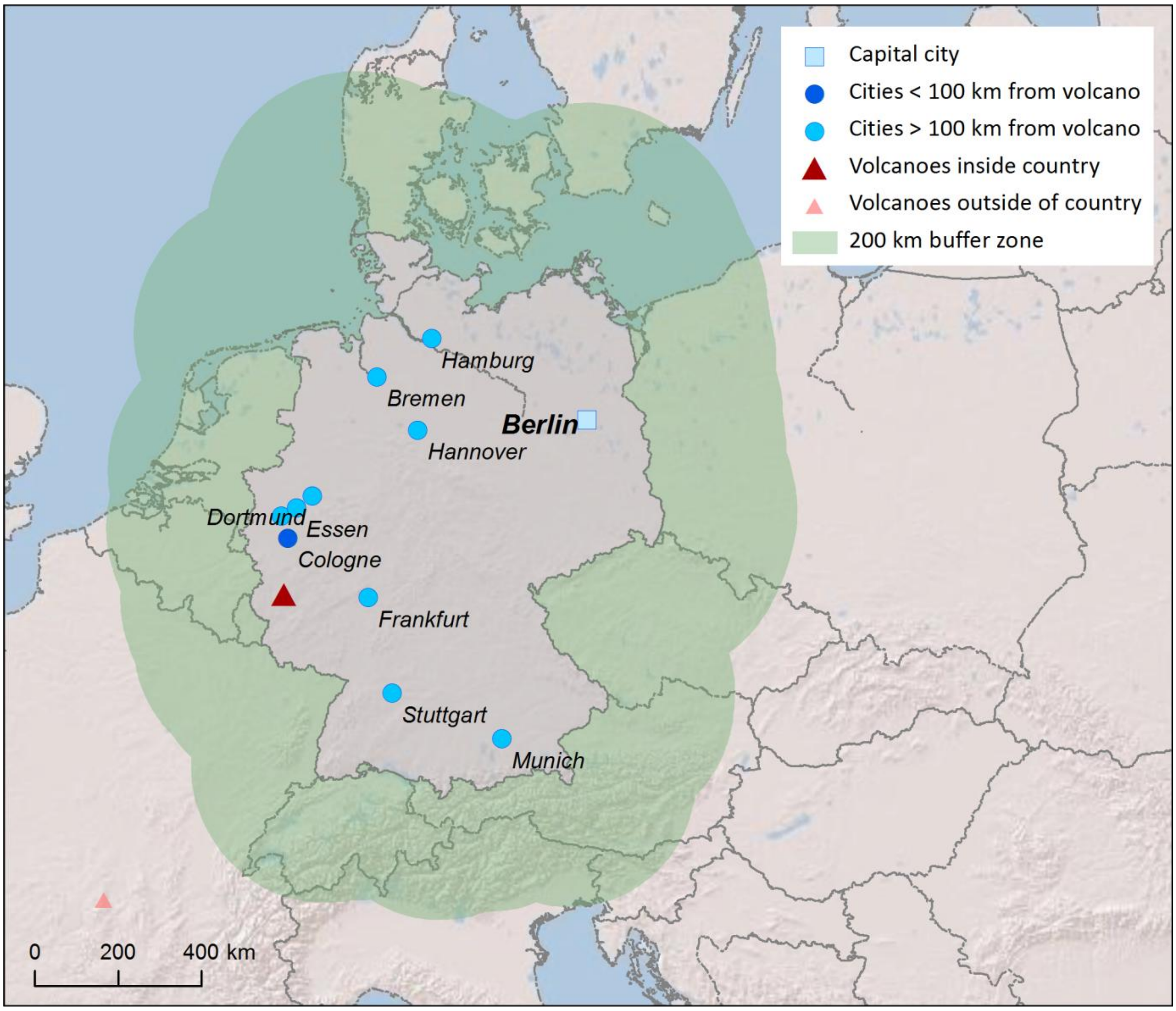

Figure 17: Location of Germany's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Germany.

One volcano of Holocene age is recorded in Germany: the West Eifel Volcanic Field. This volcano is located in the west of Germany, near the border with Luxembourg, Belgium and France. Volcanism here is related to a rift zone.

The West Eifel Volcanic Field covers an area of about 600 square kilometres and comprises multiple scoria cones, maars and small stratovolcanoes, indicating that monogenetic activity has been a common feature here.

Just two confirmed eruptions are recorded here, with no eruptions recorded since 8300 BC. The size of the eruptions is unknown, however many of the cones have associated lavas and the formation of these volcanic centres indicates moderate localised explosive activity. The calculation of the hazard at West Eifel is associated with large uncertainties due to the sparse nature of the eruptive record.

Multiple small towns are located close to this volcanic field and several large cities are located within 100 km, with over 4.7 million people residing within this distance. Were eruptions of monogenetic vents to occur forming similar small lava flows and cones, these would likely have dominantly a localised effect, with more explosive events required to extend to the distal populations.

A Pleistocene eruption is recorded at the East Eifel Volcanic field, approximately 40 km SW of the West Eifel volcanic field. No Holocene activity is recorded in the East Eifel Volcanic Field. The eruption of the Laacher See Tephra at nearly 13,000 years ago was a large explosive eruption of magnitude 6.2.

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	The M6.2 eruption of the Laacher See Tephra at 12,916 BP at the East Eifel Volcanic Field.
Largest recorded Holocene eruption	Both eruptions were of Unknown VEI.
Number of Holocene eruptions	2 confirmed eruptions.
Recorded Holocene VEI range	Unknown
Number of historically active volcanoes	0
Number of historical eruptions	0

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
1	Small cone(s)	Foiditic (1)

Table 24: The number of volcanoes in Germany, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	82,760,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	34,437

Gross National Income (GNI) per capita (2005 PPP $)	35,431
Human Development Index (HDI) (2012)	0.920 (Very High)

Population Exposure

Capital city	Berlin
Distance from capital city to nearest Holocene volcano	523.1 km
Total population (2011)	81,471,834
Number (percentage) of people living within 10 km of a Holocene volcano	16,787 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	187,351 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	4,720,394 (5.8%)

Ten largest cities, as measured by population, and populations:

Berlin	3,426,354
Hamburg	1,739,117
Munich	1,260,391
Cologne	963,395
Frankfurt	650,000
Essen	593,085
Stuttgart	589,793
Dortmund	588,462
Dusseldorf	573,057
Bremen	546,501

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	5,596
Total length of railroads within 100 km of a volcano (km)	378

The West Eifel Volcanic Field is located in the west of Germany. Here the 100 km radius extends beyond Germany's borders, into Luxembourg, Belgium and France. The major city of Cologne is within 100 km and several major cities lie just beyond this radius. Two airports in Germany are located within the 100 km radius, as is Luxembourg airport. Luxembourg in its entirety is located in this radius, exposing all critical infrastructure here. Many towns and cities are exposed within the radius in Germany, as is an extensive road and rail network.

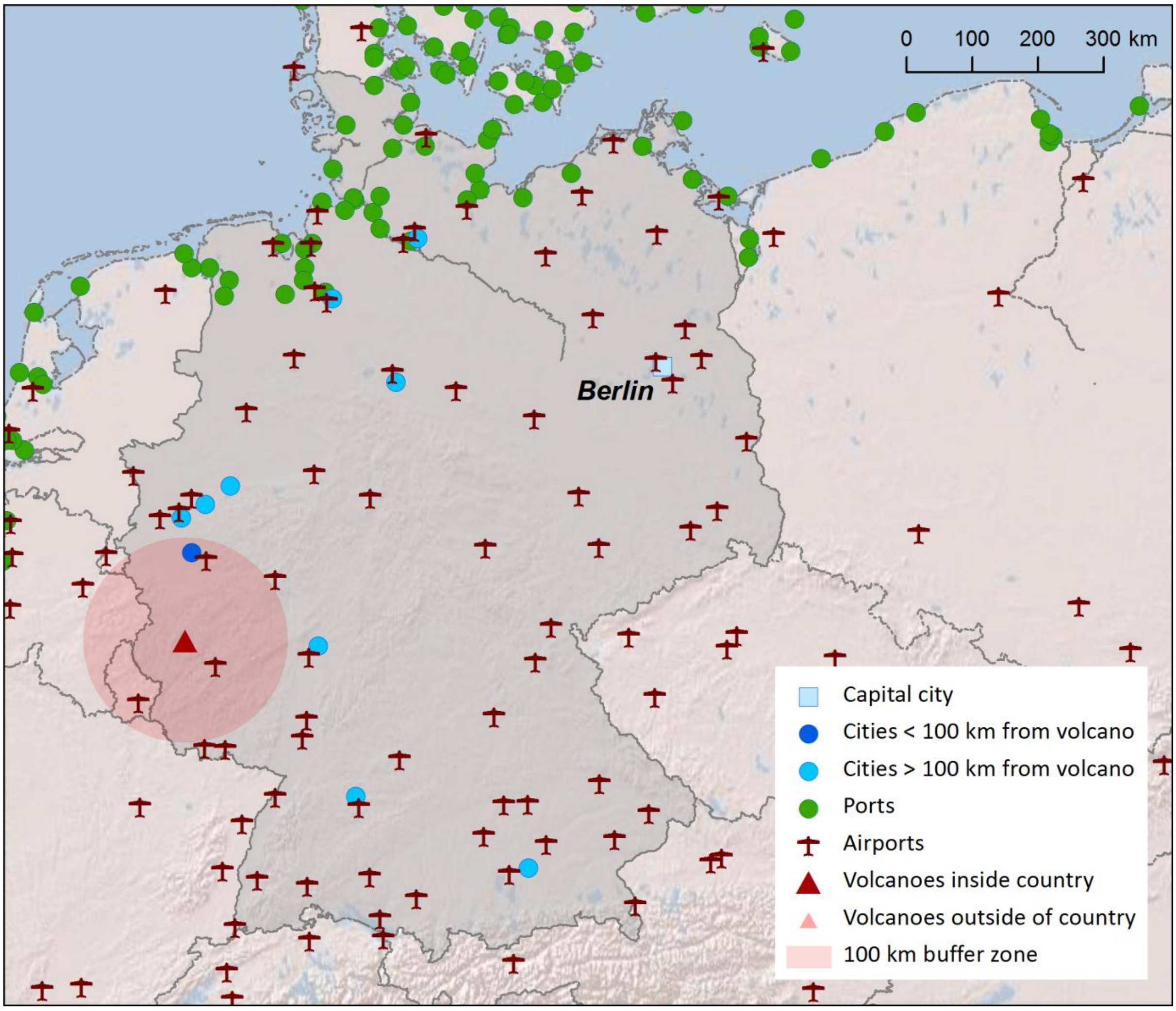

Figure 18: The location of Germany's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The West Eifel Volcanic Field has two confirmed eruptions recorded during the Holocene, both of unknown size. The hazard level cannot therefore be determined for this volcano without significant uncertainties, and this is therefore unclassified.

There are multiple small towns located in close proximity to this volcano and several large cities within 100 km distance. The resulting high PEI would indicate that this would classify as a Risk Level II to III volcano dependent on the hazard level.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR						West Eifel Volcanic Field	
	U- NHHR							
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 25: Identity of Germany's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Germany have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Germany.

Greece

Description

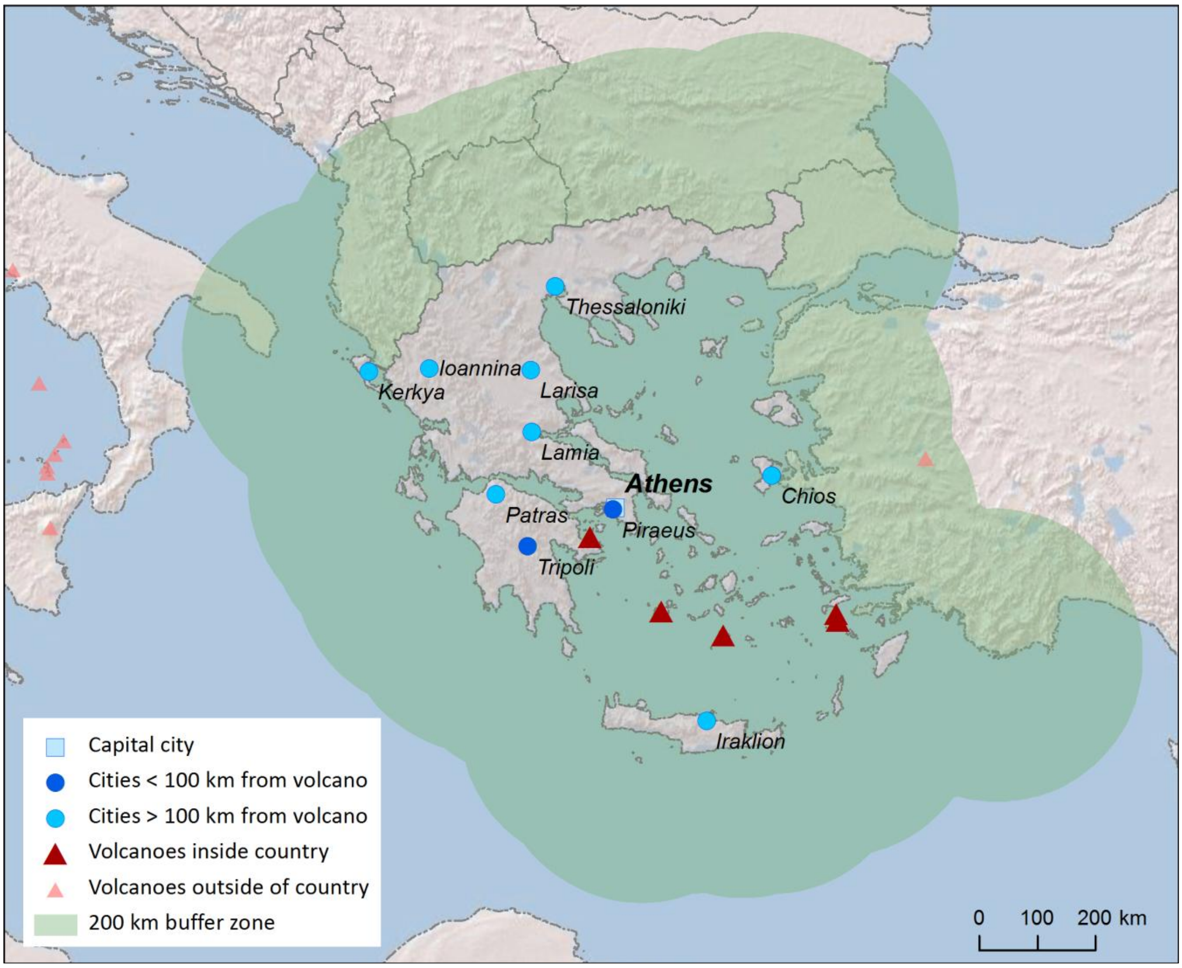

Figure 19: Location of Greece's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Greece.

Five Holocene volcanoes are located in the Hellenic Arc in Greece, stretching from Methana in the east to Yali and Nisyros in the west. Volcanoes here result from the subduction of the African Plate under the Eurasian Plate. The volcanoes range in composition from andesitic to rhyolitic, with such felsic compositions often associated with explosive activity. The morphology of the volcanoes varies: Santorini is a complex of shield volcanoes and calderas, Methana is a lava dome complex, Yali is a system of lava domes related to the submarine Kos caldera, and Mílos and Nisyros are stratovolcanoes.

Eighteen eruptions of VEI 1 to 7 are recorded from four volcanoes during the Holocene, including eleven eruptions from Santorini and Nisyros in historical times. The range in VEI indicates that activity has varied widely during the Holocene, from mild eruptions to very large explosive events. The largest Holocene eruption was the 1610 BC Minoan eruption of Santorini. This eruption measured VEI 7 and produced extensive pyroclastic flows, ash fall, lahars and a tsunami implicated in the fall of the Minoan civilisation. Large explosive eruptions are also recorded in Greece in the Pleistocene, with four volcanoes having records of M≥4 eruptions.

The activity of Santorini, which is the most frequently active volcano in Greece, is not restricted to large explosive eruptions, with a record of five VEI 2 eruptions since 1866.

The capital, Athens, lies about 54 km from Methana volcano and two of the most populous cities in Greece, Tripoli and Piraeus, also lie within about 80 km. The total population residing within 100 km of one or more volcanoes in Greece is over 4.6 million.

The assessment of hazard at Methana and Milos is difficult with only one Holocene eruption record at each volcano. Given the proximity to large cities, focussed research to better understand the hazard may be beneficial. Santorini and Nisyros are more fully understood, and with a history of large explosive eruptions, frequent events and a population of nearly 70,000 within 100 km, Santorini is classed here at Risk Level III, the highest in Greece.

The Institute for the Study and Monitoring of Santorini Volcano (ISMOSAV) and the Nisyros Volcano Observatory monitor the historically active volcanoes of Greece. The latter also monitors Yali. Multiple dedicated ground-based monitoring systems are used, including seismic and deformation surveillance. The seismic monitoring is continuous and the background baseline data is known for both Santorini and Nisyros, which should permit identification of anomalous activity. Few resources are available to extend monitoring to other volcanoes.

The monitoring institutions are responsible for both monitoring and scientific research, and personnel include seismologists, volcanologists, experts in remote sensing, geochemistry and ground deformation. None of the staff have experience of responding to an eruption.

Unrest was detected at Santorini in 2011-2012 comprising seismic activity and deformation. A National Committee for volcano monitoring was formed and contact was established with the Secretary General of Civil Protection. International scientific and technical support was given and this could be advantageous in future crises.

Were unrest to increase or eruption to occur, protocols exist to notify and advise national and local authorities. ISMOSAV provides risk assessments and engages within the public providing a hazard education program. Alert levels are not directly released, instead the scientific committee advises the Secretary General of Civil Protection to release alerts.

Although monitoring is undertaken at Santorini and Nisyros, a fully funded state national monitoring institution responsible for monitoring and hazard and risk assessments would be beneficial to Greece.

See also:

Santorini volcano, http://santorini.earth.ox.ac.uk/home for discussion of the 2011-12 unrest and monitoring.

Nisyros Volcano Observatory, http://nisyros.igme.gr/nisyros_en/index.php?option=com_content&task=view&id=48&Itemid=65

Volcano Facts

Number of Holocene volcanoes	5
Number of Pleistocene volcanoes with M≥4 eruptions	4
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	3
Number of volcanoes generating lava flows	2
Number of fatalities caused by volcanic eruptions	?>184
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M7.1 Kos Plateau Tuff (KPT) eruption of Kos at 161 ka.
Largest recorded Holocene eruption	The M6.5 Minoan eruption of Santorini at 3,560 BP.
Number of Holocene eruptions	18 confirmed eruptions. 1 uncertain and 1 discredited eruption.
Recorded Holocene VEI range	1 – 7
Number of historically active volcanoes	2
Number of historical eruptions	11

Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Dacitic (1), Rhyolitic (1)
2	Lava dome(s)	Andesitic (1), Rhyolitic (1)
1	Shield(s)	Dacitic (1)

Table 26: The number of volcanoes in Greece, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	11,118,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	22,558
Gross National Income (GNI) per capita (2005 PPP $)	20,511
Human Development Index (HDI) (2012)	0.860 (Very High)

Population Exposure

Capital city	Athens
Distance from capital city to nearest Holocene volcano	53.3 km
Total population (2011)	10,760,136
Number (percentage) of people living within 10 km of a Holocene volcano	26,006 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	115,808 (1.1%)
Number (percentage) of people living within 100 km of a Holocene volcano	4,633,833 (43.1%)

Ten largest cities, as measured by population, and populations:

Athens	729,137
Thessaloniki	354,290
Piraeus	172,429
Patras	163,360
Iraklion	137,154
Larisa	128,758
Ioannina	64,012
Lamia	47,246
Kerkya	27,003
Tripoli	26,561

Infrastructure Exposure

Number of airports within 100 km of a volcano	6
Number of ports within 100 km of a volcano	21
Total length of roads within 100 km of a volcano (km)	2,189
Total length of railroads within 100 km of a volcano (km)	594

The Holocene volcanoes in Greece are located in the Aegean island arc between Greece and Turkey. The 100 km radii surrounding these volcanoes therefore extends into both countries and many islands are located here. Being island volcanoes numerous ports are exposed to the volcanic hazard, as are a number of airports in both Greece and Turkey. The capital, Athens, lies within 100 km of Methana volcano, as do the major cities of Tripoli and Piraeus, therefore exposing much critical infrastructure here, including an extensive road and rail network.

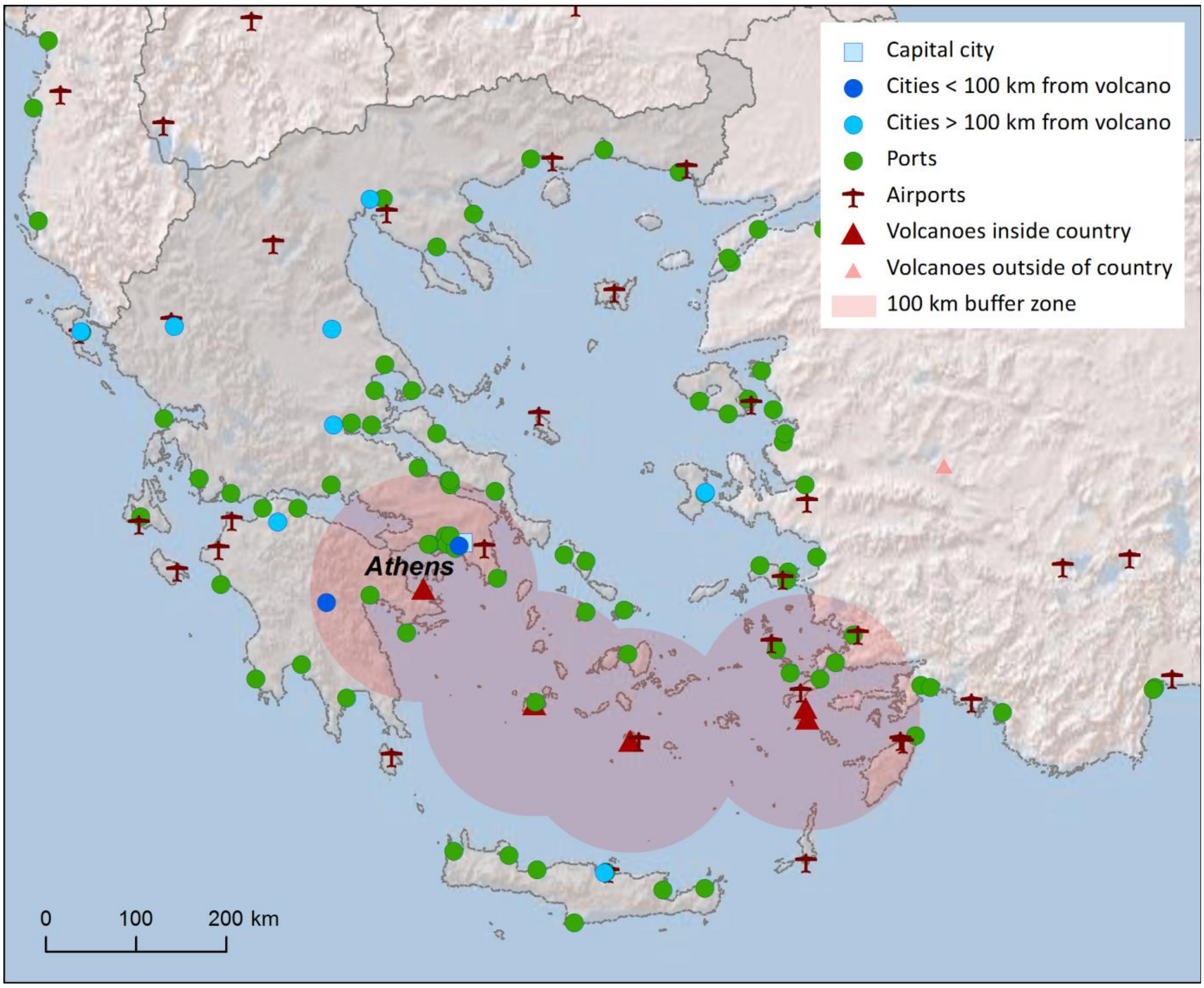

Figure 20: The location of Greece's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The volcanoes of Greece have varying levels of data available in the eruption record. Just two out of the five have appropriate eruptive histories to define the hazard level: Santorini and Nisyros. Of these, Santorini has erupted four times since 1900, whilst Nisyros has a historic eruption record. Santorini is classified at Hazard Level III, whilst Nisyros is at Level III.

Milos, Methana and Yali are unclassified, with just one eruption at Milos and one at Methana in the Holocene. Yali has no confirmed eruptions in the Holocene.

All Greek volcanoes have low to moderate PEI levels. With a population of nearly 70,000 within 100 km and a hazard level of III, the risk here is classed at Risk Level III. Nisyros is classified at Risk Level I, with a much smaller local population.

CLASSIFIED	**Hazard III**				Santorini			
	Hazard II		Nisyros					
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR			Mílos	Methana			
	U- NHHR		Yali					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 27: Identity of Greece's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Santorini	4	III
Nisyros	2	I

Table 28: Classified volcanoes of Greece ordered by descending Population Exposure Index (PEI). The Risk Level as determined through the combination of the Hazard Level and PEI is given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 1 volcano.

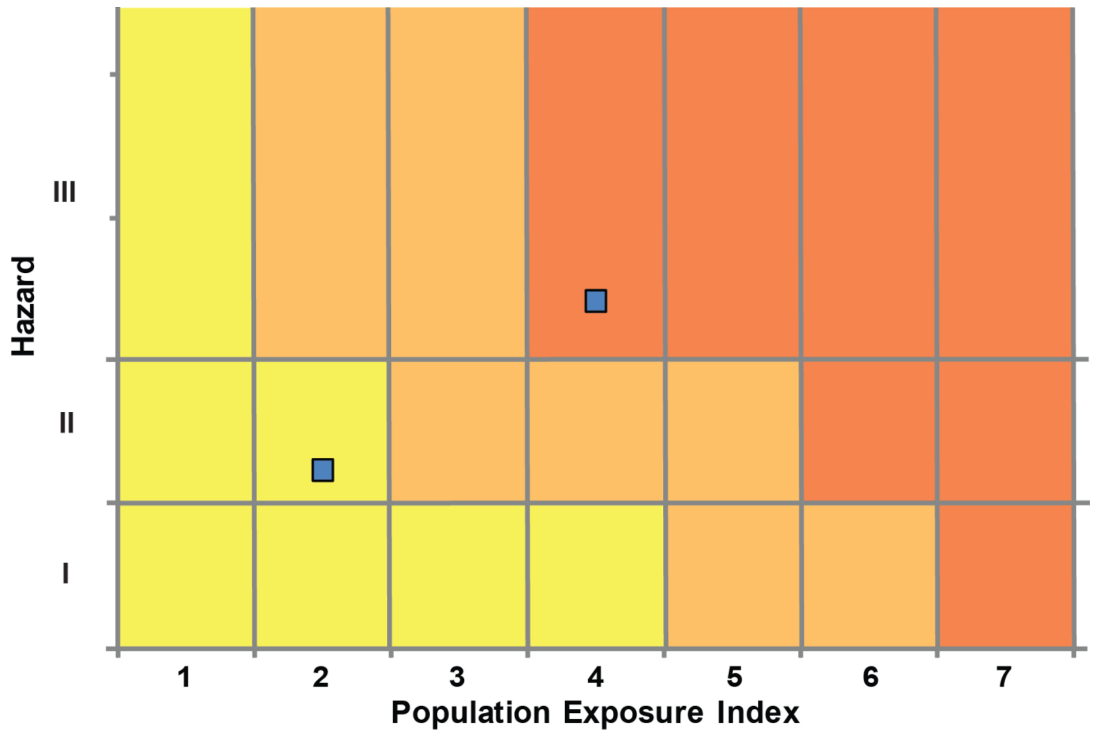

Figure 21: Distribution of Greece's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Both Nisyros and Santorini have recorded historical activity and both are monitored by the Nisyros Volcano Observatory and the Institute for the Study and Monitoring of Santorini Volcano (ISMOSAV) respectively. Both volcanoes have multi-system ground based monitoring, including seismic, gas and deformation surveillance. With the highest Risk Level assigned in Greece, Santorini has a dedicated monitoring network and institution that should permit episodes of unrest to be detected and some forecasts of activity to be made. Despite no recorded historical activity, Yali is also monitored by the Nisyros Volcano Observatory.

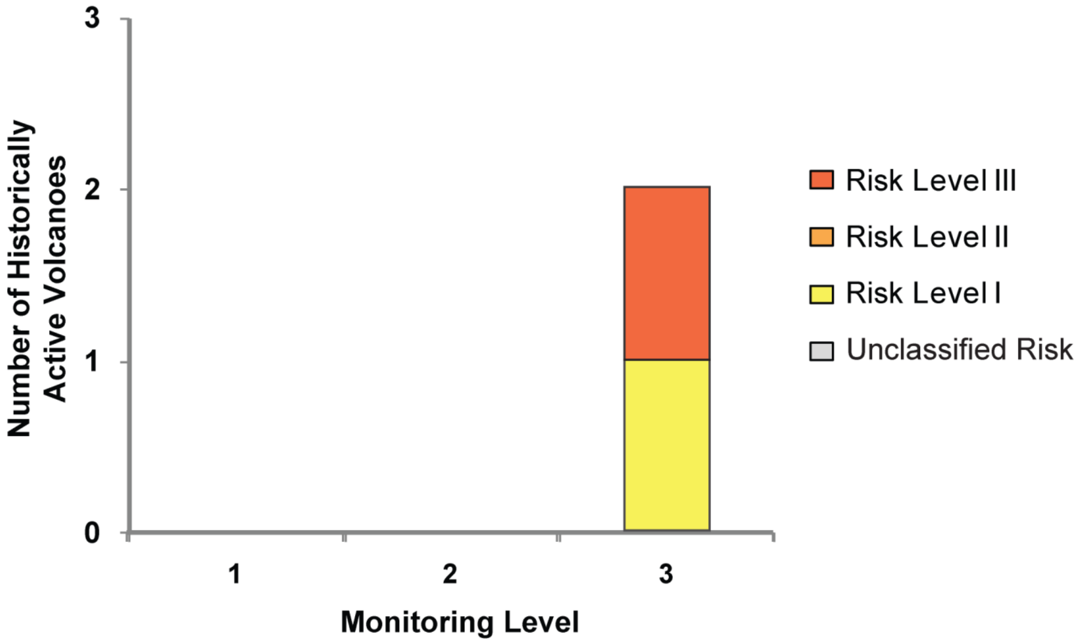

Figure 22: The monitoring and risk levels of the historically active volcanoes in Greece. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Italy

Description

There are 14 Holocene volcanoes in Italy according to VOTW4.0 (see footnotes), although two of these (Panarea and Alban Hills) have no known Holocene eruptions. Larderello and Vulsini are included in VOT4.0, but are removed from this analysis. Volcanoes are distributed throughout the west of the country, extending through the Aeolian Islands, Sicily and beyond. Most volcanism is related to complex compressional tectonics associated with the convergence of the European Plate with the northward moving African Plate, including the Aeolian island arc. However, the active volcanism of the Sicily Channel related to the Pantelleria island and to the submarine volcano of Ferdinandea[1] is associated with tensional continental regimes linked to rotation and stretching of the continental crust in the region behind the Afro-Eurasian collision zone. Volcanoes range in compositions from mafic to felsic, with felsic compositions usually associated with explosive activity. The morphology of the volcanoes includes seven large stratovolcanoes (Etna, Ischia, Lipari, Panarea, Stromboli, Vesuvius and Vulcano). Pantelleria is described as a shield volcano with sub-types of caldera, lava domes and pyroclastic cones and can also be described as a polygenetic stratovolcano. In addition to these, two[2] calderas (Alban Hills and Campi Flegrei), three submarine volcanoes (Ferdinandea, Marsili[3] and Palinuro). VOTW4.0 includes Larderello (explosion craters) however this is considered a relic of phreatic explosions unrelated to volcanism. Some volcanoes are best described by more than one volcano morphology. During the Holocene Campi Flegrei has produced about 70 explosive eruptions from monogenetic vents distributed in a wide area within the Campi Flegrei caldera, however the last caldera-forming eruption here occurred about 15,000 years ago.

There are 371 confirmed Holocene eruptions in VOTW4.22 with a range of VEI from unknown, to 0 through to 5. The range in VEI indicates that activity has varied widely during the Holocene, from mild persistent activity (e.g. Stromboli) to large magnitude explosive eruptions (e.g. Vesuvius). The largest magnitude Holocene eruptions in Italy (VEI 5) have been produced by Campi Flegrei in ~2150 BC, by Vesuvius in ~6940 BC, ~2420 BC, 79 AD, 472 AD and 1631 AD, and by Etna in ~1500 BC and ~122 BC. In addition to the 371 Holocene eruptions, there are 43 uncertain eruptions in VOTW4.22. Alban Hills and Panarea have no confirmed recorded Holocene eruptions but are suspected to have had activity of Holocene age. Seven of the 14 Italian volcanoes have historical records of eruptions. However, all 14 volcanoes listed in VOTW4.0 have records of explosive eruptions of M≥4 in the Pleistocene.

The capital of Italy, Rome, lies less than 25 km from the nearest Holocene volcano (Alban Hills) and more than one third of Italians (>20 million people) live within 100 km of a Holocene volcano. Evacuations of at-risk populations have been recorded for eruptions at Campi Flegrei, Vesuvius, Ischia and Etna. 26 eruptions at Campi Flegrei, Vesuvius, Ischia, Strombolia and Etna have resulted in

[1] The submarine Ferdinandea volcano is called Campi Flegrei Mar Sicilia in VOTW4.0, but is known locally as Ferdinandea.
[2] Vulsini is also included in VOTW4.0, however the youngest products dated are 127 ka (Palladino et al. 2010), so it is removed from the Holocene record here.
[3] Marsili seamount developed through effusive and low energy explosive eruptions between 0.78 Ma and 3 ka BP (Iezzi et al. 2014). This volcano is not currently included in VOTW4.0.

fatalities and 107 eruptions have reports of property damage. Vesuvius, Campi Flegrei and Vulcano are classified at Hazard Level III; the high local populations around Vesuvius and Campi Flegrei mean that the Neapolitan region is assessed to have the highest volcanic risk level in Italy.

The Instituto Nazionale di Geofisica e Vulcanologia (INGV) monitors active volcanoes in Italy via integrated multiparametric systems. In particular, the INGV Observatories Vesuviano and Etneo are responsible for the surveillance of the Campi Flegrei, Vesuvius, Ischia, Etna, Stromboli, Panarea, Lipari, Vulcano and Pantelleria volcanoes. INGV is responsible for both monitoring and scientific research, and personnel include seismologists, volcanologists, experts in remote sensing, geochemistry and ground deformation and numerical modellers. There is a wealth of experience within INGV of responding to eruptions and eruption crises and INGV works alongside the Dipartimento della Protezione Civile (DPC) in carrying out hazard assessments, then used as an input in risk assessments, as well as outreach and educational activities for the population.

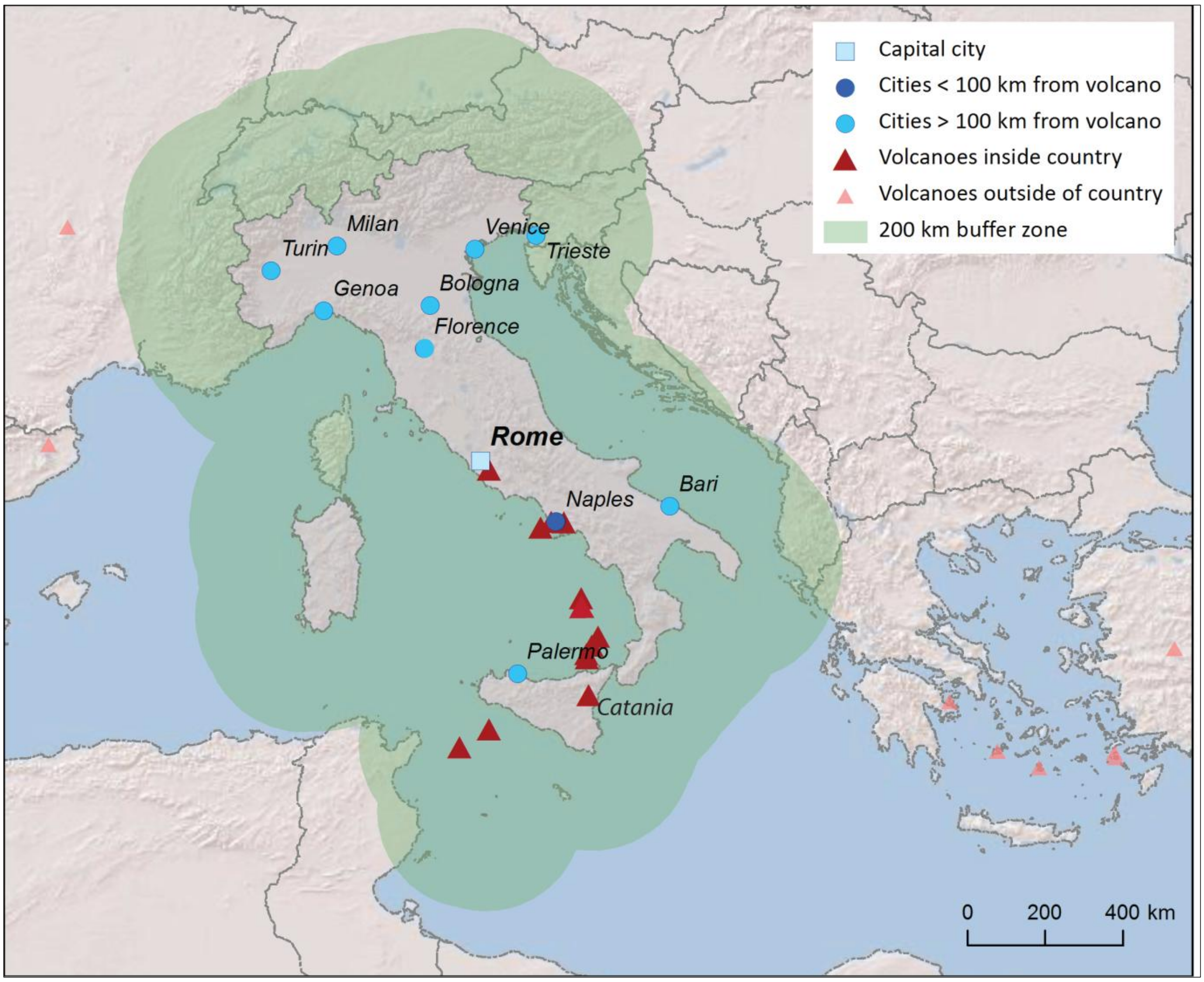

Figure 23: Location of Italy's volcanoes, the capital and largest cities. Note that Vulsini and Larderello are not included in this map as they are no longer considered Holocene volcanoes. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Italy.

Volcano Facts – amended with the exclusion of Vulsini and Larderello, and inclusion of Marsili

Number of Holocene volcanoes	13
Number of Pleistocene volcanoes with M≥4 eruptions	10
Number of volcanoes generating pyroclastic flows	7
Number of volcanoes generating lahars	4
Number of volcanoes generating lava flows	8
Number of fatalities caused by volcanic eruptions	?>7,210
Tectonic setting	Rift zone (2), Subduction zone (11)
Largest recorded Pleistocene eruption	The M7.7 Bolsena eruption at Vulsini at 300 ka.
Largest recorded Holocene eruption	The M6.6 AP1 eruption of Vesuvius at 3.5 ka.
Number of Holocene eruptions	371 confirmed eruptions. 43 uncertain and 26 discredited eruptions.
Recorded Holocene VEI range	Unknown – 5
Number of historically active volcanoes	7
Number of historical eruptions	205

Number of volcanoes	Primary volcano type	Dominant rock type
3	Caldera(s)	Foiditic (1), Trachytic/Andesitic (2)
8	Large cone(s)	Andesitic (2), Basaltic (2), Phonolitic (1), Rhyolitic (2), Trachytic/Andesitic (1)
1	Small cone(s)	Unknown (1)
3	Submarine	Basaltic (2), Phonolitic (1)

Table 29: The number of volcanoes in Italy, their volcano type classification and dominant rock type according to VOTW4.0. This has been amended based on advice from INGV to include Pantelleria as a large rhyolitic cone, not a shield as described in VOTW4.0, and to include the submarine Marsili volcano.

Socio-Economic Facts

Total population (2012)	60,828,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	27,069

Gross National Income (GNI) per capita (2005 PPP $)	26,158
Human Development Index (HDI) (2012)	0.881 (Very High)

Population Exposure

Capital city	Rome
Distance from capital city to nearest Holocene volcano	24.3 km
Total population (2011)	61,016,804
Number (percentage) of people living within 10 km of a Holocene volcano	1,621,403 (2.7%)
Number (percentage) of people living within 30 km of a Holocene volcano	8,363,679 (13.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	20,372,127 (33.4%)

Ten largest cities, as measured by population, and populations:

Rome	2,563,241
Milan	1,306,661
Naples	988,972
Turin	865,263
Palermo	672,175
Genoa	601,951
Florence	371,517
Bologna	371,217
Bari	316,532
Catania	315,576

Infrastructure Exposure

Number of airports within 100 km of a volcano	8
Number of ports within 100 km of a volcano	30
Total length of roads within 100 km of a volcano (km)	11,678
Total length of railroads within 100 km of a volcano (km)	2,708

The Italian volcanoes are distributed through the west of much of the country, extending through the Aeolian Islands, Sicily and beyond. The 100 km radius of Pantelleria in the far south extends to Tunisia, exposing ports and towns here. Being located near the coast throughout much of Italy, numerous ports are located within the 100 km radii, as are a number of the major Italian cities, including the capital, Rome, airports, an extensive road and rail network and other critical infrastructure here.

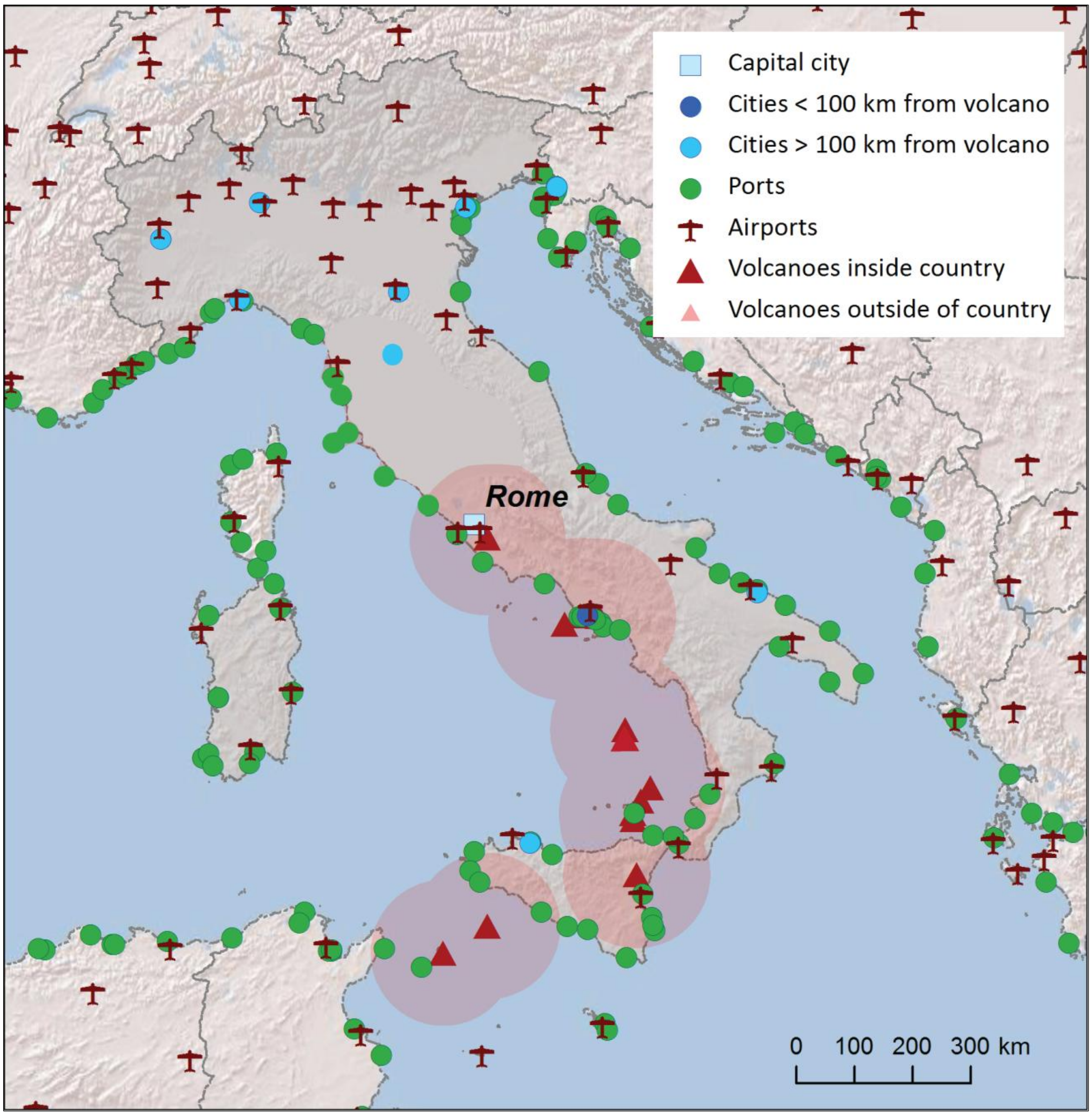

Figure 24: The location of Italy's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Six of the Italian volcanoes have sufficient information available in their records to classify into a Hazard Level. These plot across all three Hazard Levels: Sicilia Channel and Stromboli are classified at Hazard Level I; Etna at II, and Vulcano, Campi Flegrei and Vesuvius at Hazard Level III.

Of the remaining eight volcanoes, two, Alban Hills and Panarea, have no confirmed eruptions during the Holocene from which to calculate a VHI. The remaining volcanoes have sparse histories with eruptions of unknown size.

CLASSIFIED	**Hazard III**				Vulcano			Campi Flegrei, Vesuvius
	Hazard II					Etna		
	Hazard I			Stromboli			Ferninandea	
UNCLASSIFIED	**U – HHR**				Pantelleria			
	U- HR		Palinuro			Lipari, Ischia		
	U- NHHR			**Panarea**				**Alban Hills**
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 30: Identity of Italy's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Campi Flegrei	7	III
Vesuvius	7	III
Ferdinandea	6	II
Etna	5	II
Vulcano	5	III
Stromboli	3	I

Table 31: Volcanoes of Italy ordered by descending Population Exposure Index (PEI). The Risk Level as determined through the combination of the Hazard Level and PEI is given. Risk Level I – 3 volcanoes; Risk Level II – 8 volcanoes; Risk Level III – 3 volcanoes.

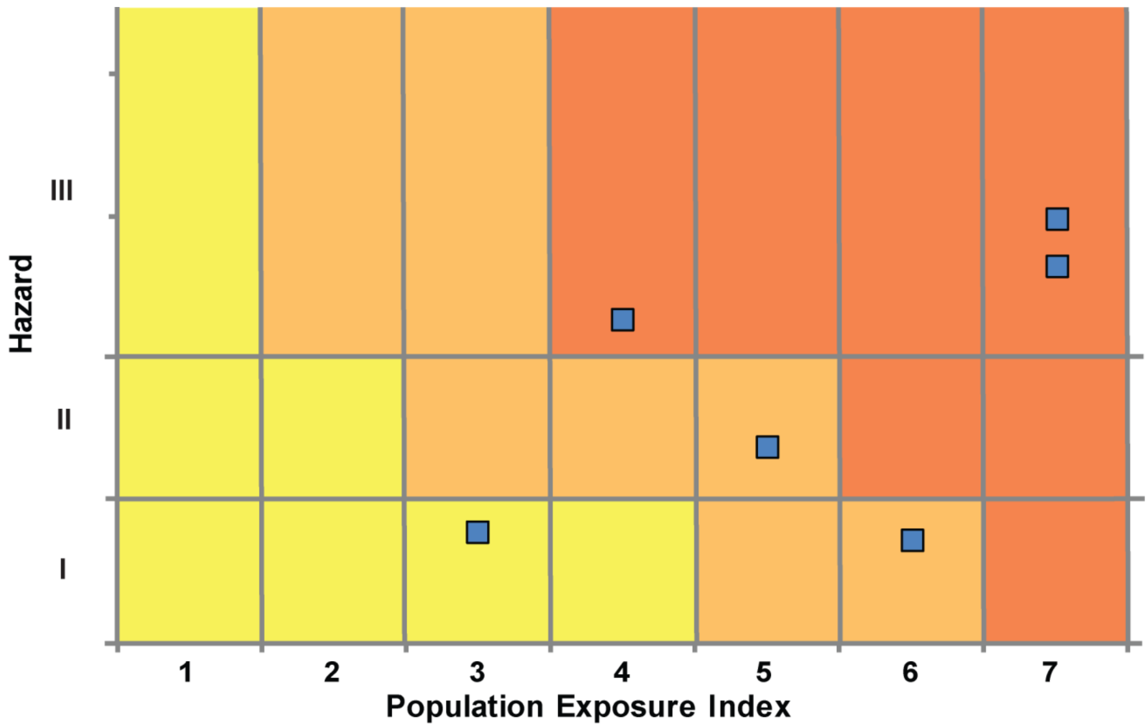

Figure 25: Distribution of Italy's volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

The PEI levels of the Italian volcanoes range from low to very high, with PEIs of 2 to 7. Nine Italian volcanoes have a high PEI of 5 – 7, including Vesuvius, which with a Hazard Level of III is classed as Risk Level III.

National Capacity for Coping with Volcanic Risk

Seven Italian volcanoes have records of historical eruptions. The Istituto Nazionale di Geofisica e Vulcanologia (INGV) is responsible for monitoring these volcanoes. The only historical Italian volcanic area with no dedicated ground-based monitoring is the submarine volcanoes of Sicilia Channel and Tyrrhenian Sea. All others are monitored through seismic stations, with deformation monitoring (GPS, levelling, tiltmeters, strain-meters) in place at the Risk Level III volcanoes: Campi Flegrei and Vesuvius, and the frequently active Etna and Stromboli. The active volcanoes of the Eolian Islands are entirely covered with permanent GPS stations. The unclassified volcano Pantelleria, which last erupted in 1891 in a submarine portion located about 5 km NE of the island named Foerstner, has seismic and deformation monitoring in place. There are, additionally, permanent visible and infrared cameras in place at Etna and Stromboli; permanent gravity stations at Etna; a number of other permanent stations to measure geochemical parameters at fumaroles and from soil diffuse degassing at Etna, Stromboli, Campi Flegrei, Vulcano, Pantelleria, Ischia (temperature, soil CO_2 flux, acidity of ground waters, etc.); permanent geochemical stations to measure parameters (SO_2 flux, C/S ratio) at Etna and Stromboli; permanent radar to detect ash in the atmosphere at Etna; permanent mareographic stations along the Campanian coast; and others. Periodic multi-parametric surveys are performed at all sub-aerial active volcanoes.

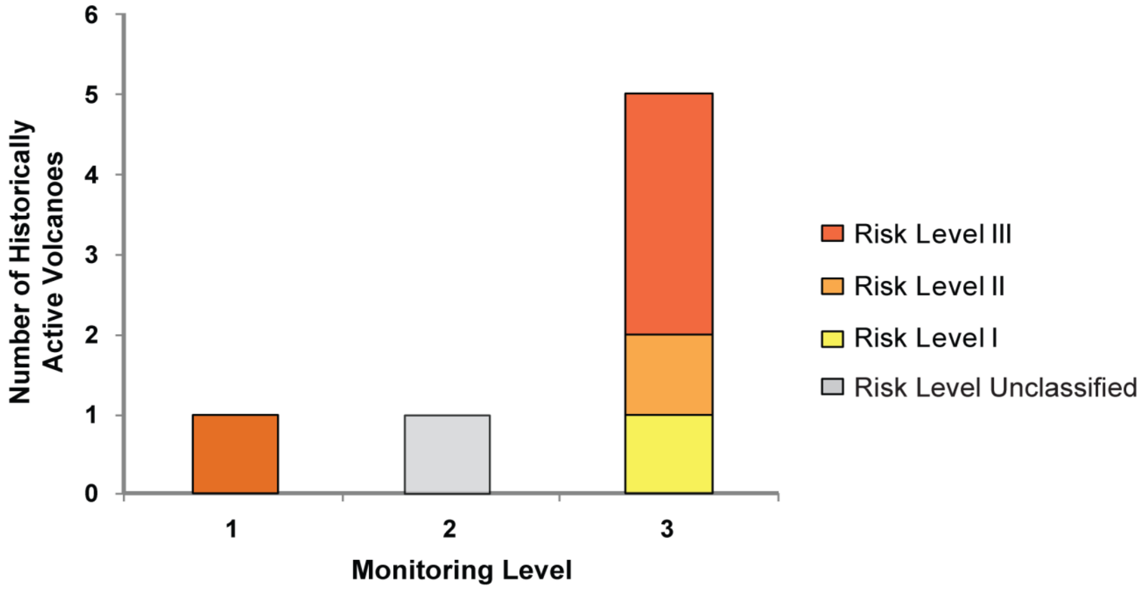

Figure 26: The monitoring and risk levels of the historically active volcanoes in Italy. Monitoring Level 1 indicates no known dedicated ground-based monitoring (the submarine Ferdinandea volcano); Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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Iezzi G., Caso C., Ventura G., Vallefuoco M., Cavallo A., Behrens H., Mollo S., Paltrinieri D., Signanini P., Vetere F. (2014). First documented deep submarine explosive eruptions at the Marsili Seamount (Tyrrhenian Sea, Italy): a case of historical volcanism in the Mediterranean Sea. Gondwana Research, doi: 10.1016/j.gr.2013.11.001.

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Spain – Mainland

Description

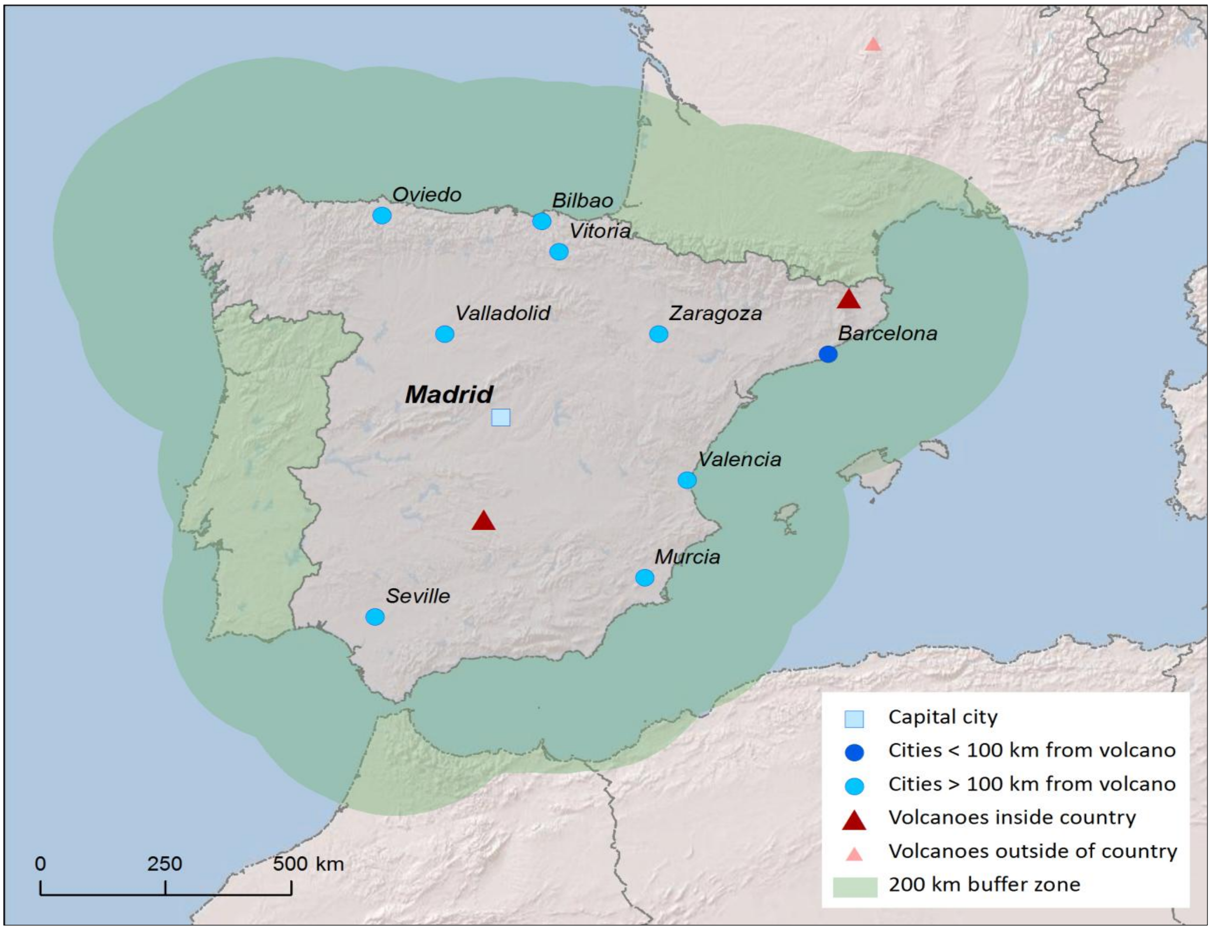


Figure 27: Location of Spain's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Spain.

There are two Holocene volcanoes located in mainland Spain: the Olot volcanic field, approximately 90 km north-east of Barcelona and near the French border, and the Calatrava volcanic field, ~ 175 km south of Madrid in the centre of the country. Both volcanic fields lie in a continental rift setting. The dominantly Pliocene Calatrava volcanic field hosts more than 300 basaltic-to-foiditic pyroclastic cones, maars, and lava domes and covers an area of more than 5000 square km. Late-stage phreatomagmatic activity in the Calatrava Volcanic Field at Columba volcano was dated as mid-Holocene and fumarolic activity has been recorded in the Sierra de Valenzuela area during the 16th-18th centuries. The Olot volcanic field (also known as the Garrotxa volcanic field) consists of a large number of strombolian pyroclastic cones and associated alkali basaltic lava flows. The pyroclastic cones are preferentially located at the intersection of E-W and NW-SE faults. There are no recorded Holocene eruptions at Olot but stratigraphic evidence suggests that Holocene eruptions have occurred.

The only recorded eruption in the Holocene is of unknown VEI and produced by the Calatrava volcanic field in ~3600 BC; no historical records exist.

More than 7.5 million people live within 100 km of the two volcanic fields. The 100 km radius around Olot volcanic field in the north is the more populated (5.2 million people) of the two fields, including parts of France and Andorra, exposing the city of Barcelona and other towns, ports and airports. The Calatrava Volcanic Field in central Spain is more remote (0.7 million people within 100 km), with no airports or major cities lying within 100 km.

Volcano Facts

Number of Holocene volcanoes	2 (Mainland)
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Unknown VEI eruption of 3600 BC at the Calatrava Volcanic Field.
Number of Holocene eruptions	1 confirmed eruption.
Recorded Holocene VEI range	Unknown
Number of historically active volcanoes	0
Number of historical eruptions	0

Number of volcanoes	Primary volcano type	Dominant rock type
2	Small cone(s)	Basaltic (2)

Table 32: The number of volcanoes in Mainland Spain, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	46,712,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	27,063

Gross National Income (GNI) per capita (2005 PPP $)	25,947
Human Development Index (HDI) (2012)	0.885 (Very High)

Population Exposure

Capital city	Madrid
Distance from capital city to nearest Holocene volcano	174.4 km
Total population (2011)	46,754,784
Number (percentage) of people living within 10 km of a Holocene volcano	163,931 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	1,750,883 (3.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	7,569,747 (16.2%)

Ten largest cities, as measured by population, and populations:

Madrid	3,117,977
Barcelona	1,581,595
Valencia	805,304
Seville	701,894
Zaragoza	649,404
Murcia	406,807
Las Palmas	378,495
Palma De Mallorca	375,773
Bilbao	351,409
Valladolid	322,304

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	5
Total length of roads within 100 km of a volcano (km)	3,514
Total length of railroads within 100 km of a volcano (km)	637

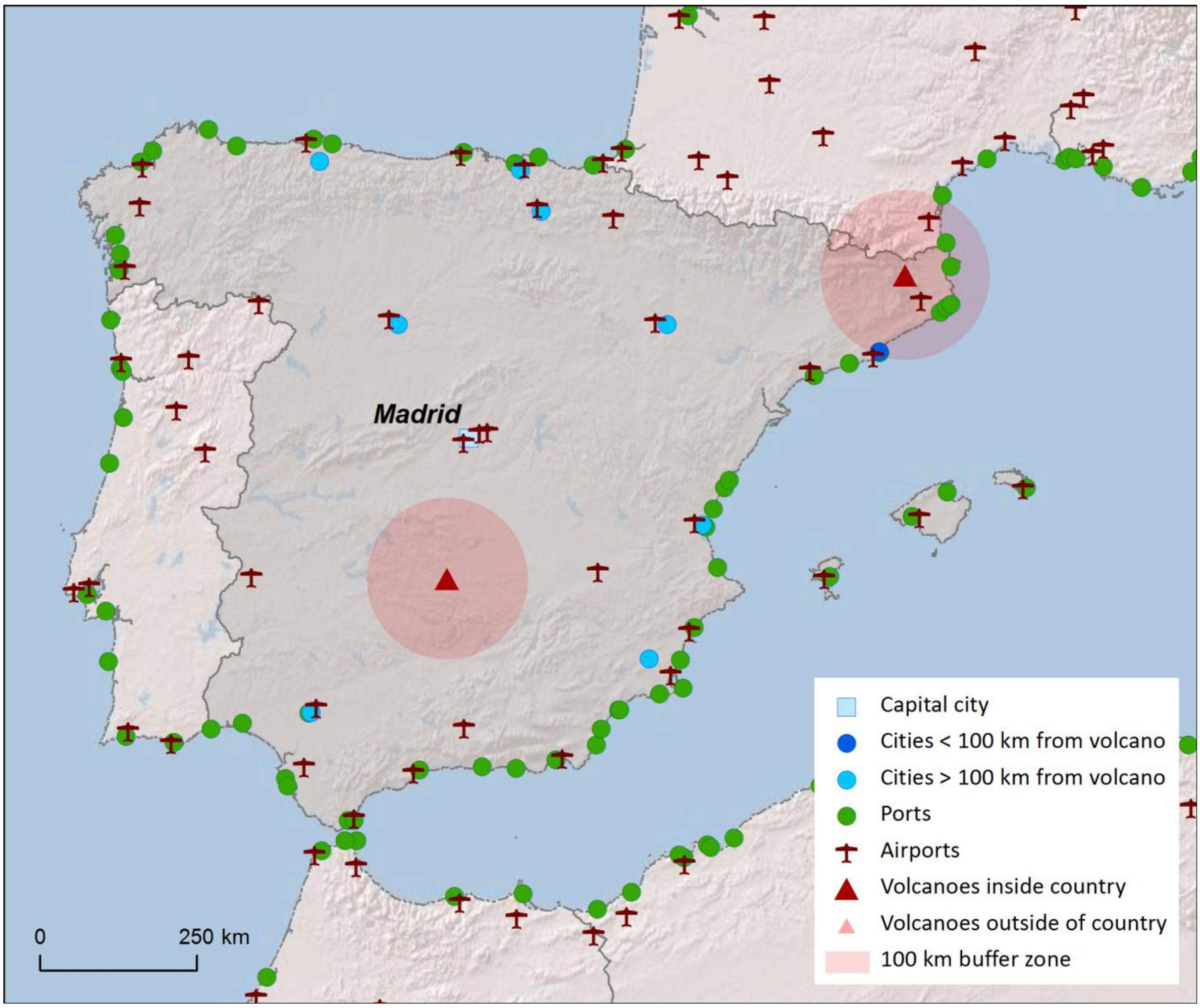


Figure 28: The location of Spain's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The two Holocene volcanoes of mainland Spain are located in the north and centre of the country. Olot Volcanic Field in the north, is located near the border with France, therefore parts of France and Andorra lie within the 100 km radius of this volcano, exposing towns, ports and airport here. Indeed much of Andorra falls in this zone. The city of Barcelona lies within this 100 km radius, and several ports, an airport and extensive road network is exposed. The Calatrava Volcanic Field in central Spain is more remote, with no airports or major cities lying within 100 km.

Hazard, Uncertainty and Exposure Assessments

Of the volcanoes in Mainland Spain, only the Calatrava Volcanic Field has a confirmed eruption on record during the Holocene, but of unknown size. Holocene activity at Olot Volcanic Field is suspected from stratigraphic studies, however this is unconfirmed. The absence of extensive eruption records means that the hazard levels cannot be determined for the volcanoes here without significant associated uncertainties. No post-1900 AD unrest has been recorded at these volcanoes, however unrest was recorded in the 16th to 18th centuries at Calatrava Volcanic Field.

Both Spanish volcanoes have high local populations and hence PEI values of 5 and 6, indicative of Risk Levels of II or III dependent on the hazard.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR						Calatrava Volcanic Field	
	U- NHHR					Olot Volcanic Field		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 33: Identity of Mainland Spain's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in mainland Spain have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in mainland Spain.

Turkey

Description

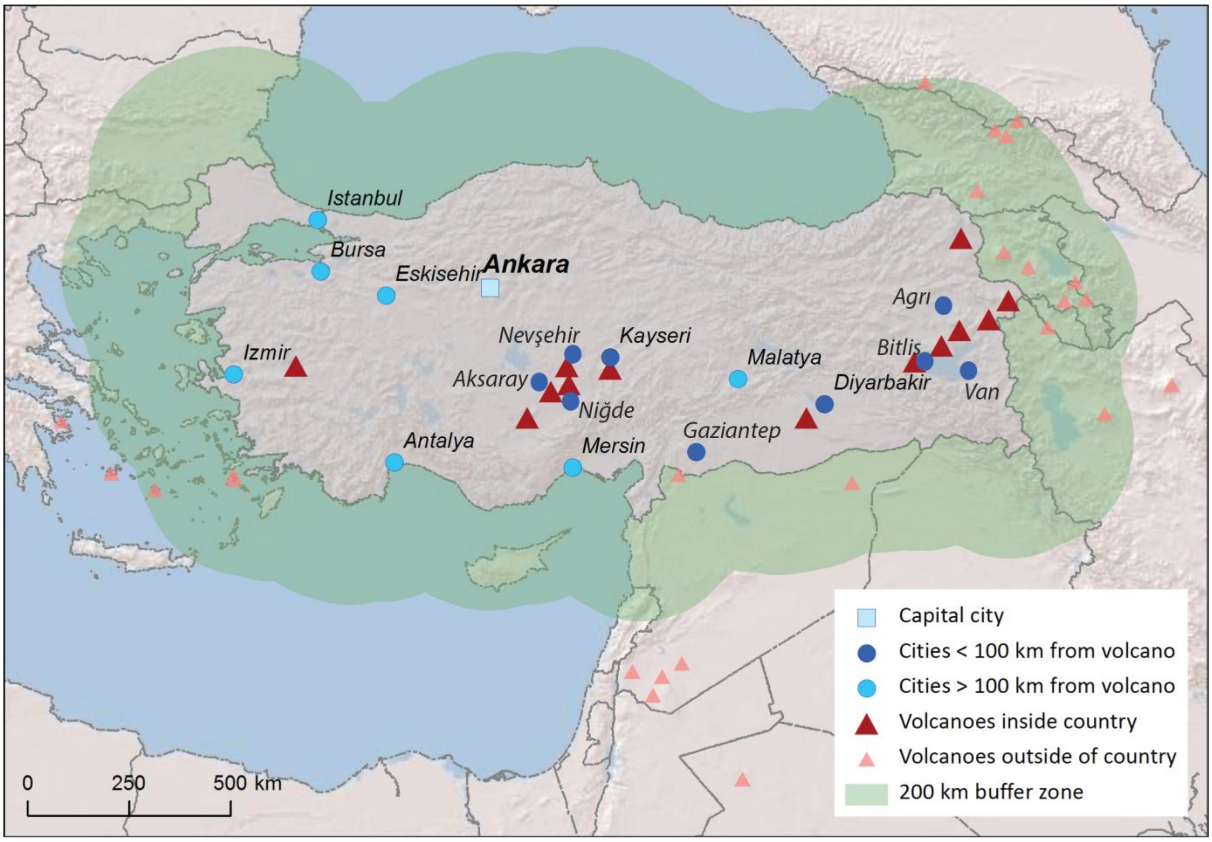


Figure 29: Location of Turkey's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Turkey.

Thirteen Holocene volcanoes are located throughout Turkey, from Kula in the west to Ararat (Turkish name: Agri Dagi) in the east. Two main clusters of volcanoes lie in the centre and east of the country. The origin of volcanism in Turkey is not fully understood, with a complex system of plate interaction and intra-plate and subduction processes postulated. The morphology of the volcanoes ranges from small cones in volcanic fields, shield volcanoes and large stratovolcanoes. The magma composition here is dominantly intermediate to felsic with andesitic and rhyolitic features.

Thirty-eight Holocene eruptions are recorded from six volcanoes, including four historical eruptions from three volcanoes. The size of the eruptions is largely unknown, with just one historical eruption of Ararat (Agri Dagi) in 1840 being attributed a VEI of 3. Large explosive eruptions are recorded in the Pleistocene at two volcanoes, the largest eruption being the M6.2 eruption of the Upper Acigöl Tuff at Acigöl-Nevsehir in 110 ka. The absence of detailed eruption histories with known eruption sizes makes hazard assessment at Turkey's volcanoes difficult, and focussed research would be beneficial to expand the knowledge of past activity.

Nemrut Dagi has the most eruptions recorded in the Holocene and has had two historical eruptions in 1597 and 1650. The only other historical activity was at Ararat (Agri Dagi) with the 1840 VEI 3 eruption and the 1855 eruption of Tendürek Dagi. Unrest has been reported at Ararat since 1900.

Loss of life is recorded in two eruptions of Ararat. The 1840 eruption resulted in about 1,900 fatalities due to pyroclastic flows.

Although the capital, Ankara, lies distal to the Holocene volcanoes, two of the most populous cities in Turkey, Kayseri and Diyarbakir, fall within 100 km of Erciyes Dagi and Karaca Dag volcanoes. A large population resides within 10 km of four of Turkey's volcanoes, and across the country over 15.7 million people live within 100 km of one or more Holocene volcanoes.

The Turkish National Commission for Volcanology and Chemistry of the Earth's Interior (TUVAK) has coordinated efforts to research volcanism in Turkey. No official monitoring institutions are currently operational, though Holocene monitoring research projects are undertaken at Hacettepe University Department of Geological Engineering. Plans are being developed for development of monitoring institutions. Three seismic stations are in place at Nemrut Dagi, and baseline seismic data is available which should allow anomalous activity to be identified. This seismic network is maintained by scientists at the Hacettepe University. No plans or protocols are currently in place for handling developing unrest and eruption.

See also:

TUVAK: http://www.mta.gov.tr/v2.0/eng/birimler/tuvak/index.php

Volcano Facts

Number of Holocene volcanoes	13
Number of Pleistocene volcanoes with eruptions M>=4	2
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	3
Number of fatalities caused by volcanic eruptions	1,900
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	The M6.2 eruption of the Upper Acigöl Tuff at Acigöl-Nevsehir in 110 ka.
Largest recorded Holocene eruption	The VEI 3 eruption of Ararat in 1840 AD.
Number of Holocene eruptions	38 confirmed eruptions. 8 uncertain eruptions.
Recorded Holocene VEI range	Unknown – 3
Number of historically active volcanoes	3

Number of historical eruptions	4

Number of volcanoes	Primary volcano type	Dominant rock type
1	Caldera(s)	Rhyolitic (1)
5	Large cone(s)	Andesitic (2), Dacitic (2), Rhyolitic (1)
1	Lava dome(s)	Rhyolitic (1)
3	Shield(s)	Andesitic (1), Basaltic (2)
3	Small cone(s)	Andesitic (2), Basaltic (1)

Table 34: The number of volcanoes in Turkey, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2013, from Turkish Statistical Institute)	76,667,864
Gross Domestic Product (GDP) per capita (2005 PPP $)	13,466
Gross National Income (GNI) per capita (2005 PPP $)	13,710
Human Development Index (HDI) (2012)	0.722 (High)

Population Exposure

Capital city	Ankara
Distance from capital city to nearest Holocene volcano	209.1 km
Total population (2011)	78,785,548
Number (percentage) of people living within 10 km of a Holocene volcano	>3.3 million
Number (percentage) of people living within 30 km of a Holocene volcano	>4.5 million
Number (percentage) of people living within 100 km of a Holocene volcano	>15 million

Ten largest cities, as measured by population, and populations (2013; Turkish Statistical Institute):

Istanbul	14,160,467
Ankara	5,045,083
Izmir	4,061,074
Bursa	2,740,970
Antalya	2,158,265
Adana	2,149,260
Konya	2,079,225
Gaziantep	1,844,438
Şanlıurfa	1,801,980

Mersin	1,705,774

Infrastructure Exposure

Number of airports within 100 km of a volcano	4
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	8,432
Total length of railroads within 100 km of a volcano (km)	1,825

The volcanoes of Turkey are widespread through the country, though are located inland away from the coast, therefore no ports are located within 100 km radius of these volcanoes. The volcanoes in the east lie near the borders with Armenia, Azerbaijan and Iran, and the 100 km radii extend into these countries. Volcanoes in these countries likewise expose parts of Turkey to volcanic hazard. The major cities of Kayseri and Diyarbakir fall within 100 km of Erciyes Dagi and Karaca Dag respectively, exposing critical infrastructure here including road and rail networks.

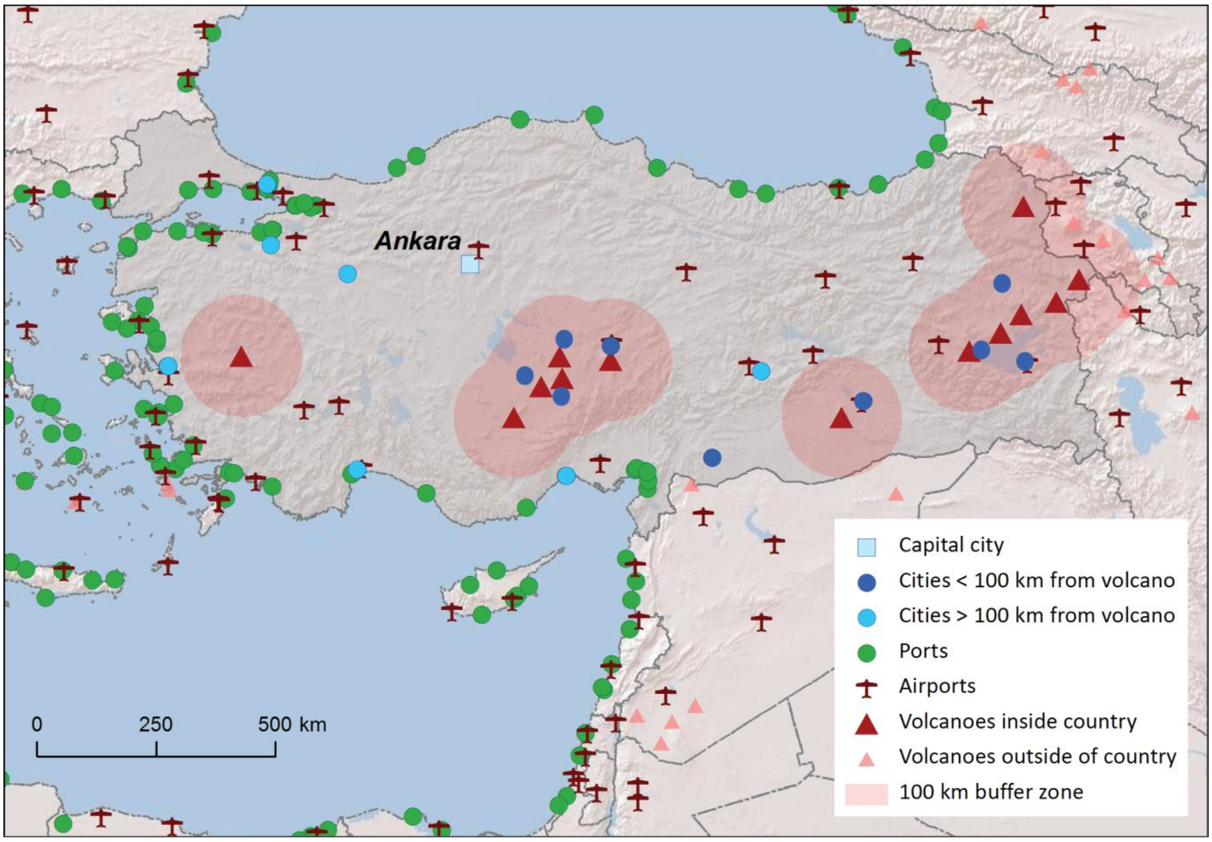


Figure 30: The location of Turkey's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Despite records of 38 confirmed eruptions during the Holocene in Turkey, the eruption size is only known in one event, and thus the hazard levels cannot be determined at Turkey's volcanoes without significant uncertainties. Nemrut Dagi, Tendürek Dagi and Ararat all have confirmed historical eruptions (since 1500 AD), whilst Süphan Dagi, Erciyes Dai and Acigöl-Nevsehir have Holocene eruption records. The remaining seven volcanoes have suspected Holocene activity only. No unrest above background levels is recorded at any Turkish volcano since 1900 AD.

The PEI levels of Turkish volcanoes range from a moderate PEI 4 to a very high PEI 7 at Kars Plateau. The risk levels cannot be determined without the hazard, however with such large local populations, the risk is not insignificant.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**				Nemrut Dagi; Tendürek Dagi; Ararat			
	U- HR				Süphan Dagi	Erciyes Dagi	Acigöl-Nevsehir	
	U- NHHR				Hasan Dagi; Göllü Dag; Karaca Dag; Girekol Tepe	Kula; Karapinar Field		Kars Plateau
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 35: Identity of Turkey's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since*

National Capacity for Coping with Volcanic Risk

The Turkish National Commission for Volcanology and Chemistry of the Earth's Interior and Hacettepe University undertake some monitoring in Turkey. Three volcanoes have records of historic activity – Nemrut Dagi, Ararat (Agri Dagi) and Tendürek Dagi. Of these, only Nemrut Dagi, has three seismometers dedicated to the monitoring of the volcano.

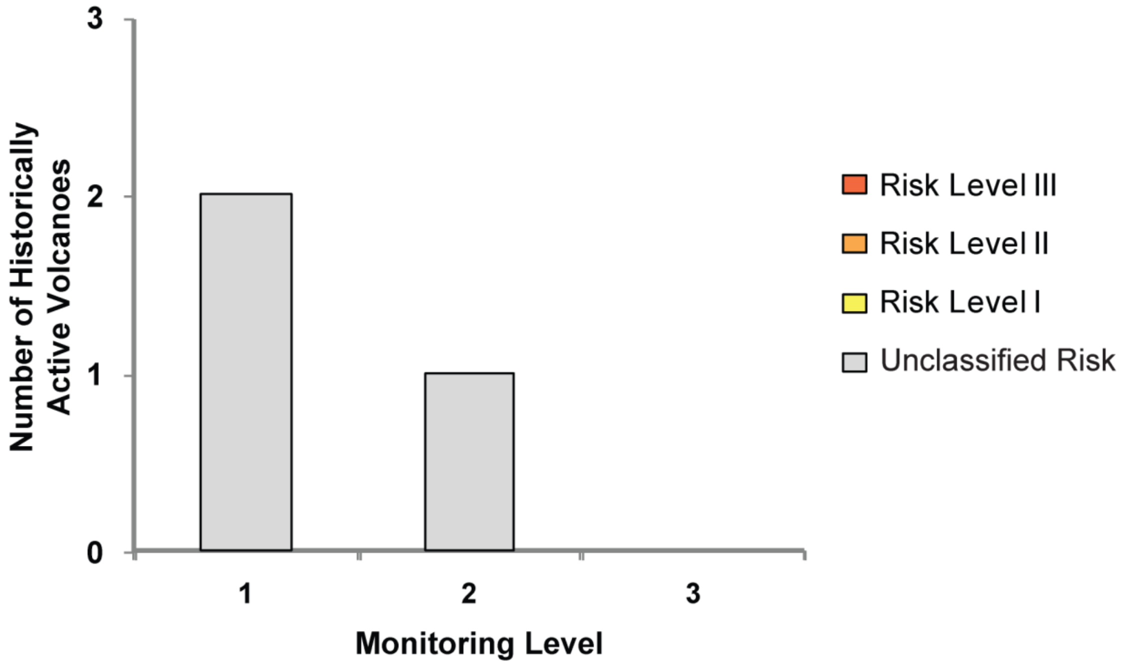


Figure 31: The monitoring and risk levels of the historically active volcanoes in Turkey. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 2: Africa and Red Sea

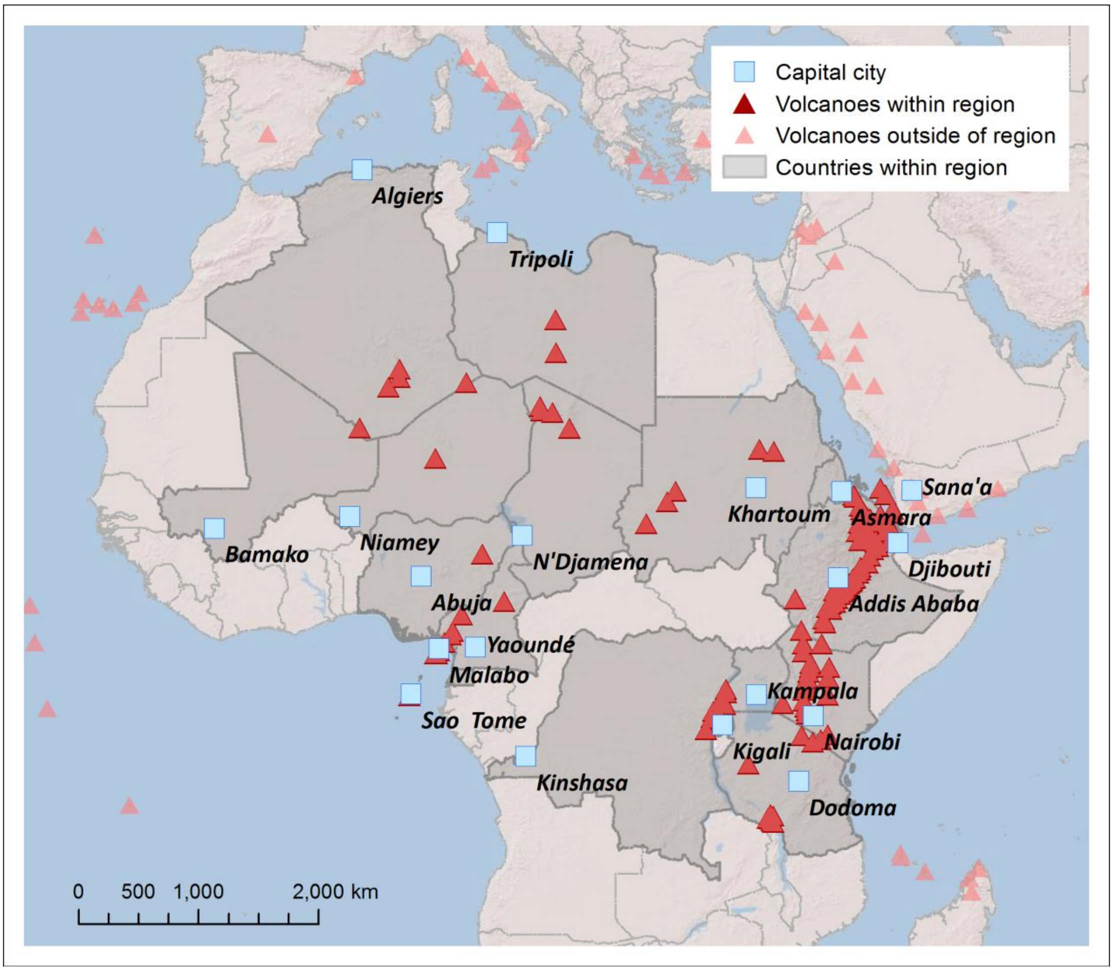


Figure 32: The distribution of Holocene volcanoes through the Africa and Red Sea region. The capital cities of the constituent countries are shown.

Description

Of all the regions of world we have the least historic and geologic information about Africa's 152 volcanoes. In part this is a result of limited historic records of past eruptions but also a result of limited past and present research in Africa by contrast with other areas of the world. Africa as a region has the highest percentage of volcanoes that are undated but known to be Holocene. Given highly variable data availability and uncertainty it is likely that volcanic hazards from African volcanoes are underestimated in both frequency and magnitude and the impact only loosely constrained.

Many of Africa's volcanoes are located in the East African Rift where the African, Arabian and Somalian plates of the Earth's crust are moving apart and new crust is being formed. This dynamic movement has resulted in a dense concentration of large volcanic complexes and low-lying rift volcanoes formed from multiple elongate fissures in a series of lines down the Red Sea and the East African Rift. Approximately 10% of the world's volcanoes lie in continental rifts (Siebert et al., 2010) mostly in the East African Rift (EAR) System. The contrasting styles of effusive eruptions and explosive eruptions of many of the past eruptions from these volcanoes result in a different series of hazards for each setting.

Population and infrastructure exposure to volcanic hazards is high and rapidly expanding with growth of the population and increasing investment, notably in the geothermal energy field.

With one exception in the Democratic Republic of Congo, there are no dedicated volcano monitoring institutions or networks in Africa. Whilst some areas have seismometers that could be used in the event of eruption there is no systematic monitoring of magmatic activity that may be used to detect changing base levels which may precede an eruption.

Strategic research to target data gaps, increased access to satellite-based monitoring for observatories and responsible in-country institutions, and local capacity building will make a significant difference to support future volcanic hazard and risk assessments as well as planning and response in Africa and the Red Sea.

Country	Number of volcanoes
Algeria	4
Cameroon	5
Chad	4
Djibouti	4
DRC	6
Equatorial Guinea	3
Eritrea	9
Ethiopia	59
Kenya	22
Libya	2
Mali	1
Niger	2
Nigeria	1
Rwanda	3
Sao Tome and Principe	1
Sudan	5
Tanzania	10
Uganda	7
Yemen (see Region 3)	4

Table 36: The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

Volcano facts

Number of Holocene volcanoes	141
Number of Pleistocene volcanoes with M≥4 eruptions	18

Number of volcanoes generating pyroclastic flows	9
Number of volcanoes generating lahars	5
Number of volcanoes generating lava flows	111
Number of eruptions with fatalities	11
Number of fatalities attributed to eruptions	2,276
Largest recorded Pleistocene eruption	The largest recorded Quaternary eruption in region 2 occurred at 1 Ma, with the M8 Awasa caldera formation at the Corbetti Caldera in Ethiopia.
Largest recorded Holocene eruption	The Caldera 2 eruption of Menengai, Kenya, at 8985 BP is the largest recorded Holocene eruption in this region, at M6.8.
Number of Holocene eruptions	196 confirmed eruptions
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	30
Number of historical eruptions	149

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
8	Caldera(s)	Basaltic (2), Rhyolitic (4), Trachytic/Andesitic (2)
1	Hydrothermal field	Unknown (1)
50	Large cone(s)	Andesitic (2), Basaltic (17), Foiditic (3), Phonolitic (2), Rhyolitic (18), Trachytic/Andesitic (8)
2	Lava dome(s)	Phonolitic (1), Rhyolitic (1)
30	Shield(s)	Basaltic (23), Phonolitic (1), Trachytic/Andesitic (6)
59	Small cone(s)	Andesitic (1), Basaltic (44), Foiditic (7), Phonolitic (1), Rhyolitic (3), Unknown (3)

Table 37 The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	1000

Table 38: Average recurrence interval (years between eruptions) for small and large eruptions in Africa and the Red Sea.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 ocurr in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is much longer, at about 1000 years.

Eruption Size

Eruptions of VEI 0 to 6 are recorded through the Africa and Red Sea region, representing a range of eruption styles, from gentle effusive events to large explosive eruptions (Figure 33). VEI 0 to 2 eruptions dominate the record, making up about 80% of eruptions. Nearly 8% of eruptions in this region are VEI≥4.

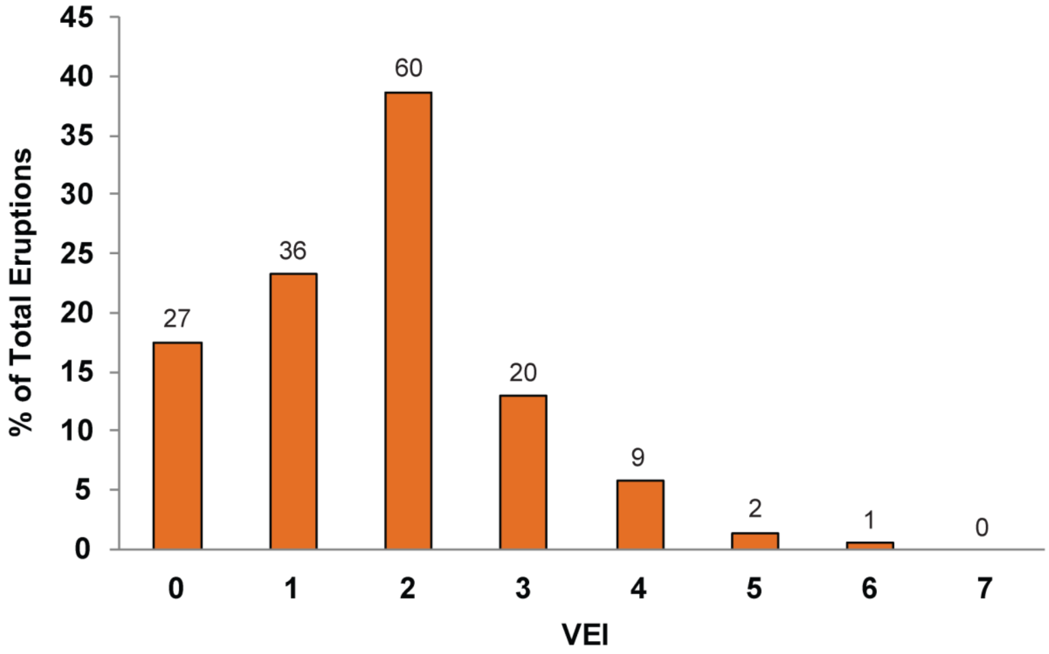


Figure 33: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 41 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	653,926,812
Gross Domestic Product (GDP) per capita (2005 PPP $)	329 – 32,026 (Mean 4,457)
Gross National Income (GNI) per capita (2005 PPP $)	319 – 21,715 (Mean 3,826)
Human Development Index (HDI) (2012)	0.304 – 0.769 (Low to High: Mean 0.470 Low)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	4,089,632 (0.63 %)
Number (percentage) of people living within 30 km of a Holocene volcano	27,606,598 (4.22 %)
Number (percentage) of people living within 100 km of a Holocene volcano	123,172,684 (18.84 %)

Infrastructure Exposure

Number of airports within 100 km of a volcano	20
Number of ports within 100 km of a volcano	19
Total length of roads within 100 km of a volcano (km)	18,589
Total length of railroads within 100 km of a volcano	2,192

CLASSIFIED	Hazard III			Meidob Volcanic Field				
	Hazard II			Lengai, Ol Doinyo				
	Hazard I		Tair, Jebel at; Barrier, The	Erta Ale		Nyamuragira; Nyiragongo; Cameroon		
UNCLASSIFIED	U – HHR		**Zubair Group; Dallol**; **Dalaffilla**; Dubbi; **Nabro**; **Alayta**; **Manda Hararo; Manda-Inakir**; South Island; **Emuruangogolak**	**Dabbahu**; **Ardoukôba**; Dama Ali	Fentale; Chyulu Hills	Kone; **Tullu Moje**; Olkaria; Longonot; **Meru**; Kyejo; **Santa Isabel**	**Visoke**	
	U- HR		Namarunu; Bayuda V.F.	Silali; Paka	Marra, Jebel	Alutu; Rungwe	Menengai; Fort Portal; Karisimbi	Ngozi
	U- NHHR		Hanish; Gada Ale; Alu; Borale Ale; Ale Bagu; Hayli Gubbi; Mallahle; Sork Ale; Asavyo; Mat Ala; Tat Ali; Borawli; **Kurub**; Mousa Alli; Gufa; Assab V.F.; Gabillema; Yangudi; North Island; **Central Island**; San Carlos; San Joaquin; Todra V.F.; Tin Zaouatene V.F.; In Ezzane V.F.; Tahalra V.F.; Atakor V.F.; Manzaz V.F.; Haruj; Wau-en-Namus; Tôh, Tarso; Toussidé, Tarso; Voon, Tarso; Koussi, Emi	Zukur; Alid; Afderà; Dabbayra; Manda Gargori; Ayelu; Adwa; Hertali; Mega Basalt Field; Segererua Plateau	Jalua; Ma Alalta; Groppo; Liado Hayk; Dofen; Korath Range; Marsabit; Korosi; Ol Kokwe; Suswa; Kilimanjaro; Unnamed; Sao Tome; Kutum V.F.	Borawli; Beru; Boset-Bericha; Bora-Bericcio; Tepi; Chiracha; Unnamed; Homa Mountain; Eburru, Ol Doinyo; Igwisi Hills; SW Usangu Basin; May-ya-moto; Manengouba; Ngaoundere Plateau; Biu Plateau; Umm Arafieb, Jebel	Unnamed; Gedamsa; Unnamed; East Zway; O'a Caldera; Tosa Sucha; Nyambeni Hills; Elmenteita Badlands; Kyatwa; Bunyaruguru; Katunga; Muhavura; Tshibinda; Tombel Graben; **Oku V.F.**	Bishoftu V.F.; Unnamed; Sodore; Butajiri-Silti Field; Corbetti Caldera; Bilate River Field; Hobicha Caldera; Izumbwe-Mpoli; Katwe-Kikorongo; Bufumbira
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 39: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption. Note: V.F. is an abbreviation for Volcanic Field.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
11	7
19	6
28	5
17	4
18	3
48	2
0	1

Table 40: The number of volcanoes in Africa and the Red Sea classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
0	III
5	II
3	I
133	Unclassified

Table 41: The number of volcanoes in the Africa and Red Sea region classified at each Risk Level.

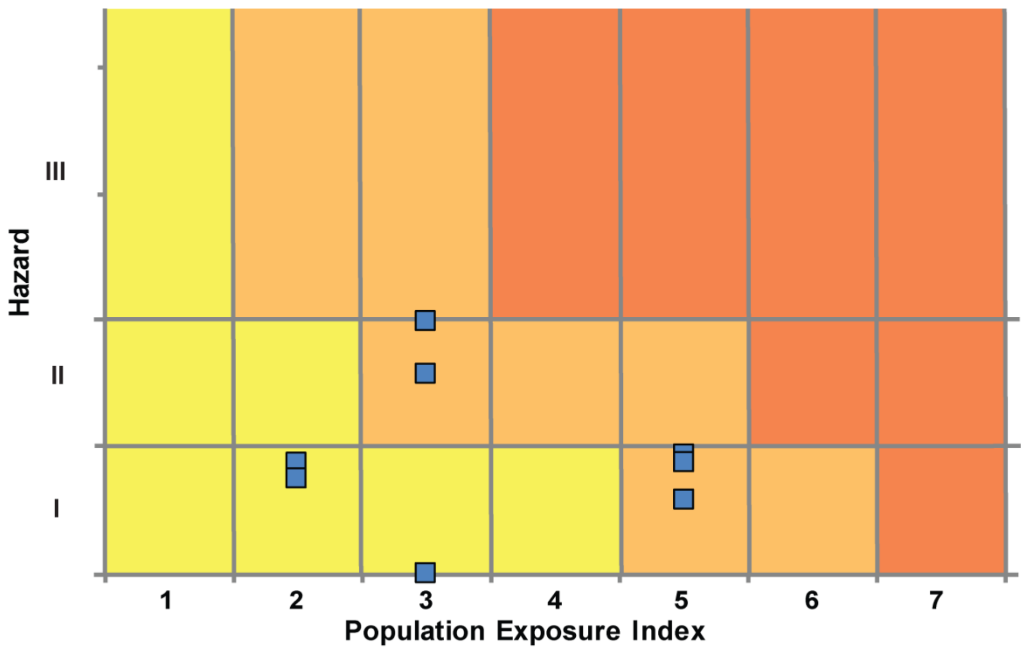


Figure 34: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

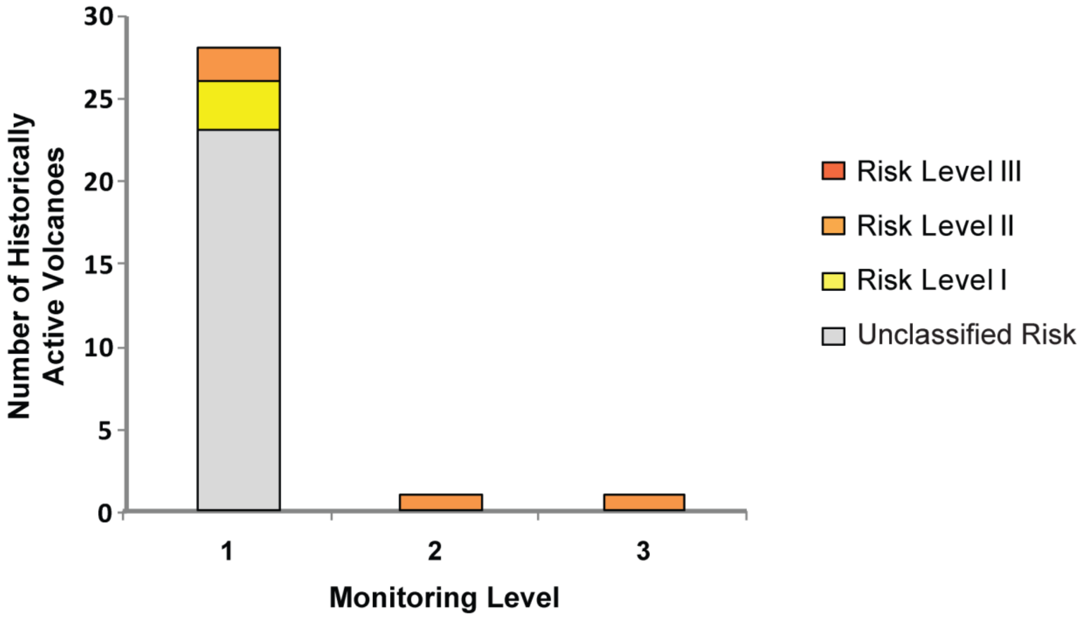


Figure 35: The monitoring and risk levels of the historically active volcanoes in Africa and the Red Sea. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Algeria

Description

Four volcanoes are located in southern Algeria and on the border with neighbouring Niger. These volcanoes are related to intra-plate processes which have dominantly led to the formation of volcanic fields, scoria and pyroclastic cones, with a dominantly basaltic composition.

No Holocene eruptions are recorded at any volcano in Algeria, however all have activity of suspected Holocene age. Historical unrest has been recognised at the Atakor Volcanic Field, with mild seismicity and fumaroles.

These volcanoes are remote, with the most populous cities in Algeria being concentrated in the north of the country. Only a small local population of about 10,000 resides within 30 km of one or more of these volcanoes, rising to about 120,000 at 100 km. This represents less than 1% of Algeria’s population.

Given the absence of detailed eruptive histories at Algeria’s volcanoes, the assessment of hazard here is associated with large uncertainties. Further research is required to better constrain the age and size of Holocene eruptions.

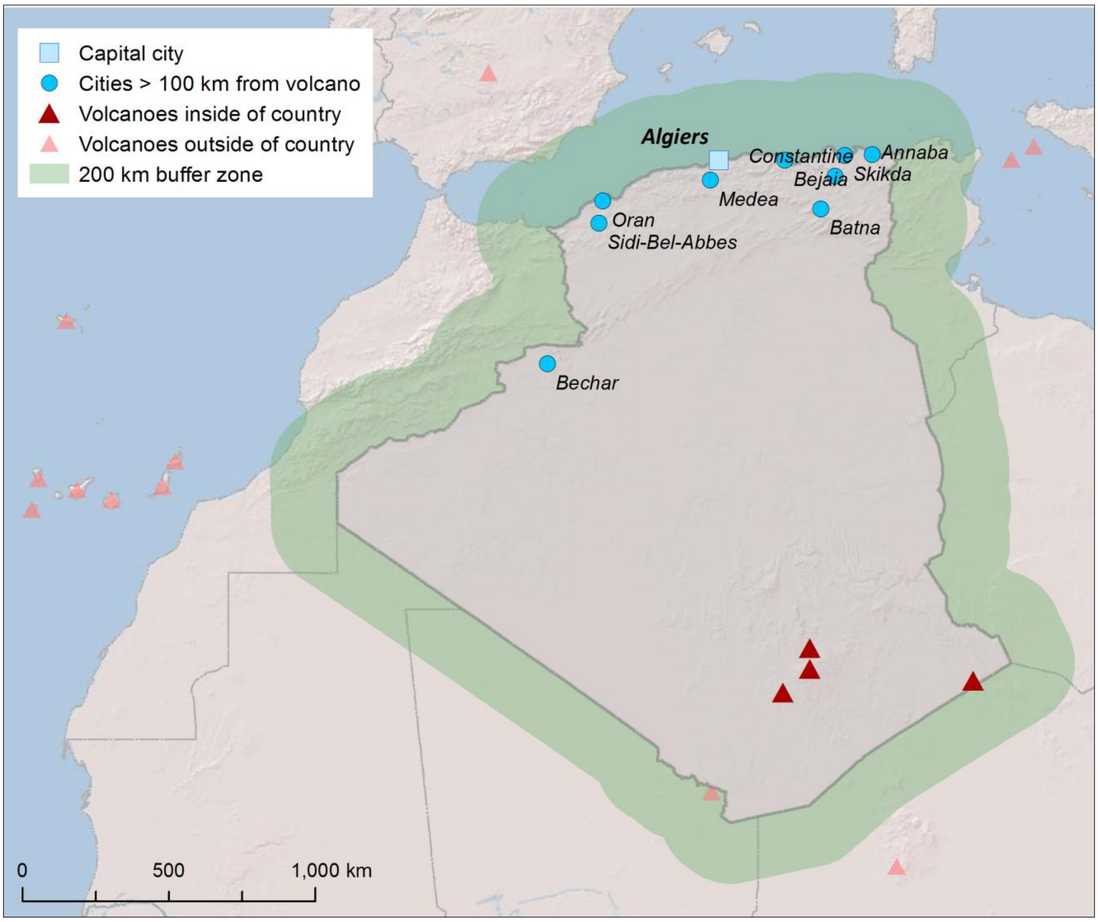


Figure 36: Location of Algeria's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Algeria.

Volcano Facts

Number of Holocene volcanoes	4, inclusive of one on the border with Niger
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	-
Number of Holocene eruptions	-
Recorded Holocene VEI range	-
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
4	Small cone(s)	Basaltic (4)

Table 42: The number of volcanoes in Algeria, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	38,406,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	7,643
Gross National Income (GNI) per capita (2005 PPP $)	7,418
Human Development Index (HDI) (2012)	0.713 (High)

Population Exposure

Capital city	Algiers

Distance from capital city to nearest Holocene volcano	603.2 km
Total population (2011)	34,994,937
Number (percentage) of people living within 10 km of a Holocene volcano	425 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	10,320 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	122,840 (<1%)

Ten largest cities, as measured by population, and populations:

Algiers	1,977,663
Oran	645,984
Constantine	450,097
Batna	280,798
Annaba	206,570
Sidi-Bel-Abbes	191,769
Bejaia	164,103
Skikda	162,702
Medea	147,707
Bechar	143,382

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	335
Total length of railroads within 100 km of a volcano (km)	0

The largest cities in Algeria are mainly concentrated in the north of the country, including the capital Algiers, away from the volcanoes. Being inland volcanoes, no ports are located within 100 km of the volcanoes, however one airport is located within 100 km: the Aguenar-Hadj Bey Akhamok international airport, between the Tahalra and Atakor Volcanic Fields.

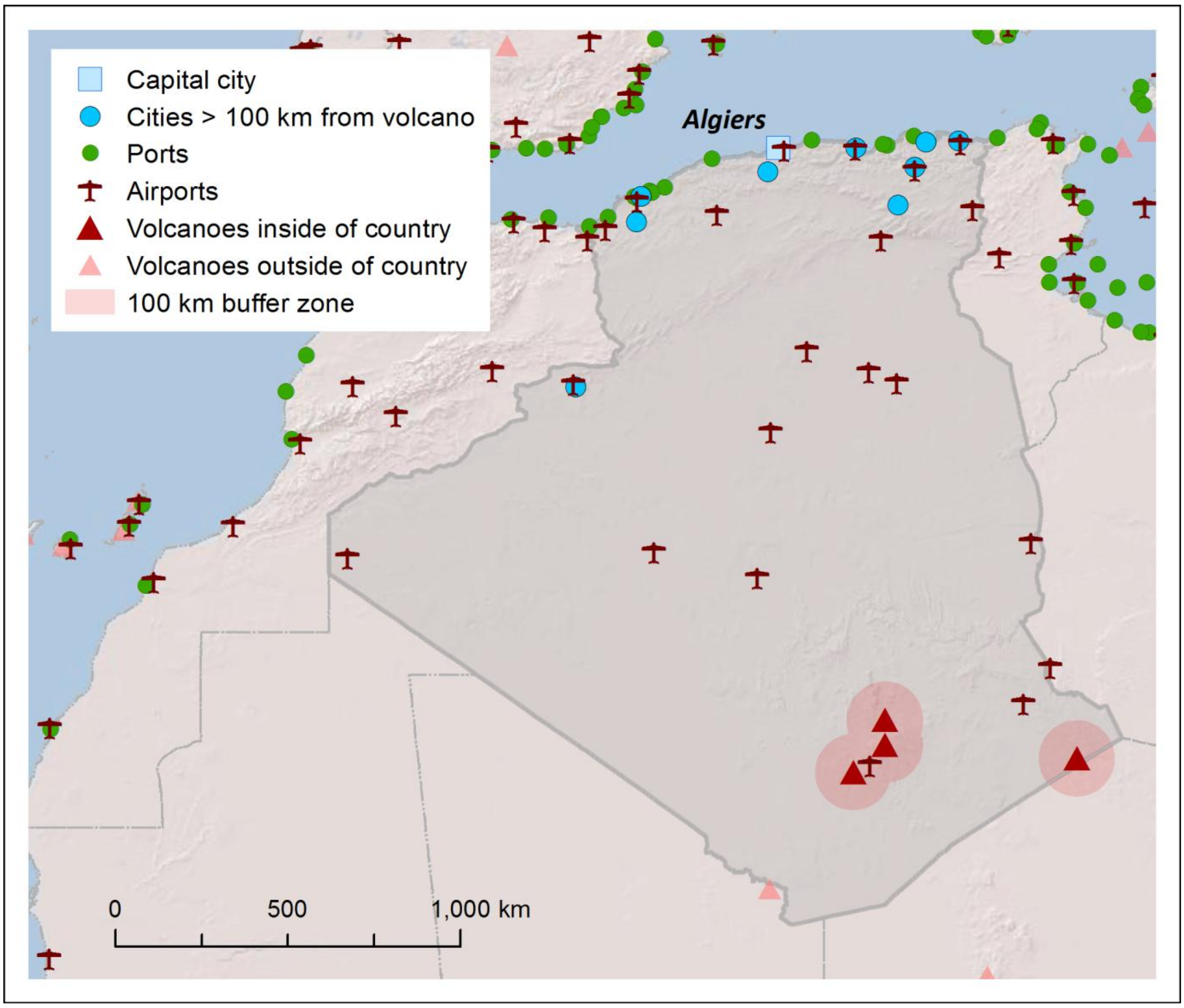


Figure 37: The location of Algeria's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are no confirmed eruptions at any of Algeria's volcanoes during the Holocene. The absence of a thorough eruptive history means that the hazard levels cannot be determined for these volcanoes, and hence risk levels are also unclassified. All of Algeria's volcanoes have a low PEI of 2. No post-1900 AD unrest is recorded at Algeria's volcanoes.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR							
	U- NHHR		In Ezzane Volcanic Field; Tahalra Volcanic Field; Atakor Volcanic Field; Manzaz Volcanic Field					
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 43: Identity of Algeria's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Algeria have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Algeria.

Cameroon

Description

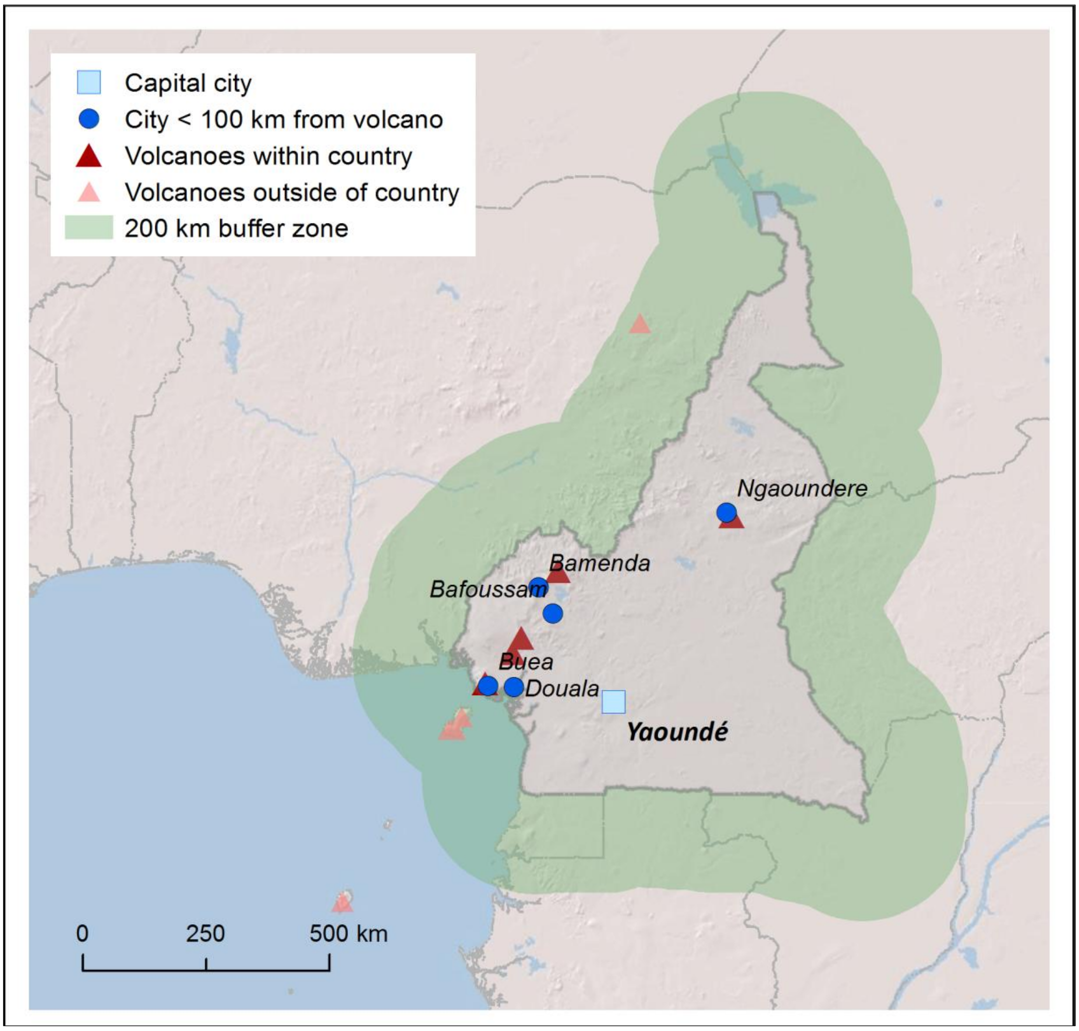


Figure 38: Location of Cameroon's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Cameroon.

Cameroon has five Holocene volcanoes: Cameroon, Manengouba, Ngaoundere Palteau, Oku Volcanic Field and Tombel Graben. Cameroon, Manengouba and Oku Volcanic Field are basaltic to trachybasaltic stratovolcanoes, while Ngaoundere Palteau is a trachybasaltic volcanic field and Tombel Graben is a trachybasaltic cinder cone. Only Cameroon is known to have been historically active.

Cameroon volcano is a basaltic to trachybasaltic stratovolcano with a height of 4095 m, located near the Atlantic coast in western Cameroon. Numerous parasitic cinder cones occur on its flanks and the surrounding lowlands. Historical activity was first observed in the 5th Century, and numerous explosive and effusive eruptions have occurred from both summit and flanks vents since. In 1922 a lava flow from a vent on the SW flank reached the coast, 14 km away. The last known eruption was in 2000.

Manengouba stratovolcano is just over 100 km NE of Cameroon volcano. It has a 3 km wide summit caldera with younger volcanism of unknown age having produced a series of crater lakes and cinder cones across the caldera floor. Oku Volcanic Field comprises a series of maars and basaltic cinder cones on the flanks of Mount Oku, a stratovolcano which is dissected by a large caldera. The Oku volcanic field comprises two crater lakes: Lake Nyos to the north; and Lake Monoun to the south. Both lakes produced catastrophic carbon-dioxide release events causing hundreds to thousands of fatalities, in 1986 and 1984, respectively. The overturn of Lake Monoun was attributed to an earthquake triggered landslide, while the cause of the overturn of Lake Nyos is unknown and has been suggested to relate to non-volcanic processes, phreatic explosions or the injection of hot gas into the lake.

The Ngaoundere Volcanic Field comprises a series of cinder cones, lava flows, maars and tuff cones in the north of Cameroon. The youngest activity is assumed to be of Holocene age which formed a chain of cinder cones aligned WNW-ESE.

Tombel graben lies between Mount Cameroon and Mount Manengouba. The graben is punctuated by numerous cinder cones and maars. The last eruption in the Tombel Graben is unknown.

Volcano Facts

Number of Holocene volcanoes	5
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	?1,737
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	Two M4 eruptions are recorded at Manengouba – the Eboga Caldera formation and the Elengoum Caldera formation at 250 ka and 700 ka respectively.
Largest recorded Holocene eruption	Three VEI 3 eruptions are recorded at Mt. Cameroon in 450 BC, 1650 and 1807 AD.
Number of Holocene eruptions	19 confirmed eruptions. 2 uncertain eruptions
Recorded Holocene VEI range	Unknown – 3

Number of historically active volcanoes	1
Number of historical eruptions	18

Number of volcanoes	Primary volcano type	Dominant rock type
3	Large cone(s)	Basaltic (3)
2	Small cone(s)	Basaltic (2)

Table 44: The number of volcanoes in Cameroon, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	21,779,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	2,090
Gross National Income (GNI) per capita (2005 PPP $)	2,114
Human Development Index (HDI) (2012)	0.495 (Low)

Population Exposure

Capital city	Yaoundé
Distance from capital city to nearest Holocene volcano	227.3 km
Total population (2011)	19,711,291
Number (percentage) of people living within 10 km of a Holocene volcano	185,716 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	1,842,101 (9.4%)
Number (percentage) of people living within 100 km of a Holocene volcano	9,046,134 (45.9%)

Ten largest cities, as measured by population, and populations:

Douala	1,338,082
Yaounde	1,299,369
Garoua	436,899
Bamenda	393,835
Maroua	319,941
Bafoussam	290,768
Ngaoundere	231,357
Bertoua	218,111
Ebolowa	87,875

Buea	<50,000

Infrastructure Exposure

Number of airports within 100 km of a volcano	6
Number of ports within 100 km of a volcano	5
Total length of roads within 100 km of a volcano (km)	2,446
Total length of railroads within 100 km of a volcano (km)	187

Five of the largest cities in Cameroon are located within 100 km of the volcanoes, although the capital Yaoundé lies further east. The proximity of these large population centres to the volcanoes also places critical infrastructure within 100 km distance of the volcanoes, including 6 airports and nearly 2,500 km of roads. With Mt Cameroon and Tobel Graben located near the coast, 5 ports are situated within 100 km distance.

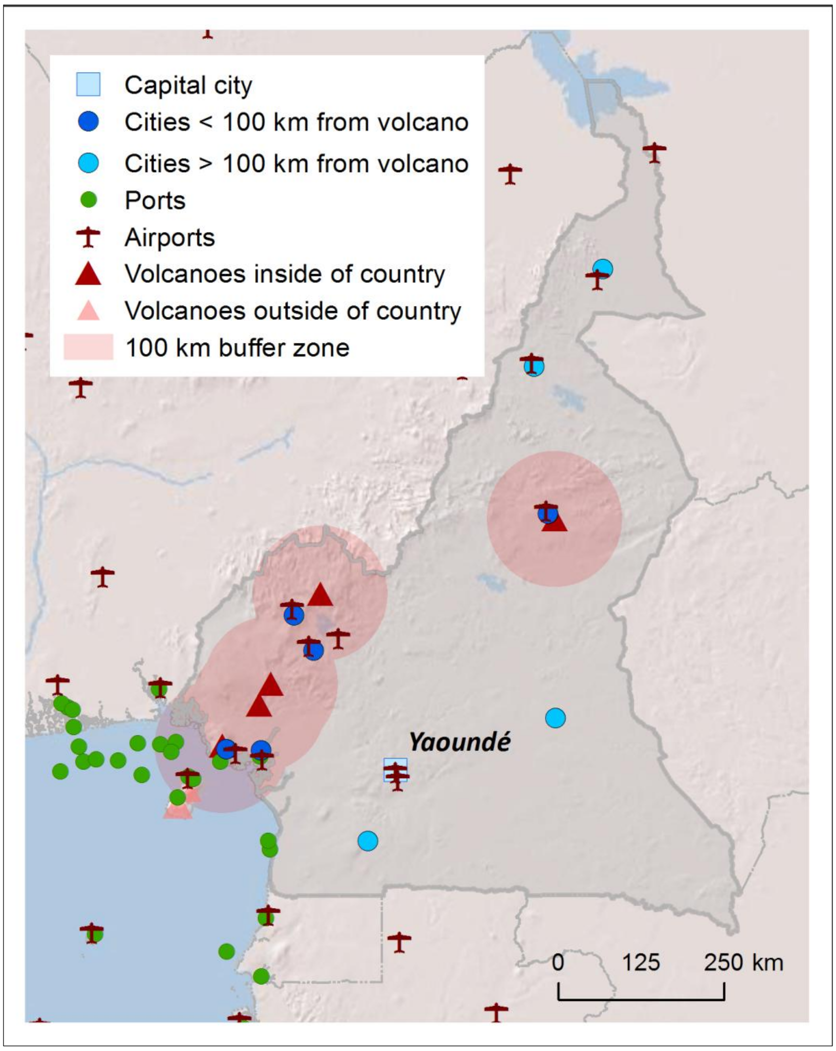


Figure 39: The location of Cameroon's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Of Cameroon's volcanoes, only Mt. Cameroon has a sufficiently detailed eruptive history to determine the hazard level, with 19 confirmed Holocene eruptions, 18 of which have a known VEI most commonly at VEI 2. The Hazard Level here is I.

The PEI at all five volcanoes in Cameroon is high, at PEI 5 – 6. The PEI 5 and Hazard Level I of Mt. Cameroon indicates a Risk Level of II.

The remaining volcanoes have no confirmed Holocene eruptions on record. Unrest has been recorded at Oku Volcanic Field since 1900 AD, with the catastrophic gas releases from Lake Monoun and Lake Nyos. The Lake Nyos overturn may have resulted from phreatic explosions or the injection of hot gases.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I					Cameroon		
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR					Manengouba; Ngaoundere Plateau	Tombel Graben; **Oku Volcanic Field**	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 45: Identity of Cameroon's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Cameroon	5	II

Table 46: Classified volcanoes of Cameroon ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 1 volcano; Risk Level III – 0 volcanoes.

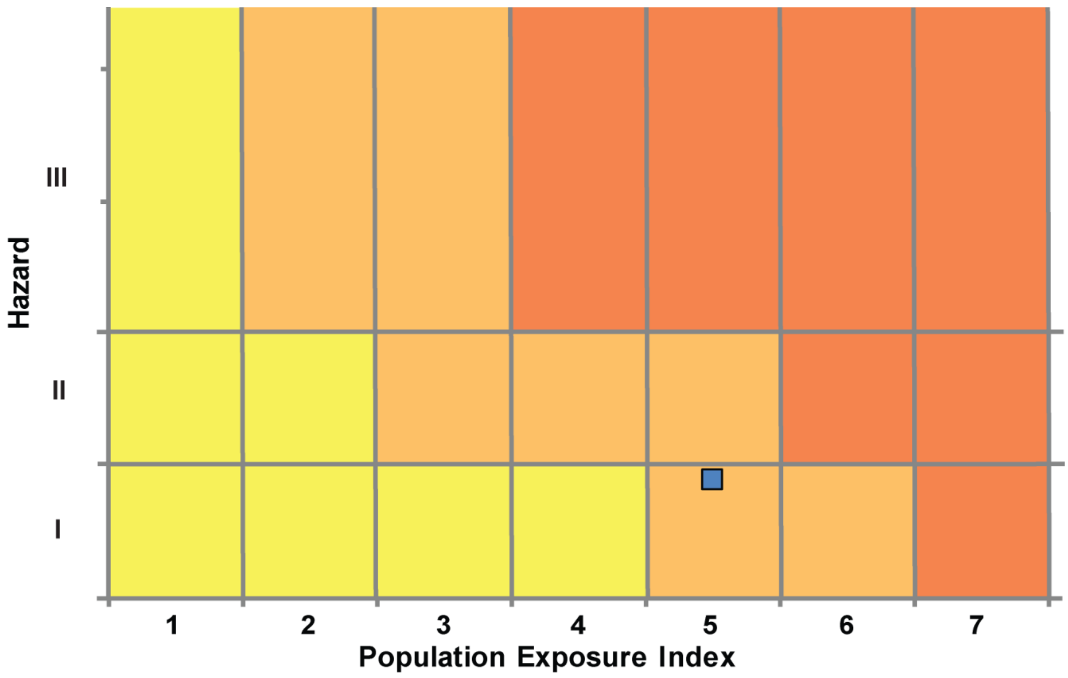


Figure 40: Distribution of Cameroon's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

One volcano, Mt. Cameroon, has historical eruption records in this country. No information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any of the volcanoes in Cameroon.

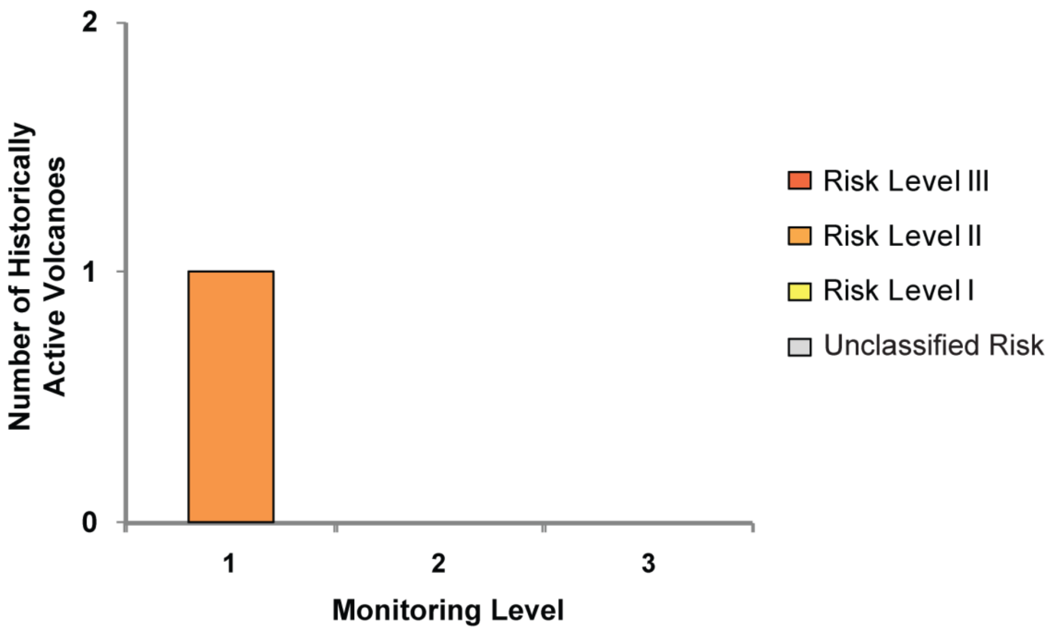


Figure 41: The monitoring and risk levels of the historically active volcanoes in Cameroon. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Chad

Description

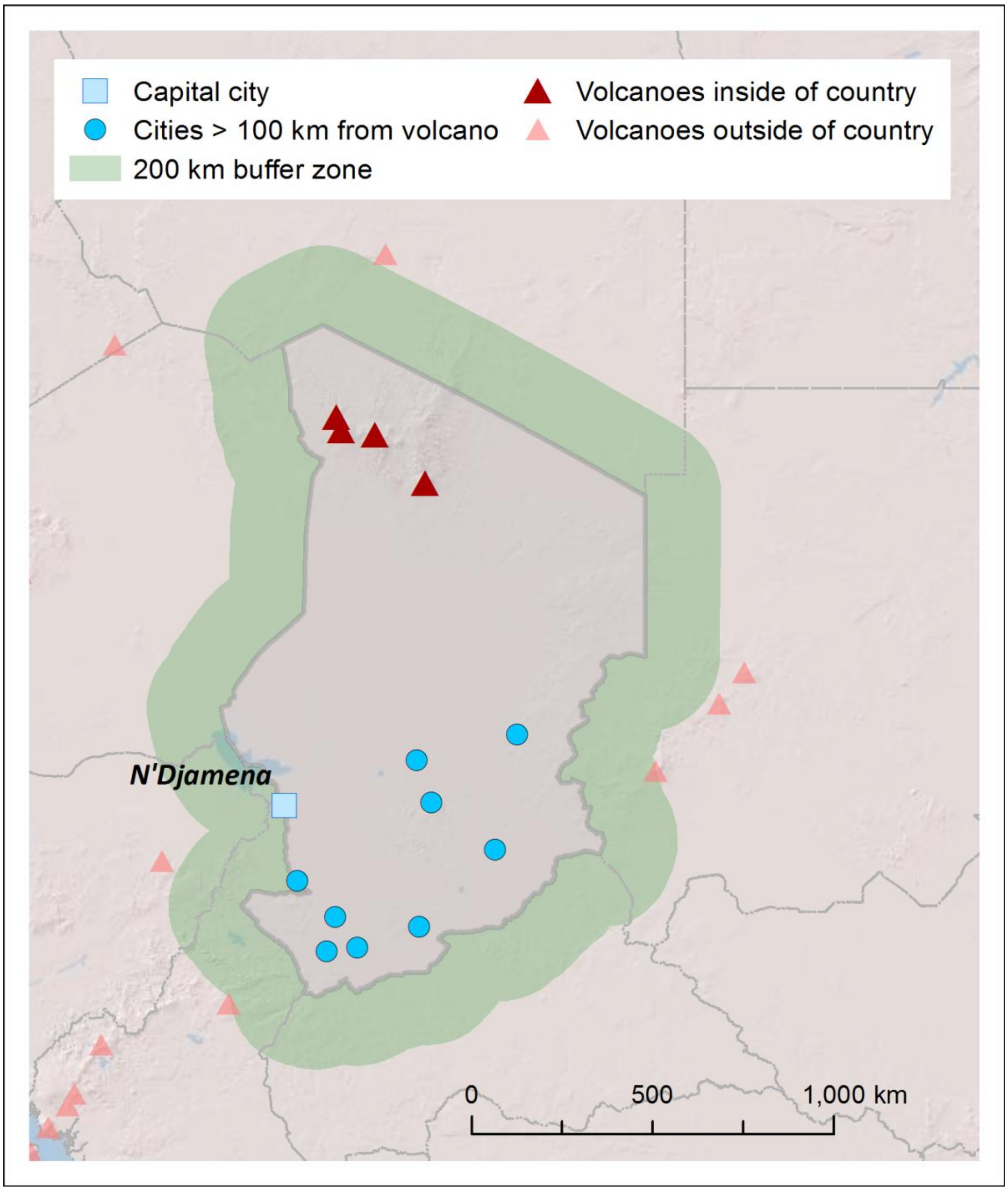


Figure 42: Location of Chad's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Chad.

Four volcanoes are located in the Tibesti Mountains in the north of Chad. These volcanoes are related to intra-plate processes.

No Holocene eruptions are recorded at any volcano in Chad, however they all have activity of suspected Holocene age. Since 1900 AD, unrest in the form of thermal springs and steam blasts have been recorded at Tarso Voon and Emi Koussi.

One explosive Pleistocene eruption of M4 is recorded at Emi Koussi, 1.32 million years ago. Many lava flows and cones are distributed across the volcanoes.

Only a small population of about 15,000 live within 100 km of these remote volcanoes; less than 1% of Chad's population.

Volcano Facts

Number of Holocene volcanoes	4
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	The M4 Era Kohor caldera formation (Koussi III) of Emi Koussi at 1.32 Ma
Largest recorded Holocene eruption	-
Number of Holocene eruptions	-
Recorded Holocene VEI range	-
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
1	Caldera(s)	Trachytic/Andesitic (1)
2	Large cone(s)	Trachytic/Andesitic (2)
1	Small cone(s)	Basaltic (1)

Table 47: The number of volcanoes in Chad, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	12,502,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	1,343
Gross National Income (GNI) per capita (2005 PPP $)	1,258
Human Development Index (HDI) (2012)	0.340 (Low)

Population Exposure

Capital city	N'Djamena
Distance from capital city to nearest Holocene volcano	365.6 km
Total population (2011)	10,758,945
Number (percentage) of people living within 10 km of a Holocene volcano	18 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	555 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	15,190 (<1%)

Ten largest cities, as measured by population, and populations:

Ndjamena	721,081
Moundou	135,167
Sarh	102,528
Abeche	74,188
Am Timan	28,885
Bongor	27,770
Mongo	27,763
Doba	24,336
Ati	24,074
Lai	19,382

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	310
Total length of railroads within 100 km of a volcano (km)	0

The largest cities in Chad are concentrated in the south of the country, including the capital N'Djamena, away from the volcanoes in the north. Being inland volcanoes, no ports are located within 100 km. The volcanoes of Chad are remote and as such no airports and only a small system of roads are found within 100 km.

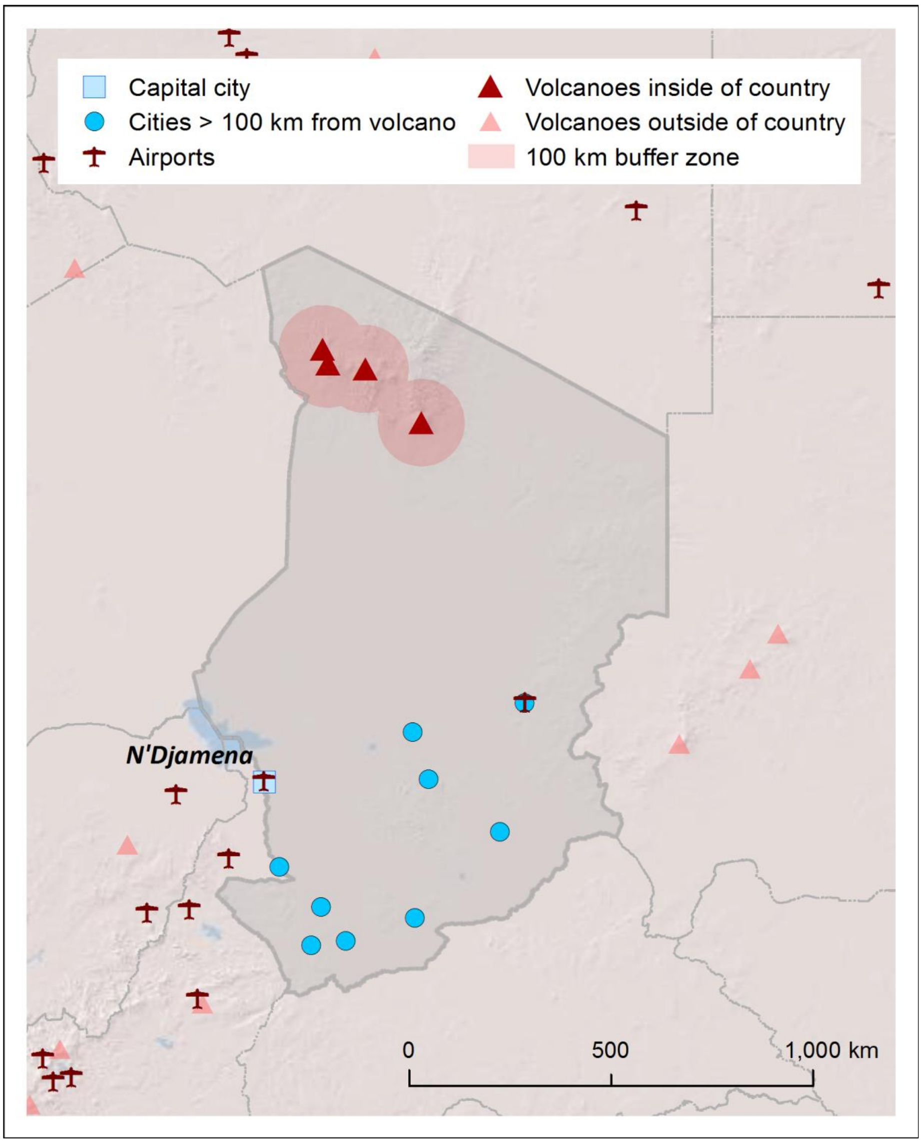


Figure 43: The location of Chad's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

No volcanoes in Chad have a confirmed Holocene record of eruptions. This absence of thorough eruptive histories means that the Hazard Levels cannot be determined and these volcanoes are therefore unclassified in both hazard and risk. However, the PEI at all four of Chad's volcanoes is low at PEI 2 indicative of reasonably small local populations who would be at risk to activity from these volcanoes.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR							
	U- NHHR		Tôh, Tarso; Toussidé, Tarso; Voon, Tarso; Koussi, Emi					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 48: Identity of Chad's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Chad have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Chad.

Djibouti

Description

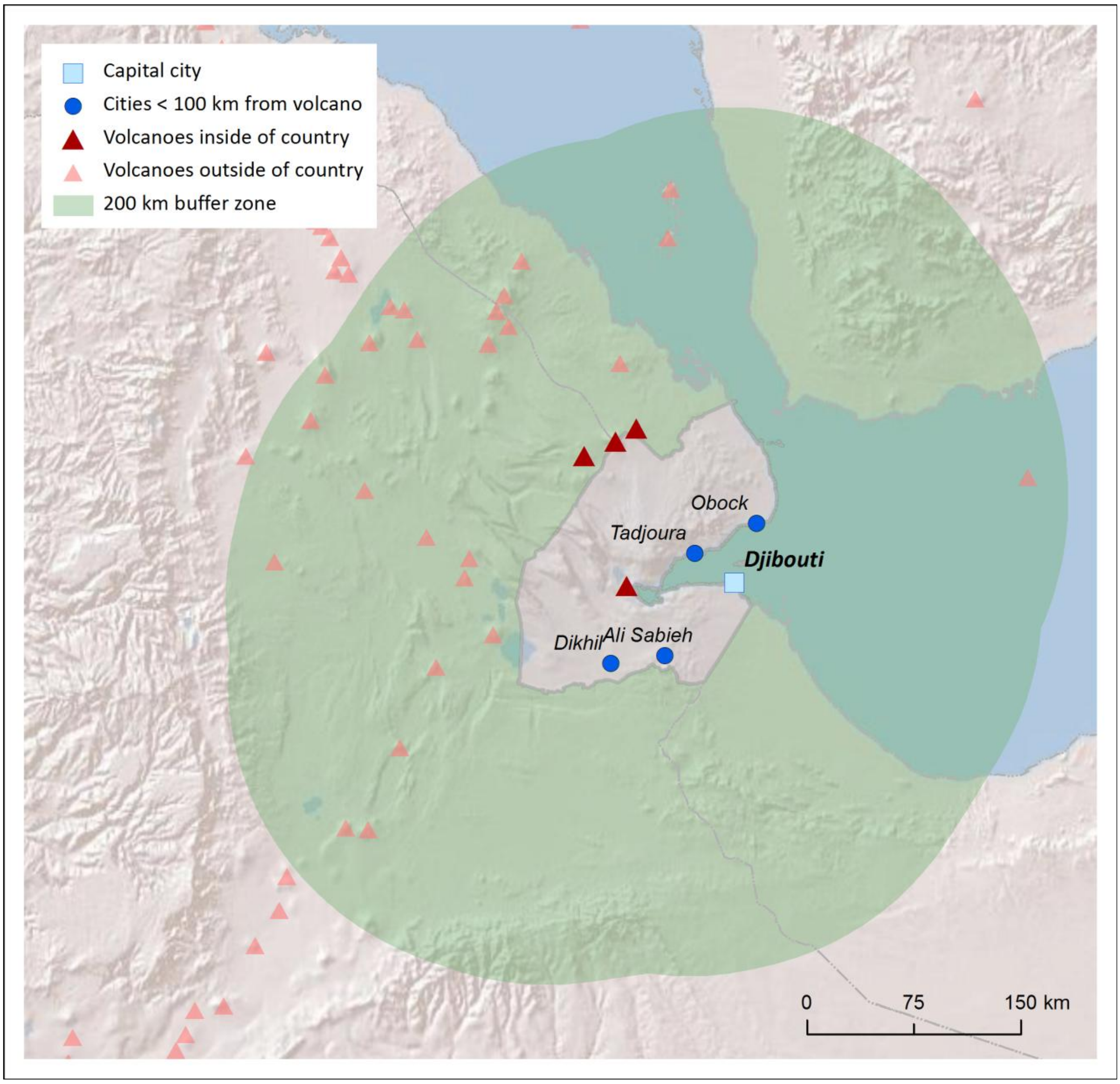


Figure 44: Location of Djibouti's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Djibouti.

Djibouti has one Holocene volcano: Ardoukôba. Ardoukôba comprises a series of fissures within the Ardoukôba Rift in central Djibuti. The Rift extends 12 km NW from the Red Sea, and contains numerous basaltic cinder and spatter cones.

The most recent lavas are thought to have erupted during the past 3000 years. The last known eruption from the Ardoukôba fissure was in 1978 during which lava flows erupted from a cinder cone near the Red Sea.

There are three other Holocene volcanoes: one on the border with Ethiopia, Manda-Inakir; one on the border with Eritrea, Gufa; and one on the border with Ethiopia and Eritrea, Mousa Alli.

The Gufa volcanic field comprises a group of basaltic scoria cones and lava flows aligned in an E-W orientation along the Eritrea border. The last eruption here is unknown. Manda-Inakir also comprises a series of NW trending fissure vents and pyroclastic cones. The fissures vents lie along the Ethiopia-Djibouti border. The last known eruption occurred in 1928-29 producing a cinder cone and lava flow at the southern end of the Manda-Inakir fissure system.

Mousa Alli lies on the border with both Ethiopia and Eritrea and is a large trachytic to rhyolitic stratovolcano. The summit comprises a series of rhyolitic lava domes and flows. The last eruption of Mousa Alli is unknown.

The Institute for Geophysics, Space Science and Astronomy (IGSSA) at Addis Ababa University in Ethiopia has responsibility for Manda Inakir; however, there are no known dedicated monitoring systems in place at this volcano and monitoring is not a supported or mandated activity for IGSSA. Activity at Ardoukôba is monitored by L'Observatoire Geophysique d'Arta, although the seismic network was not set up as a dedicated volcano monitoring system.

Due to the proximity of many of Ethiopia's volcanoes to Djibouti eruptions from many volcanoes are likely to disperse volcanic ash, gases and aerosols in the air space over Djibouti and may also result in deposits at ground level.

Volcano Facts

Number of Holocene volcanoes	4, inclusive of one on the border with Eritrea, one on the border with Ethiopia and one on the border with both Eritrea and Ethiopia
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	2
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The VEI 2 eruption in 1928 of Manda-Inakir.
Number of Holocene eruptions	2 confirmed eruptions.

Recorded Holocene VEI range	1 – 2
Number of historically active volcanoes	2
Number of historical eruptions	2

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Rhyolitic (1)
3	Small cone(s)	Basaltic (3)

Table 49: The number of volcanoes in Djibouti, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	862,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	2,087
Gross National Income (GNI) per capita (2005 PPP $)	2,350
Human Development Index (HDI) (2012)	0.445 (Low)

Population Exposure

Capital city	Djibouti
Distance from capital city to nearest Holocene volcano	74.1 km
Total population (2011)	757,074
Number (percentage) of people living within 10 km of a Holocene volcano	5,137 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	46,125 (6.1%)
Number (percentage) of people living within 100 km of a Holocene volcano	845,134 (>100%)

Largest cities, as measured by population, and populations:

Djibouti	623,891
Ali Sabieh	40,074
Tadjoura	22,193
Obock	17,776
Dikhil	12,043

Infrastructure Exposure

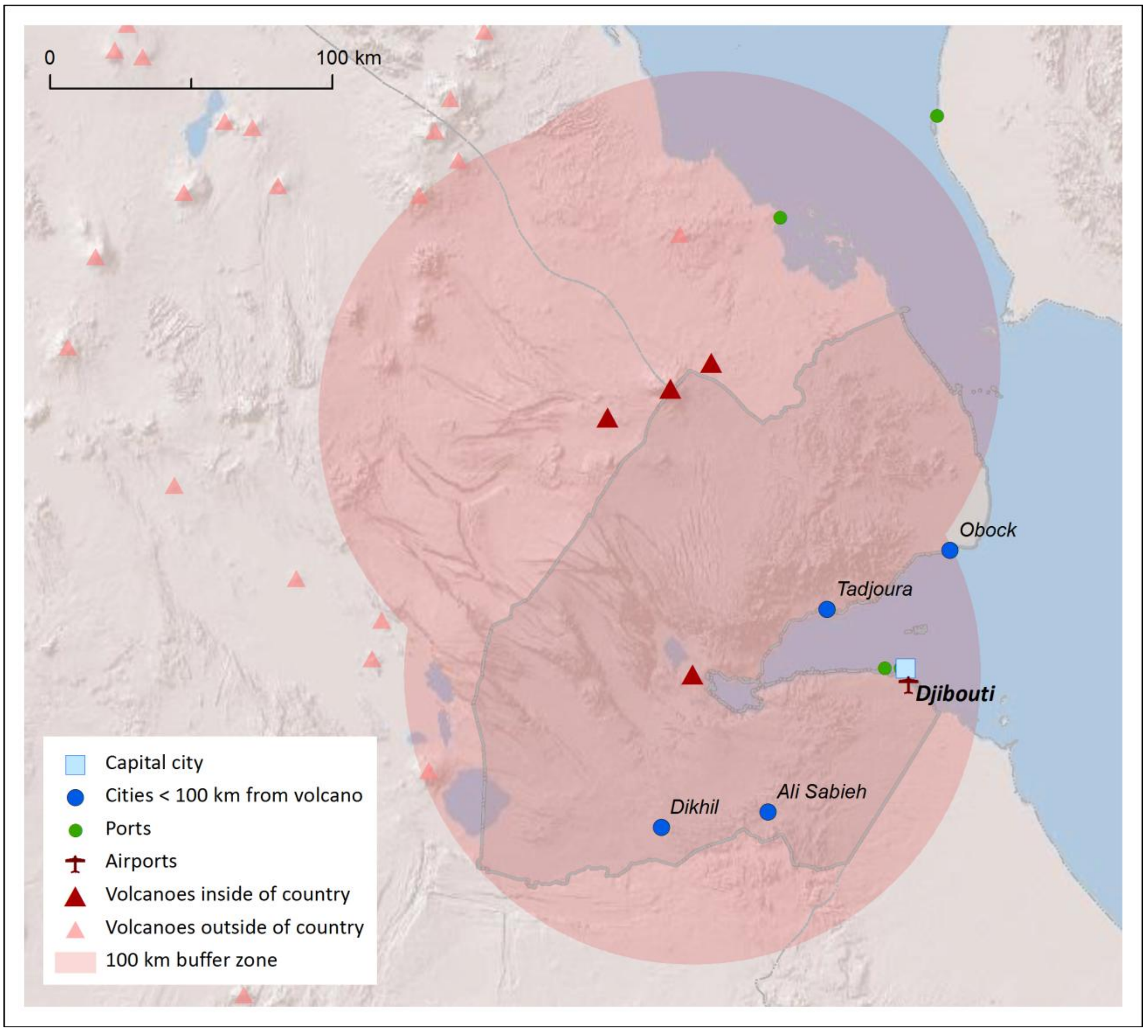


Figure 45: The location of Djibouti's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	455
Total length of railroads within 100 km of a volcano (km)	0

Being a small country, measuring no more than 300 km across, almost the whole country is situated within 100 km of either the central Ardoukôba volcano, those volcanoes on the borders with the neighbouring countries or indeed Ethiopian volcanoes. As such, almost all the critical infrastructure within Djibouti is exposed to the volcanic hazard, including the capital, Djibouti and the international airport located here.

Hazard, Uncertainty and Exposure Assessments

The volcanoes in Djibouti have sparse eruption records, with just one Holocene eruption recorded at both Ardoukôba and Manda-Inakir. The absence of a thorough eruptive history means that the Hazard Levels cannot be calculated without significant uncertainties and therefore both hazard and risk are unclassified at Djibouti's volcanoes.

The PEI in Djibouti ranges from low to moderate at PEI 2 – 3. The highest PEI is at Ardoukôba, with over 560,000 living within 100 km.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		**Manda-Inakir**	**Ardoukôba**				
	U- HR							
	U-NHHR		Mousa Alli; Gufa					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 50: Identity of Djibouti's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

A regional network of 15 seismometers is located near the volcano Ardoukouba, run by L'Observatoire Geophysique d'Arta. This is not dedicated to volcano monitoring but is described as having sufficient stations to detect small magnitude events in the Asal Rift in which Ardoukouba sits. The Ethiopia Geophysical Observatory has responsibility for Manda Inakir, however there are no known dedicated monitoring systems in place at this volcano.

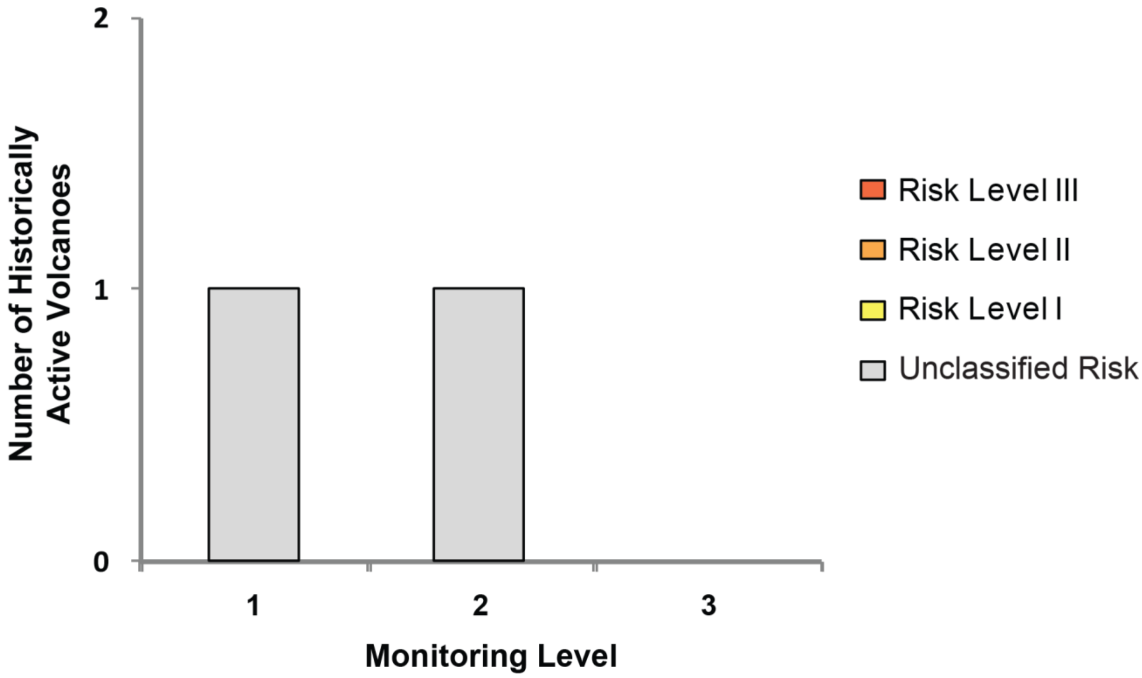


Figure 46: The monitoring and risk levels of the historically active volcanoes in Djibouti. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Democratic Republic of Congo

Description

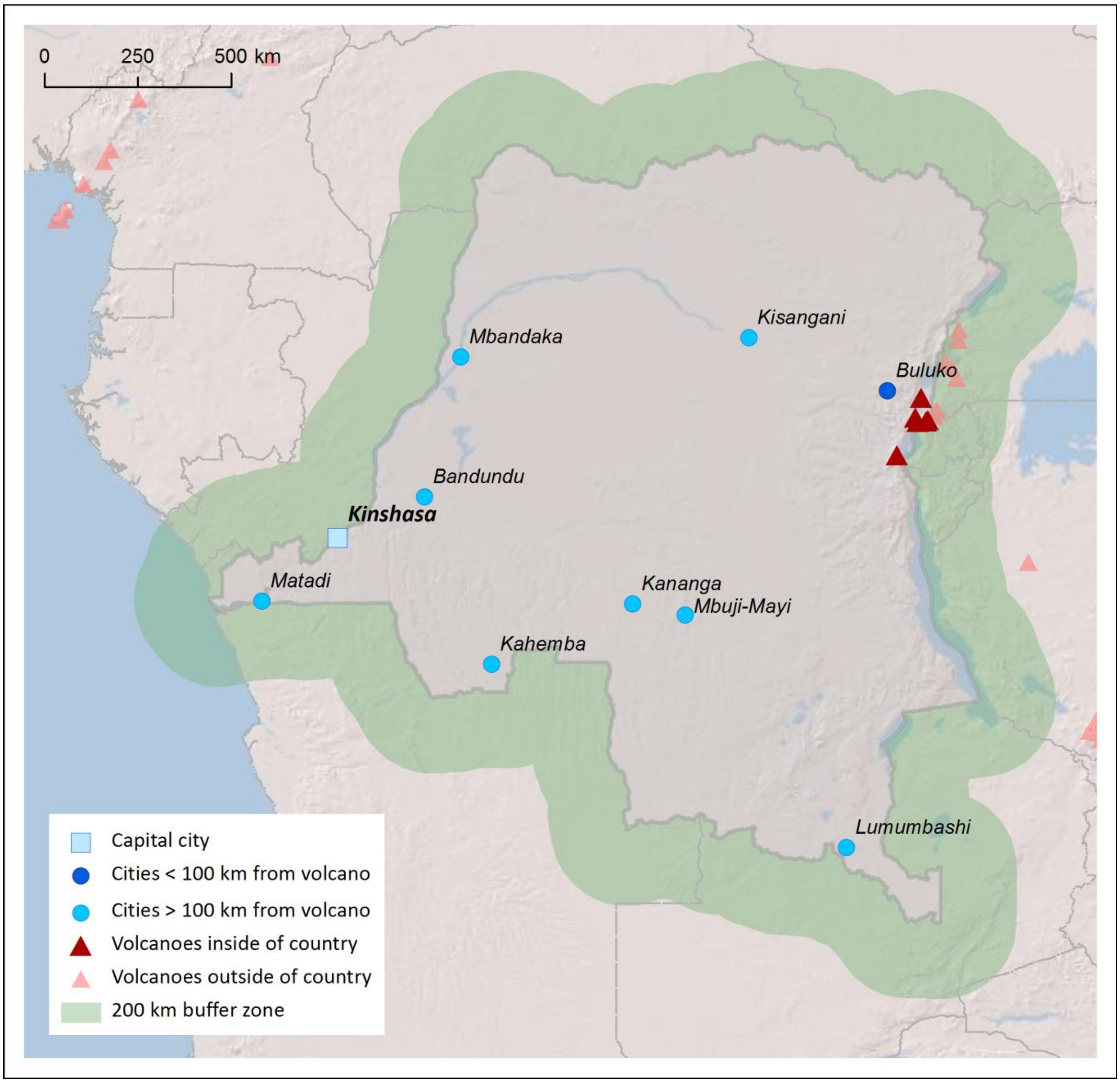


Figure 47: Location of the volcanoes of the Democratic Republic of Congo, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the DRC.

The Democratic Republic of Congo (DRC) has four Holocene volcanoes: May-ya-moto, Nyamuragira; Nyiragongo and Tshibinda; plus two on the border with Rwanda: Karisimbi and Visoke. All of the active volcanoes are in the east of DRC lying along or just west of the Virunga Mountain Range. Three of the volcanoes are stratovolcanoes: Karisimbi, Visoke and Nyiragongo; while Nyamuragira is a shield volcano, Tshibinda is a cinder cone and May-ya-moto is a hydrothermal field.

Of them, three have had historical eruptions: Nyamuragira, Nyiragongo and Visoke; Karisimbi's last known eruption was in 8050 BC, and the last eruptions of Tshibinda and May-ya-moto are unknown.

Karisimbi is the highest of the Virunga Range, and is on the border with Rwanda. It comprises a trachy-basaltic stratovolcano with a 2 km wide caldera SE of the summit and a c.1.2 km wide crater south of the summit. The caldera is filled with lava flows and two explosion craters are apparent. A broad plain comprising lava flows and a chain of parasitic cones extends SW to the shores of Lake Kivu in DRC. The youngest eruptions of Karisimbi volcano formed parasitic vents east of the summit, which fed lava flows that travelled up to 12 km to the east. The last known eruption of Karisimbi was 8050 BC.

Visoke is a symmetrical stratovolcano with a 450 m wide crater lake, also on the border with Rwanda. It lies 6.5 km to the NE of Karisimbi along the Virunga Range. The last known eruption occurred in 1957 forming two small cones on the northern flank of Visoke, 11 km from the summit. There is only one previous known historic eruption in 1891. Numerous cinder cones lie along a NE-SW trending fissure zone NE of Visoke.

Nyamuragira is a broad shield volcano comprising high-potassium basaltic lava flows covering an area of c.1500 km^2 with a volume of c.500 km^3. Historical activity has been recorded in the 2 km wide summit caldera, and from fissures and cinder cones on its flanks. Some lava flows travelled distances of more than 30 km. A lava lake in the summit crater drained in 1938 during a major flank eruption. The last known eruption was in 2011-12 on the NW flank.

Nyiragongo is a large foiditic stratovolcano with an active lava lake in its 1.2 km wide summit crater. Numerous parasitic cones are situated along radial fissures east of the summit. There are also cones along a NE-SW zone extending to Lake Kivu. Foiditic lavas are extremely fluid and can travel long distances. In 1977 the lava lake drained resulting in fast-moving lava flows that overwhelmed villages killing at least 70 people. In 2002 a 13 km long fissure opened on the southern flank of Nyiragongo, and lava flows reached the city of Goma. About 147 people died from asphyxiation by carbon dioxide, explosion of fuel stations and buildings collapsing. The lava lake is active at the time of writing this report.

The Goma Volcano Observatory is responsible for the monitoring of the historically active volcanoes, and has had dedicated ground-based systems at Nyamuragira and Nyiragongo. Due to recent unrest in the region these systems have been decommissioned and the observatory is reliant on near to real-time satellite based monitoring which is being provided by EVOSS. There is no current knowledge of ground-based monitoring of Visoke volcano.

Volcano Facts

Number of Holocene volcanoes	6, inclusive of two on the border with Rwanda
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-

Number of volcanoes generating lava flows	4
Number of fatalities caused by volcanic eruptions	318?
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	8 VEI 3 eruptions are recorded at Nyamuragira from 1907 AD to 1996 AD.
Number of Holocene eruptions	67 confirmed eruptions. 2 uncertain eruptions.
Recorded Holocene VEI range	0 – 3 and unknown.
Number of historically active volcanoes	3
Number of historical eruptions	66

Number of volcanoes	Primary volcano type	Dominant rock type
1	Hydrothermal field	Unknown (1)
3	Large cone(s)	Andesitic (1), Basaltic (1), Foiditic (1)
1	Shield(s)	Basaltic (1)
1	Small cone(s)	Basaltic (1)

Table 51: The number of volcanoes in the DRC, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	65,606,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	329
Gross National Income (GNI) per capita (2005 PPP $)	319
Human Development Index (HDI) (2012)	0.304 (Low)

Population Exposure

Capital city	Kinshasa
Distance from capital city to nearest Holocene volcano	1090.3 km

Number (percentage) of people living within 10 km of a Holocene volcano	158,902 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	2,029,394 (~3%)
Number (percentage) of people living within 100 km of a Holocene volcano	8,298,794 (~12%)

Ten largest cities, as measured by population, and populations:

Kinshasa	7,785,965
Lumumbashi	1,373,770
Goma	1,000,000
Mbuji-Mayi	874,761
Bukavu	806,940
Kisangani	539,158
Kananga	463,546
Mbandaka	184,185
Matadi	180,109
Bandundu	118,211

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	2
Total length of roads within 100 km of a volcano (km)	745
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes in the DRC are located in the east of the country, distal to the coast, the capital, Kinshasa, and the major infrastructure centres of Lumumbashi in the south-east and Kisangani in the north-east. Several airports lie within 100 km of the volcanoes, including those over the border of Rwanda and Uganda.

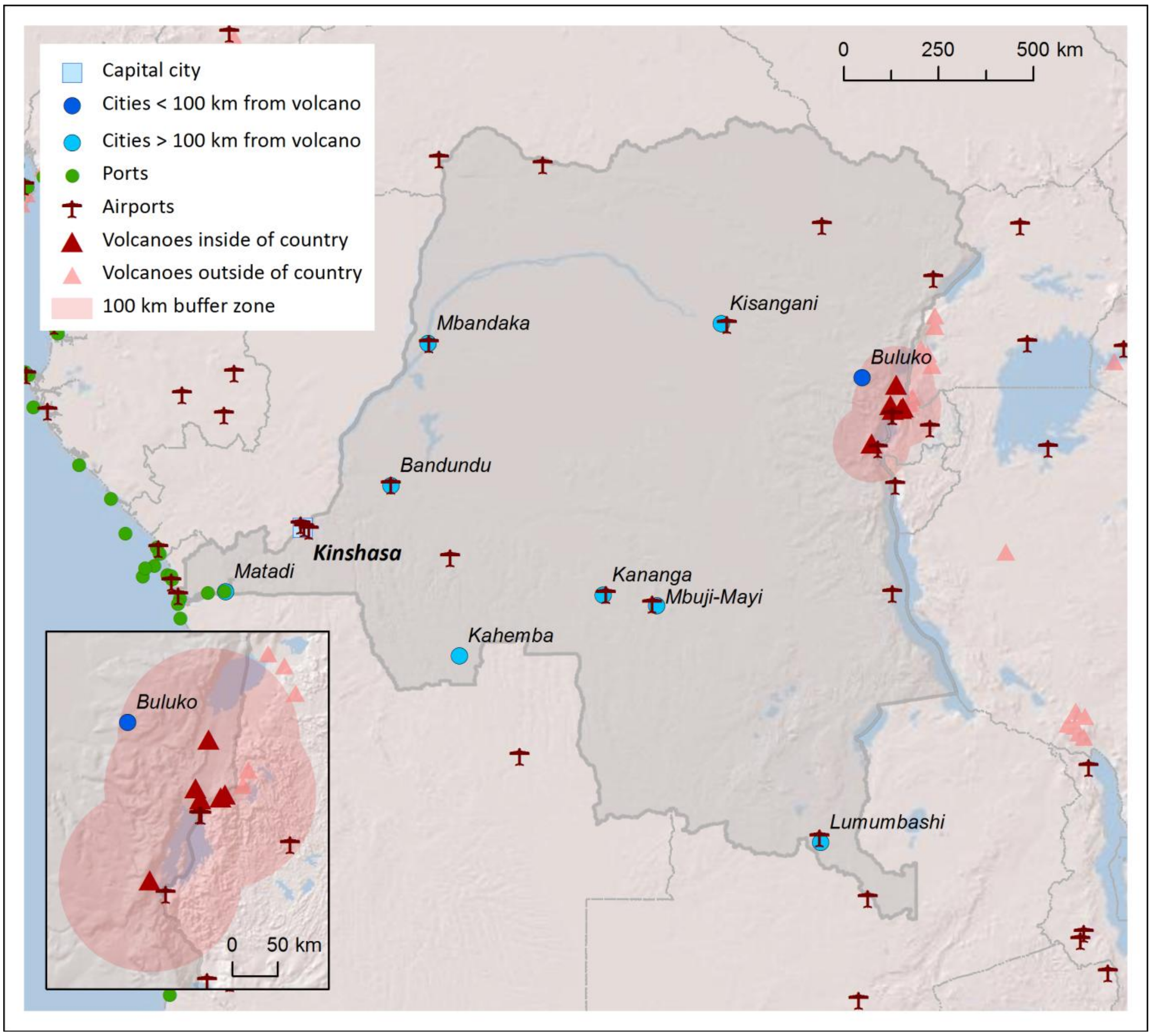


Figure 48: The location of the volcanoes of the Democratic Republic of Congo and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Of the volcanoes in the Democratic Republic of the Congo, only Nyamuragira and Nyiragongo have sufficient eruption records to determine the hazard levels without significant uncertainties. These two volcanoes have records of 64 confirmed Holocene eruptions (all post 1500 AD), many of which are assigned a VEI. With frequent lava effusions and VEIs almost always being of 1 and 2, these volcanoes are classed at Hazard Level I.

The remaining volcanoes are unclassified, with too few eruptions of known size confirmed in the Holocene record, and indeed no confirmed Holocene eruptions at either May-ya-moto or Tshibinda. Karasimbi has a Holocene record, whilst Visoke erupted as recently as 1957.

The PEI at all volcanoes in the DRC is high, indicating large proximal populations and Risk Levels of II to III, dependent on the hazard.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I					Nyamuragira; Nyiragongo		
UNCLASSIFIED	**U – HHR**						**Visoke**	
	U- HR						Karisimbi	
	U- NHHR					May-ya-moto	Tshibinda	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 52: Identity of DRC's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Nyamuragira	5	II
Nyiragongo	5	II

Table 53: Classified volcanoes of the DRC ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 2 volcanoes; Risk Level III – 0 volcanoes.

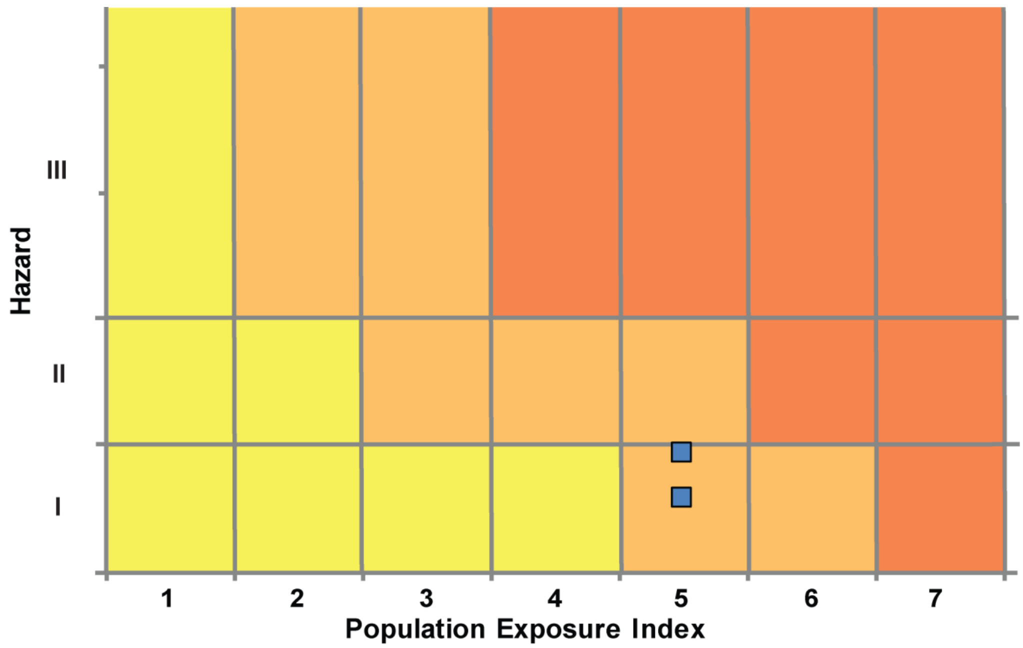


Figure 49: Distribution of the DRC's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Three volcanoes in the DRC have records of historic activity. The Goma Volcano Observatory is responsible for the monitoring of these volcanoes, and has dedicated ground-based systems at Nyamuragira and Nyiragongo (both Risk Level II). Currently there is no information to indicate that dedicated ground-based monitoring is undertaken at Visoke.

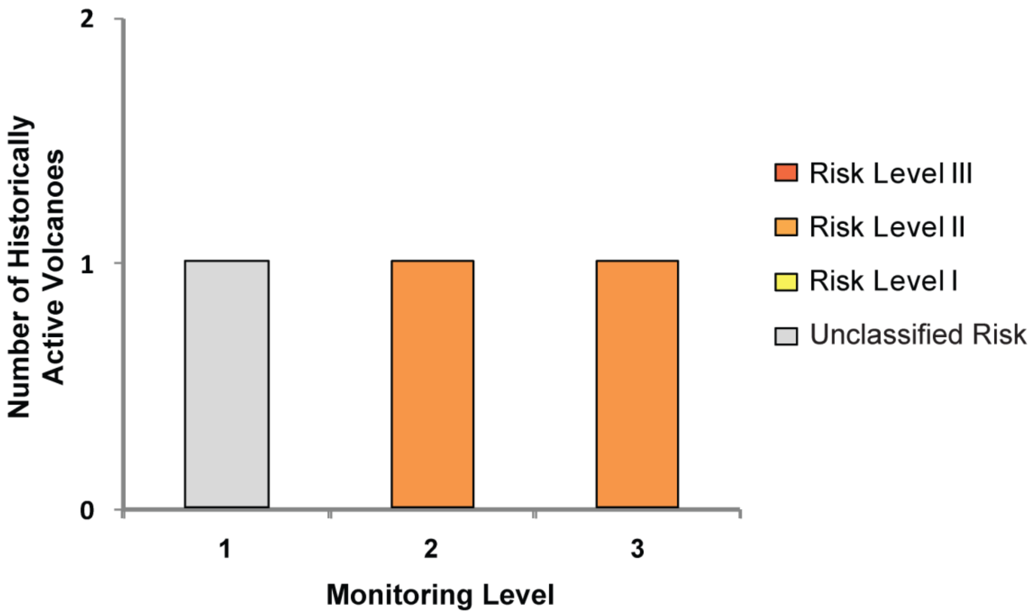


Figure 50: The monitoring and risk levels of the historically active volcanoes in the DRC. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Equatorial Guinea

Description

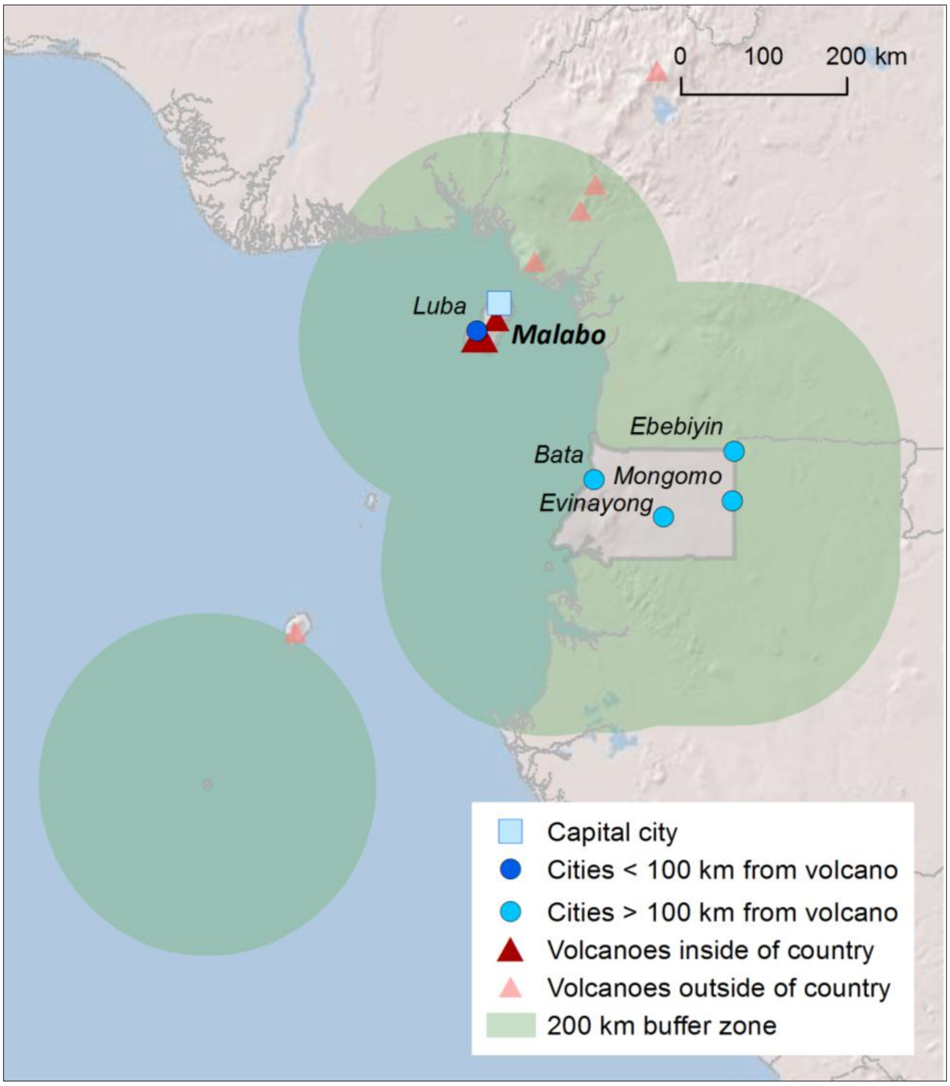


Figure 51: Location of Equatorial Guinea's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Equatorial Guinea.

Three Holocene volcanoes are located on the island of Bioko, north-west of mainland Equatorial Guinea. Volcanism here is related to intra-plate processes, which has produced the three basaltic shield volcanoes.

Of the three Holocene volcanoes, only Santa Isabel has a Holocene record of eruptions. The other two have activity of suspected Holocene age. The three eruptions of Santa Isabel were recorded in 1898, 1903 and 1923 from vents on the south-east flanks of the volcano. The size and activity style of these events is unknown. Further research is required to better understand this active volcano, which lies within 20 km of the capital, Malabo, and to more fully understand the volcanic hazards at Equatorial Guinea's other volcanoes.

Nearly 120,000 people live within 30 km of Santa Isabel, with a small population proximal to the San Carlos and San Joaquin volcanoes. The whole population of Bioko island resides within 100 km of the volcanoes.

Volcano Facts

Number of Holocene volcanoes	3
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	All eruptions are of unknown VEI.
Number of Holocene eruptions	3 confirmed eruptions.
Recorded Holocene VEI range	Unknown.
Number of historically active volcanoes	1
Number of historical eruptions	3

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
3	Shield(s)	Basaltic

Table 54: The number of volcanoes in Equatorial Guinea, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	739,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	32,026
Gross National Income (GNI) per capita (2005 PPP $)	21,715
Human Development Index (HDI) (2012)	0.554 (Medium)

Population Exposure

Capital city	Malabo
Distance from capital city to nearest Holocene volcano	19.4 km
Total population (2011)	668,225
Number (percentage) of people living within 10 km of a Holocene volcano	3,122 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	154,524 (23.1%)
Number (percentage) of people living within 100 km of a Holocene volcano	154,524 (23.1%)

Largest cities, as measured by population, and populations:

Bata	173,046
Malabo	155,963
Ebebiyin	24,831
Luba	8,655
Evinayong	8,462
Mongomo	6,393

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	181
Total length of railroads within 100 km of a volcano (km)	0

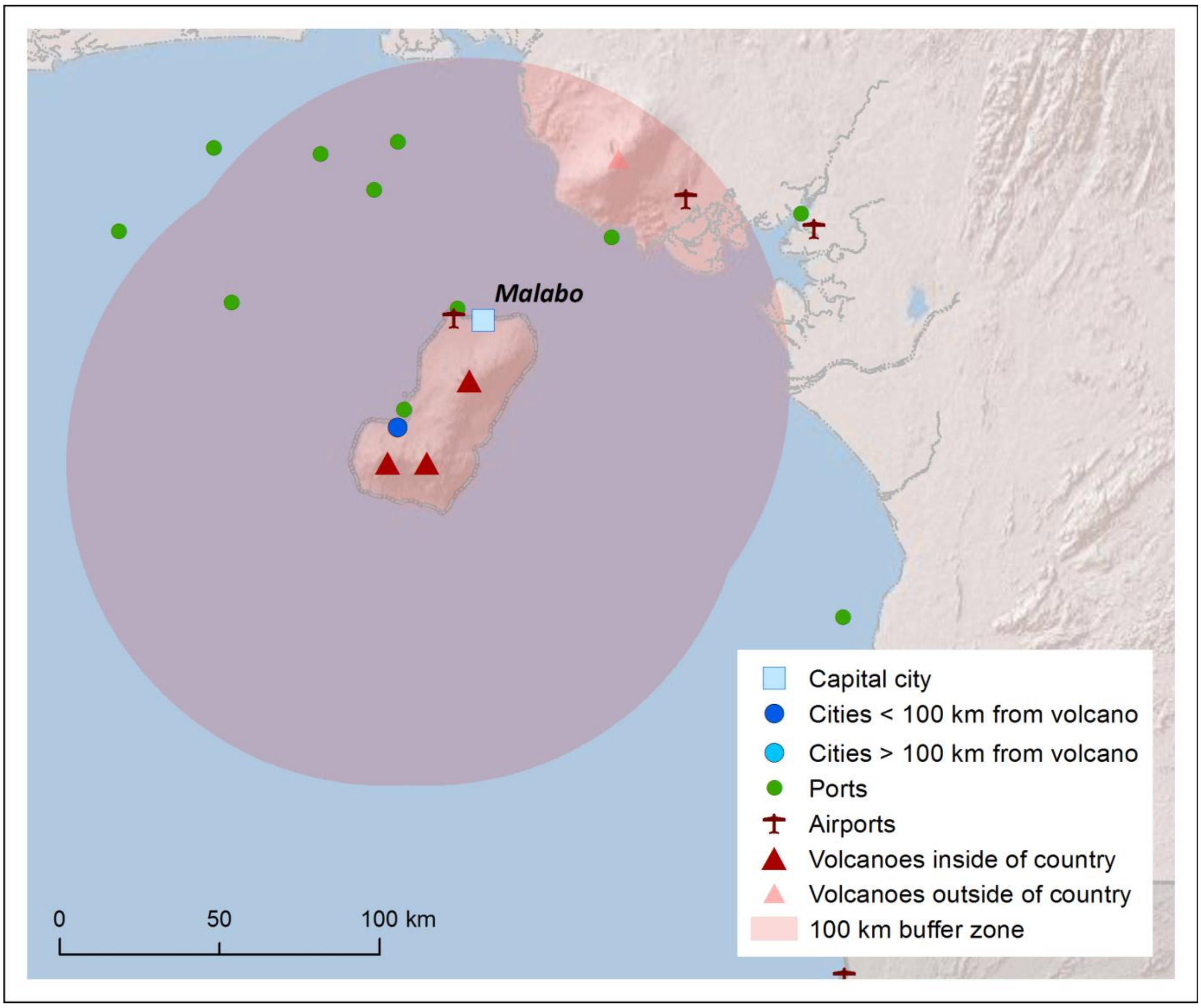


Figure 52: The location of Equatorial Guinea's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

There are no volcanoes located in the mainland region of Equatorial Guinea. Although bordered by Cameroon to the north, none of mainland Equatorial Guinea is within 100 km of a volcano. The three Holocene volcanoes are situated on an island measuring less than 100 km across, placing the entirety of the island and its population and infrastructure close to the volcanoes. Being within 40 km of the mainland, the 100 km radius of the volcanoes of Equatorial Guinea also affects the coastal region of southwest Cameroon. A number of ports and oil rigs are located within 100 km, as are two airports and the capital, Malabo.

Hazard, Uncertainty and Exposure Assessments

Only Santa Isabel in Equatorial Guinea has a record of confirmed Holocene eruptions, with eruptions in the late 1800s and early 1900s. Determination of Hazard Level cannot be undertaken without significant uncertainties at any of the volcanoes here, including Santa Isabel, due to the sparse eruption records meaning both hazard and risk are unclassified.

A low PEI of 2 at San Carlos and San Joaquin indicates small local populations here. With a high PEI of 5 at Santa Isabel, including nearly 100,000 people within 10 km, this volcano has a much larger population at risk and Risk Levels of II to III are indicated, dependent on the hazard.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR					**Santa Isabel**		
	U- HR							
	U- NHHR		San Carlos; San Joaquin					
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 55: Identity of Equatorial Guinea's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Only Santa Isabel volcano in Equatorial Guinea has a historic record of eruptions. At the time of the writing of this report, no information is available to indicate that regular ground-based monitoring is undertaken Santa Isabel or the other two Holocene volcanoes here.

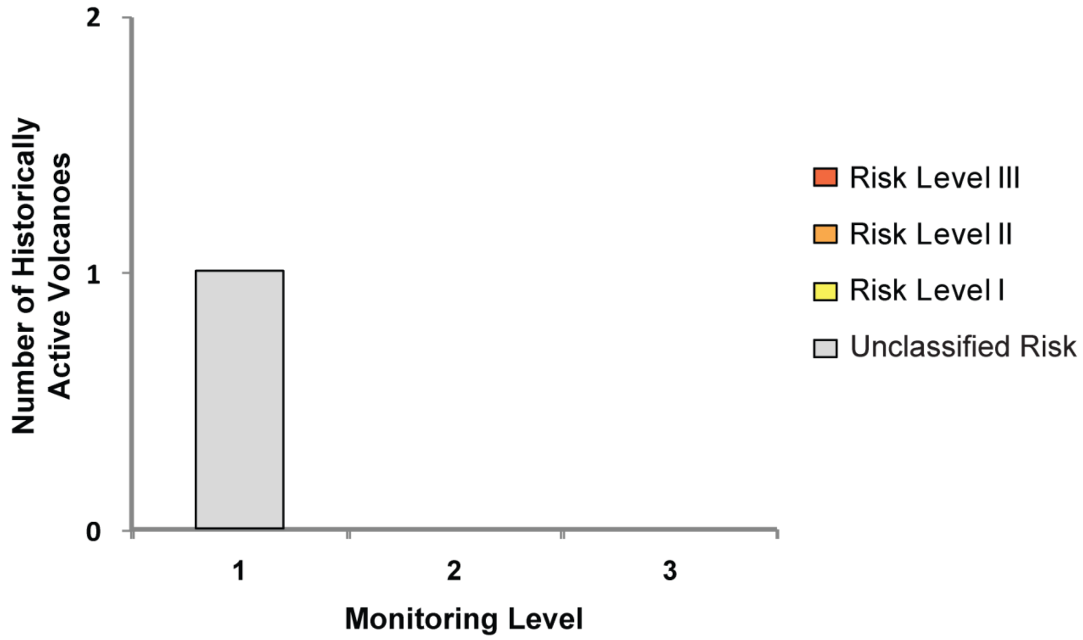


Figure 53: The monitoring and risk levels of the historically active volcanoes in Equatorial Guinea. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Eritrea

Description

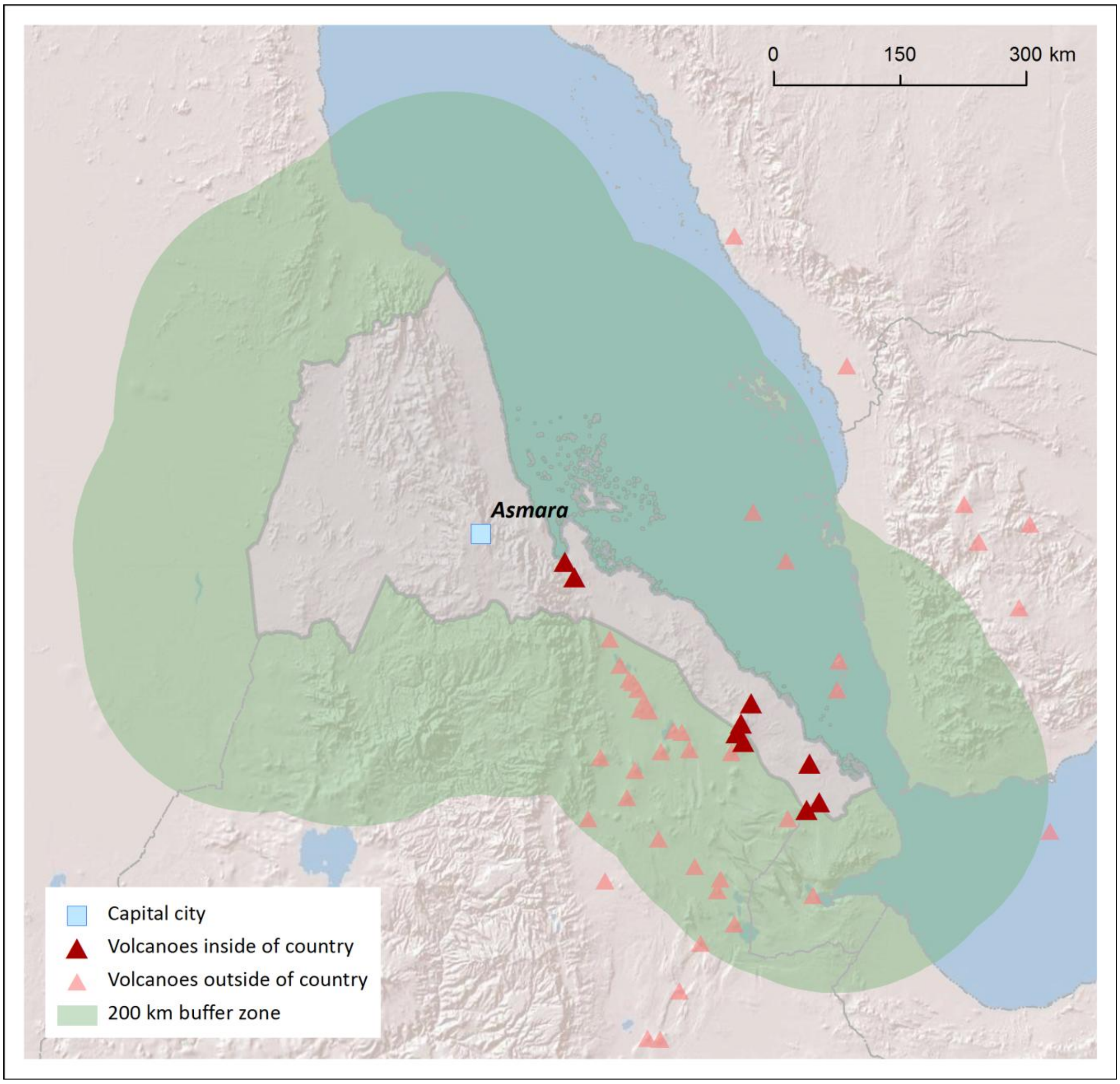


Figure 54: Location of Eritrea's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Eritrea.

Eritrea has five Holocene volcanoes: Alid, Assab Volcanic Field, Dubbi, Jalua and Nabro; plus one on the border with Djibouti: Gufa; two on the border with Ethiopia: Sork Ale and Mallahle; and one on the border with both Ethiopia and Djibouti: Mousa Ali. The majority are stratovolcanoes with compositions ranging from basaltic to rhyolitic.

Volcanism at Eritrea's volcanoes is expressed as both effusive and explosive, producing lava flows and pyroclastic deposits. Only Nabro and Dubbi are known to have erupted in historical times.

Dubbi volcano's last two eruptions were from fissure systems that extended NW-SE and NNE-SSW. The last eruption in 1861 resulted in ash fall more than 300 km away, and lava flows that travelled 22 km. Two villages were destroyed and more than 100 people were killed. The exact cause of the fatalities is unclear but may have been pyroclastic flows and impacts from the eruption are reported in neighbouring Ethiopia. This is the largest reported historical eruption in Africa and a cold summer in 1862 in the Northern Hemisphere has been attributed to the sulphates released by the eruption.

Nabro is a trachytic to trachy-andesitic stratovolcano and is the highest in the Danakil depression of northern Ethiopia and Eritrea. Nabro is truncated by nested calderas, 8 and 5 km wide. Situated on the Ethiopia – Eritrea border, the area is remote and sparsely populated. The last eruption of Nabro in 2011 caused 32 fatalities, displaced >5000 people and disrupted regional aviation including the cancellation of a number of flights in June 2011. The eruption produced lava flows as well as ash and gas plumes with a high release of sulphur dioxide. Previous eruptions from Nabro have neither been dated nor subject to any detailed petrological study, despite a prominent caldera and associated ignimbrites. The regional seismic network detected a brief period of heightened seismicity before the eruption, but the volcano itself had no monitoring programme.

Volcano Facts

Number of Holocene volcanoes	9, inclusive of one on the border with Djibouti, two on the border with Ethiopia and one on the border with both Ethiopia and Djibouti
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	2
Number of fatalities caused by volcanic eruptions	137
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	The M5.5 Rhyolite pumice (Alid Crater) eruption of Alid at 15.2 ka.
Largest recorded Holocene eruption	The VEI 4 2011 AD eruption of Nabro.
Number of Holocene eruptions	3 confirmed eruptions. 2 uncertain eruptions.
Recorded Holocene VEI range	2 – 4
Number of historically active volcanoes	2
Number of historical eruptions	2

Number of volcanoes	Primary volcano type	Dominant rock type
7	Large cone(s)	Basaltic (3), Rhyolitic (2), Trachytic / Andesitic (2)
2	Small cone(s)	Basaltic (2)

Table 56: The number of volcanoes in Eritrea, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	6,153,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	516
Gross National Income (GNI) per capita (2005 PPP $)	531
Human Development Index (HDI) (2012)	0.351 (Low)

Population Exposure

Capital city	Asmara
Distance from capital city to nearest Holocene volcano	100.7 km
Total population (2011)	5,939,484
Number (percentage) of people living within 10 km of a Holocene volcano	22,180 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	71,018 (1.2%)
Number (percentage) of people living within 100 km of a Holocene volcano	2,183,817 (36.8%)

Largest cities, as measured by population, and populations:

Asmara	563,930

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	2
Total length of roads within 100 km of a volcano (km)	445
Total length of railroads within 100 km of a volcano (km)	0

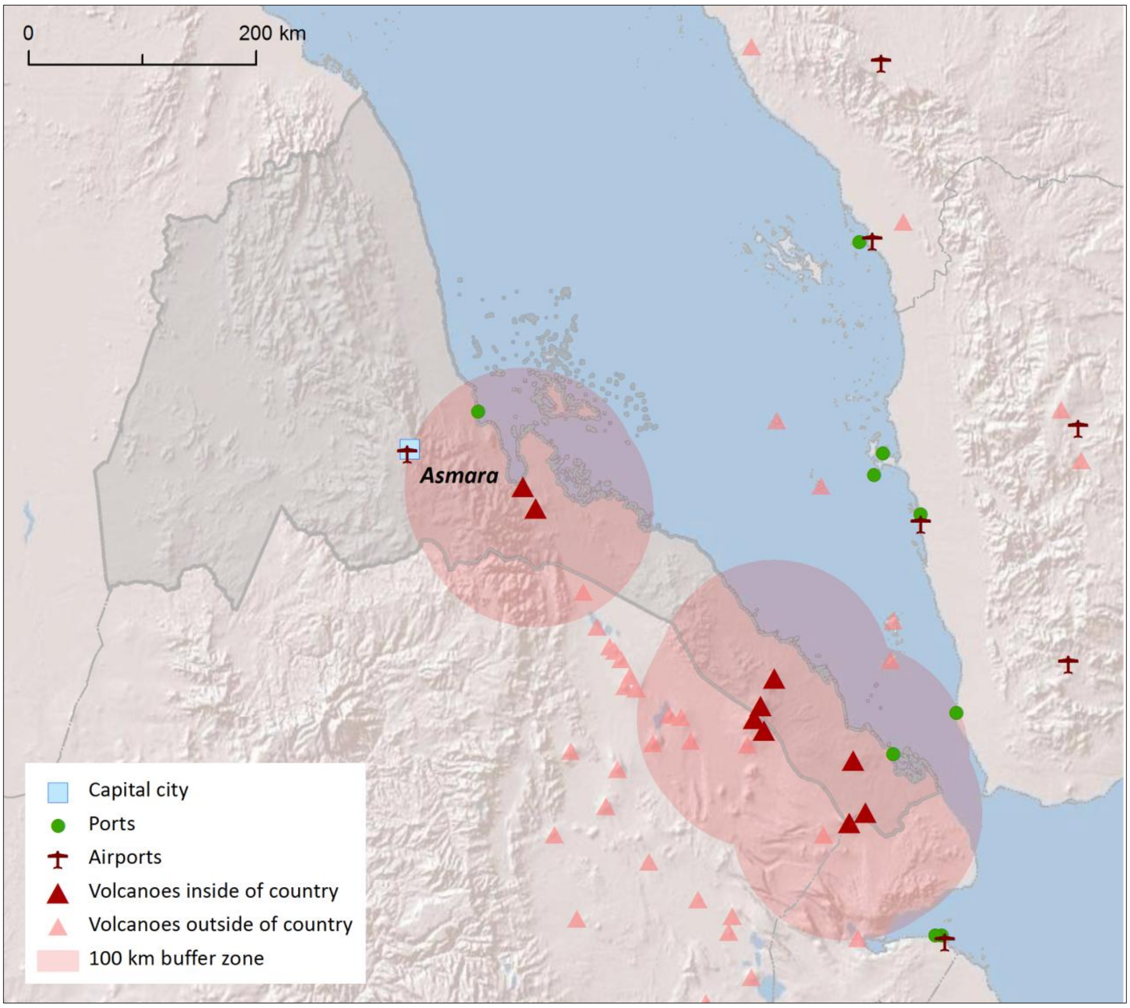


Figure 55: The location of Eritrea's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The volcanoes of Eritrea are largely situated in the south of the country, on the borders of Ethiopia and Djibouti. The strip of Eritrean land here is less than 100 km across and therefore the 100 km of the volcanoes here encompasses areas of its neighbouring countries and the Red Sea. As such, two ports are within the 100 km radius of the volcanoes. The capital Asmara lies about 100 km from Jalua volcano, as does the infrastructure here including the Asmara International Airport.

Hazard, Uncertainty and Exposure Assessments

The Hazard Level cannot be determined without significant uncertainties for any volcanoes in Eritrea due to the sparse eruptive histories with too few eruptions of a known size. Of the nine volcanoes, only Dubbi and Nabro have confirmed Holocene eruptions, and both these had historical events of VEI 3 and 4 respectively. With the hazard unclassified, the risk is also unclassified here. However, the PEI ranges from low to moderate.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR		Dubbi; **Nabro**					
	U- HR							
	U- NHHR		Mallahle; Sork Ale; Mousa Alli; Gufa; Assab Volcanic Field	Alid	Jalua			
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

Table 57: Identity of Eritrea's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Two volcanoes have historical eruption records in Eritrea: Dubbi and Nabro. No information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any of the volcanoes in Eritrea.

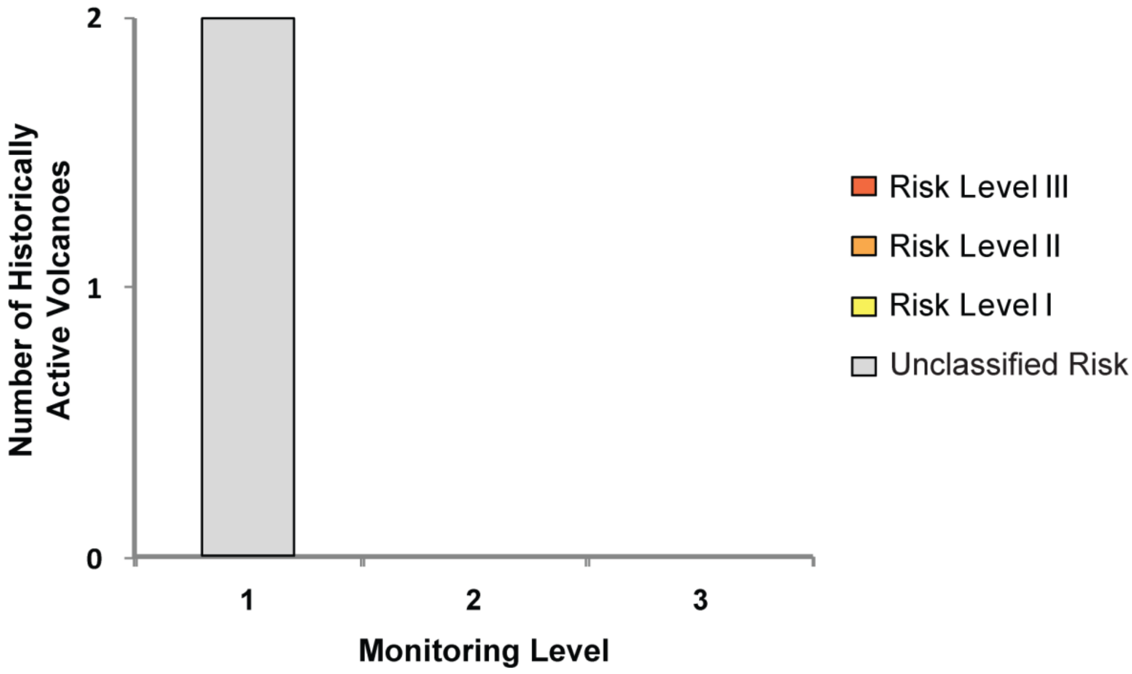


Figure 56: The monitoring and risk levels of the historically active volcanoes in Eritrea. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Ethiopia

Description

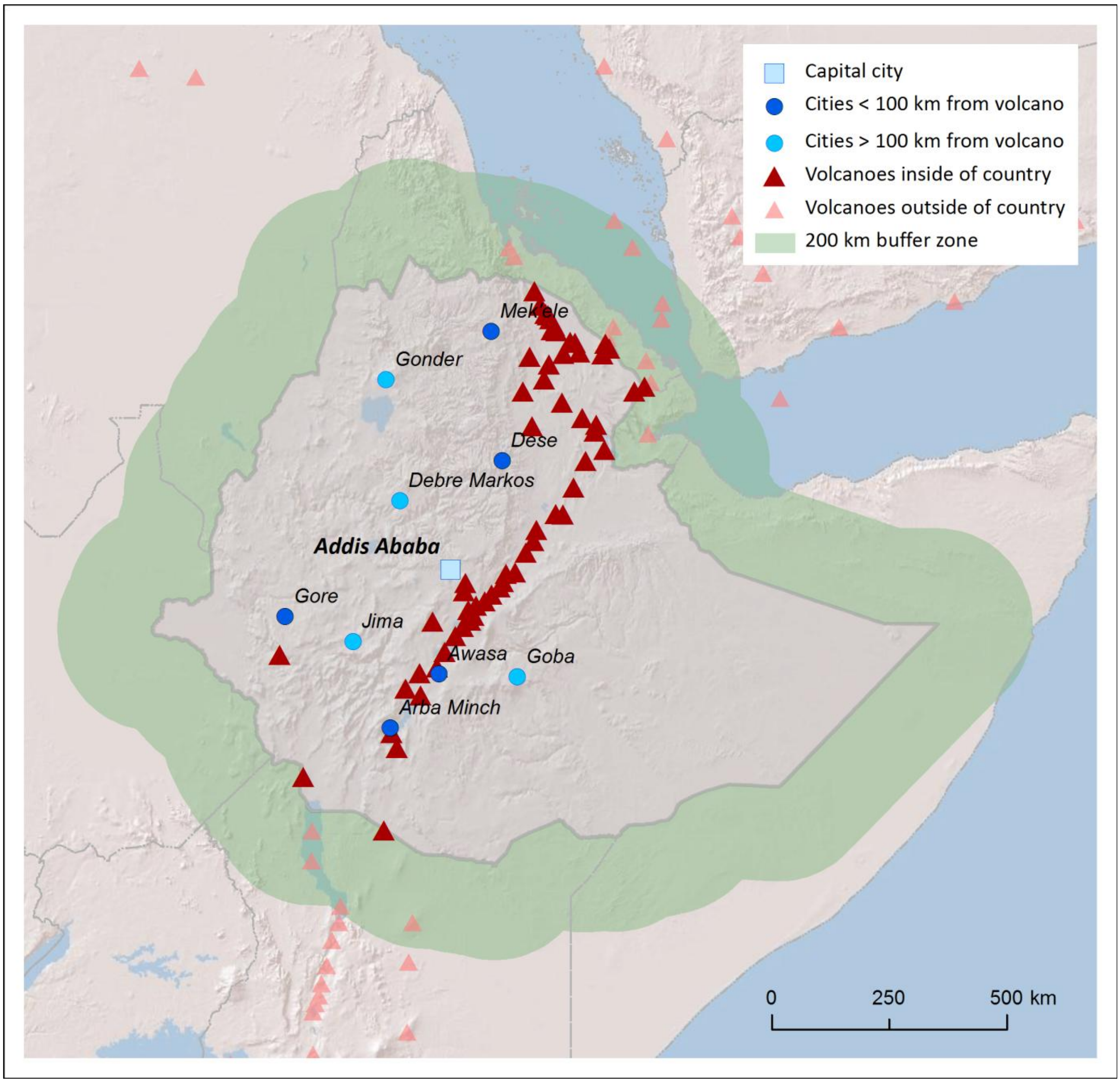


Figure 57: Location of Ethiopia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Ethiopia.

Fifty-nine Holocene volcanoes are known in Ethiopia. These form two distinct lines of volcanoes which can be seen within the East African rift. The first is the Main Ethiopian Rift, a northeast trending line that bisects the middle of the country, stretching from the Korath Range in the southwest to the Djibouti border in the northeast. The second line is oriented north northwest nearer the border with Eritrea and consists of a series of smaller lines of volcanoes in the area of the Afar Depression.

Like other countries in the East African Rift, Ethiopia has a high ratio of effusive to explosive volcano types, with thirty-one of the former and thirty-four of the latter. The single most common edifice type is the stratovolcano. However, each of the effusive volcano types may include a group of many volcanic vents spread along a line of fissures that may be tens of kilometres long.

Only seven of Ethiopia's volcanoes are currently known to have produced pyroclastic flows and none have triggered lahars. Lava flows are common, occurring at fifty-six of the volcanoes. The great prevalence of lava flows compared to other hazardous flows in Ethiopia reduces the relative hazard extent and impacts although the high incidence of volcanic gases and aerosols being released from such effusive eruptions adds a further hazardous element.

Seven of the country's ten most populous cities are more than 30 km from their nearest volcano. Ethiopia's numerous rural communities mean that twenty-five volcanoes have over 100,000 people living with a 30 km radius of their summit and 46.5% of the total population of Ethiopia lives within 100km of a volcano. The remote and sparsely populated area of the Ethiopian border near Nabro volcano still resulted in 32 fatalities and displacement of over 5000 people from the area. Rapid population growth and increasing investment in geothermal energy in the Main Ethiopian Rift mean that the exposure to volcanic hazards is rapidly increasing in Ethiopia and similar eruptions in the densely populated Main Ethiopian Rift will have considerable humanitarian and economic costs.

The distance of the country's main population centres from volcanoes and frequency of lava flows compared to other hazardous flows is reflected in the historic fatalities record; just three eruptions have records as reporting loss of life, with a combined total of 163 casualties. The greatest fatalities occurred in response to the Dubbi eruption from Eritrea in 1861.

The volcanic record is particularly poor in Ethiopia and there is no explicit eruptive history for forty-nine of Ethiopia's volcanoes. As such, under-reporting may downplay the level of hazard posed both in the past and at present.

Volcano Facts

Number of Holocene volcanoes	59, inclusive of two on the border with Eritrea, one on the border with Djibouti, one on the border with Kenya and one on the border with both Eritrea and Djibouti.
Number of Pleistocene volcanoes with M≥4 eruptions	4
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	9
Number of fatalities caused by volcanic eruptions	>65?
Tectonic setting	5 intra-plate, 54 rift zone

Largest recorded Pleistocene eruption	The M8 Awasa caldera formation at Corbetti caldera at 1 Ma.
Largest recorded Holocene eruption	The largest recorded Holocene eruption in Ethiopia occurred with the Caldera forming eruption at Fentale at 8 ka, at a magnitude of 5.5.
Number of Holocene eruptions	19 confirmed eruptions. 6 uncertain eruptions, 1 discredited eruption.
Recorded Holocene VEI range	0 – 3 and unknown.
Number of historically active volcanoes	11
Number of historical eruptions	17

Number of volcanoes	Primary volcano type	Dominant rock type
5	Caldera(s)	Basaltic (1), Rhyolitic (4)
21	Large cone(s)	Basaltic (6), Rhyolitic (14), Trachytic / Andesitic (1)
1	Lava dome(s)	Rhyolitic
11	Shield(s)	Basaltic (11)
21	Small cone(s)	Basaltic (16), Rhyolitic (2), Unknown (3)

Table 58: The number of volcanoes in Ethiopia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	92,256,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	979
Gross National Income (GNI) per capita (2005 PPP $)	1,017
Human Development Index (HDI) (2012)	0.396 (Low)

Population Exposure

Capital city	Addis Ababa
Distance from capital city to nearest Holocene volcano	41.5 km
Total population (2011)	90,873,739

Number (percentage) of people living within 10 km of a Holocene volcano	1,479,965 (1.6%)
Number (percentage) of people living within 30 km of a Holocene volcano	11,127,909 (12.3%)
Number (percentage) of people living within 100 km of a Holocene volcano	42,247,222 (46.5%)

The largest cities, as measured by population, and populations (from Statistical Agency of Ethiopia):

Addis Ababa	3.1 million
Mek'ele	286,000
Dire Dawa	269,000
Gonder	265,000
Awasa	225,000
Jima	155,000
Dese	153,000
Jigiga	152,000
Shashemene	129,000
Harar	112,000
Arba Minch	107,000

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	3,910
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes of Ethiopia stretch right across the country through the Eastern Rift Valley, including volcanoes on the borders with Eritrea, Djibouti and Kenya. With 59 volcanoes located here, a large part of the country lies within 100 km of these sites, including many major cities and the capital, Addis Ababa. Many roads lie within 100 km. The Addis Ababa Bole International Airport is affected, as is much of southern Djibouti and a port here.

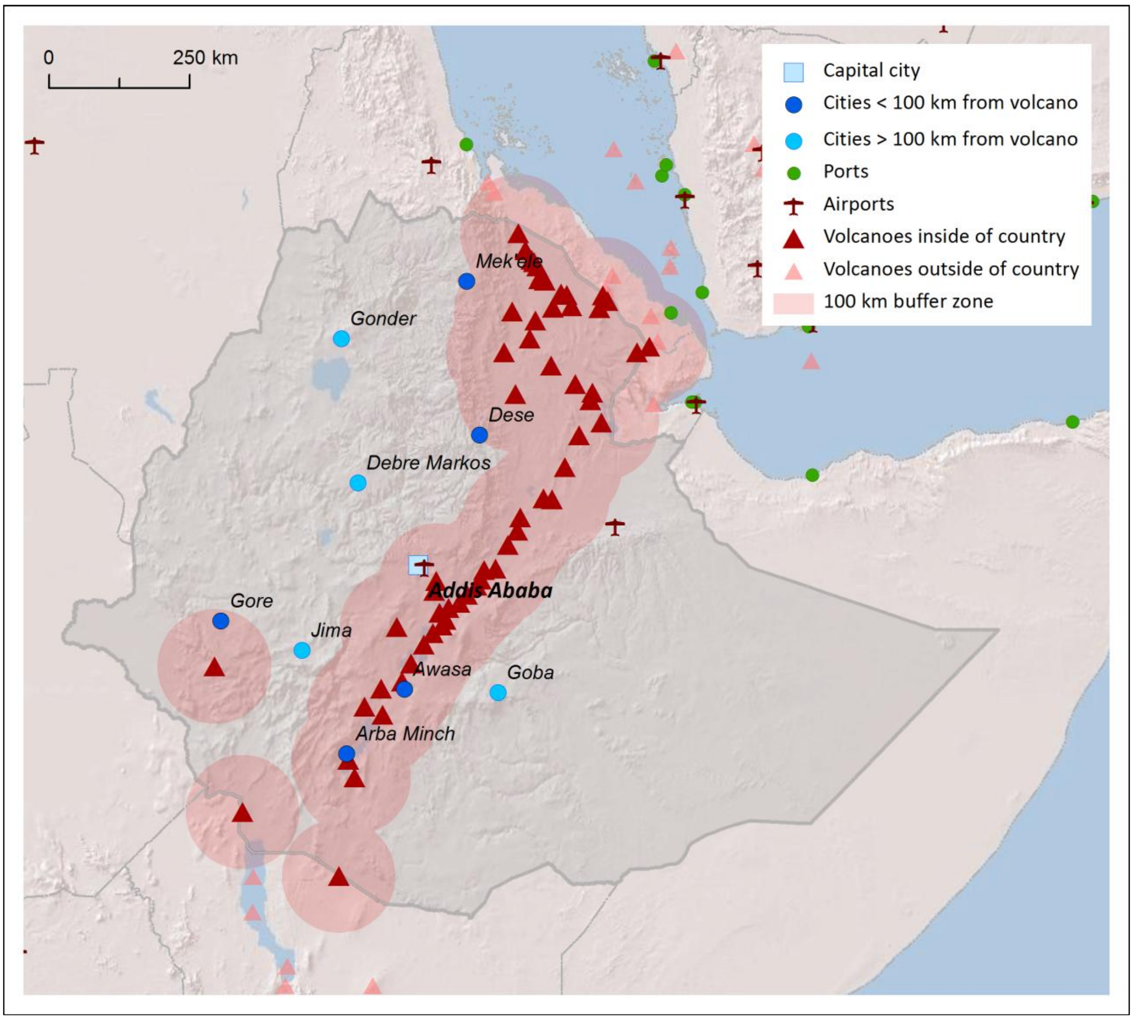


Figure 58: The location of Ethiopia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Of the 59 volcanoes in Ethiopia, just one, Erta Ale, has sufficient a record for calculation of a Hazard Level. Erta Ale has four eruptions recorded since 1900 AD, inclusive of the ongoing eruption which began in 1967. Activity at this volcano is dominantly effusive, and hence a Hazard Level of I is derived.

Hazard levels would be associated with high degrees of uncertainty at all other volcanoes in Ethiopia due to their sparse or incomplete eruption records. Ten of these unclassified volcanoes have records of historical eruptions (post 1500 AD), seven of which have experienced eruptions since 1900 AD. 47 volcanoes have no confirmed Holocene eruptions. These volcanoes are unclassified.

The PEI ranges from low to very high in Ethiopia, with most volcanoes classed at high PEIs of 5 to 7. With a moderate PEI of 3 at Erta Ale, this volcano is classed at Risk Level I. All other volcanoes are unclassified.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I			Erta Ale				
UNCLASSIFIED	**U – HHR**		**Dallol**; **Dalaffilla**; **Alayta**; **Manda Hararo;** **Manda-Inakir**	**Dabbahu**; Dama Ali	Fentale	Kone; **Tullu Moje**		
	U- HR					Alutu		
	U- NHHR		Gada Ale; Alu; Borale Ale; Ale Bagu; Hayli Gubbi; Mallahle; Sork Ale; Asavyo; Mat Ala; Tat Ali; Borawli; **Kurub**; Mousa Alli; Gabillema; Yangudi	Afderà; Dabbayra; Manda Gargori; Ayelu; Adwa; Hertali; Mega Basalt Field	Ma Alalta; Groppo; Liado Hayk; Dofen; Korath Range	Borawli; Beru; Boset-Bericha; Bora-Bericcio; Tepi; Chiracha; Unnamed	Unnamed; Gedamsa; Unnamed; East Zway; O'a Caldera; Tosa Sucha	Bishoftu Volcanic Field; Unnamed; Sodore; Butajiri-Silti Field; Corbetti Caldera; Bilate River Field; Hobicha Caldera
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 59: Identity of Ethiopia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Erta Ale	3	I

Table 60: Classified volcanoes of Ethiopia ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

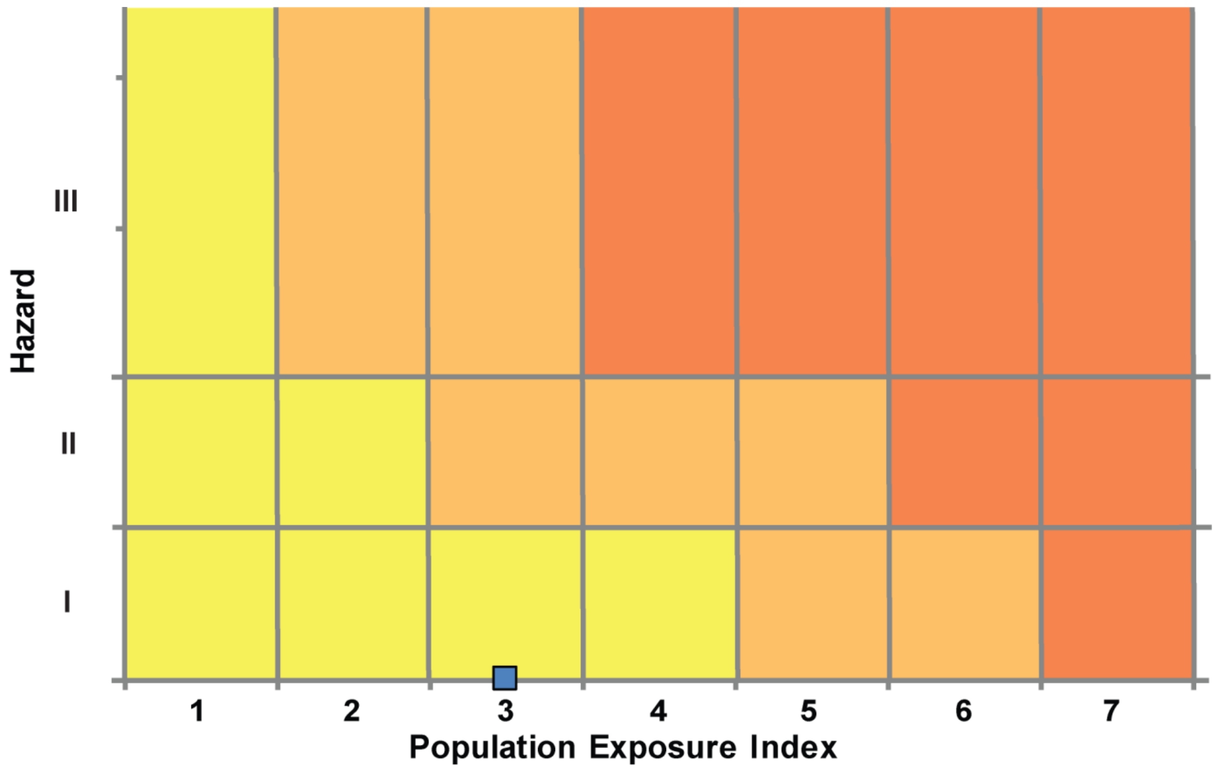


Figure 59: Distribution of Ethiopia's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The Institute of Geophysics, Space Science and Astronomy (IGSSA) of the Addis Ababa University (AAU) is responsible for the monitoring of volcanoes in Ethiopia. Eleven volcanoes here have historical records of activity. Of these, only Erta Ale has a classified risk level. No information is available at the time of the writing of this report to indicate that regular dedicated ground-based monitoring is in place at any of these volcanoes.

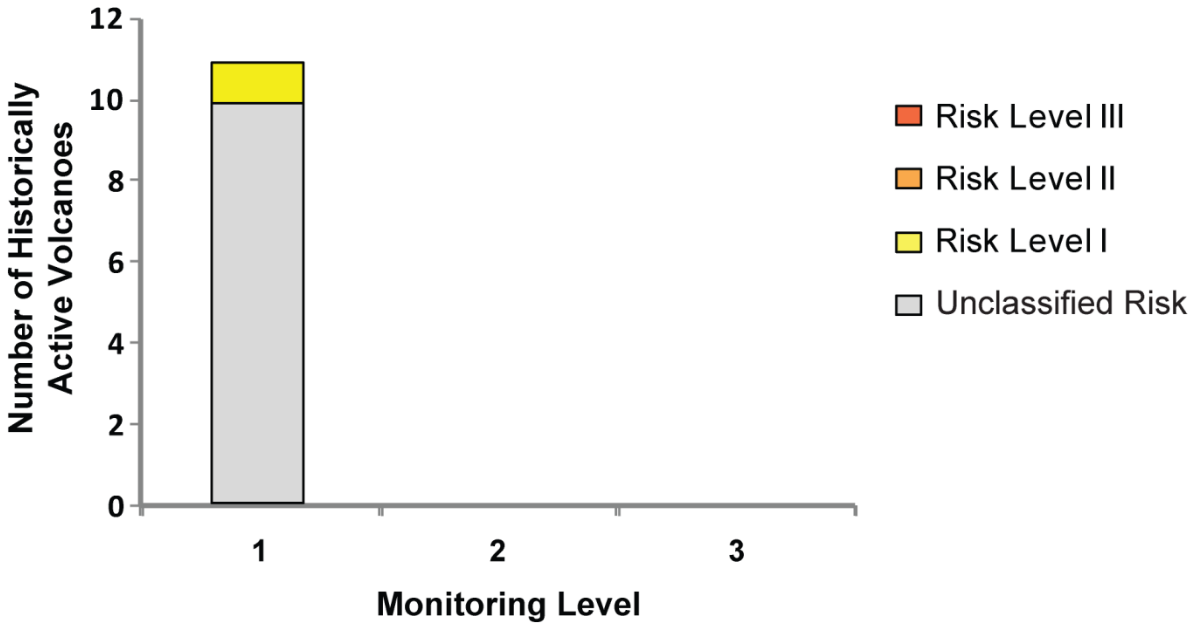


Figure 60: The monitoring and risk levels of the historically active volcanoes in Ethiopia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Kenya

Description

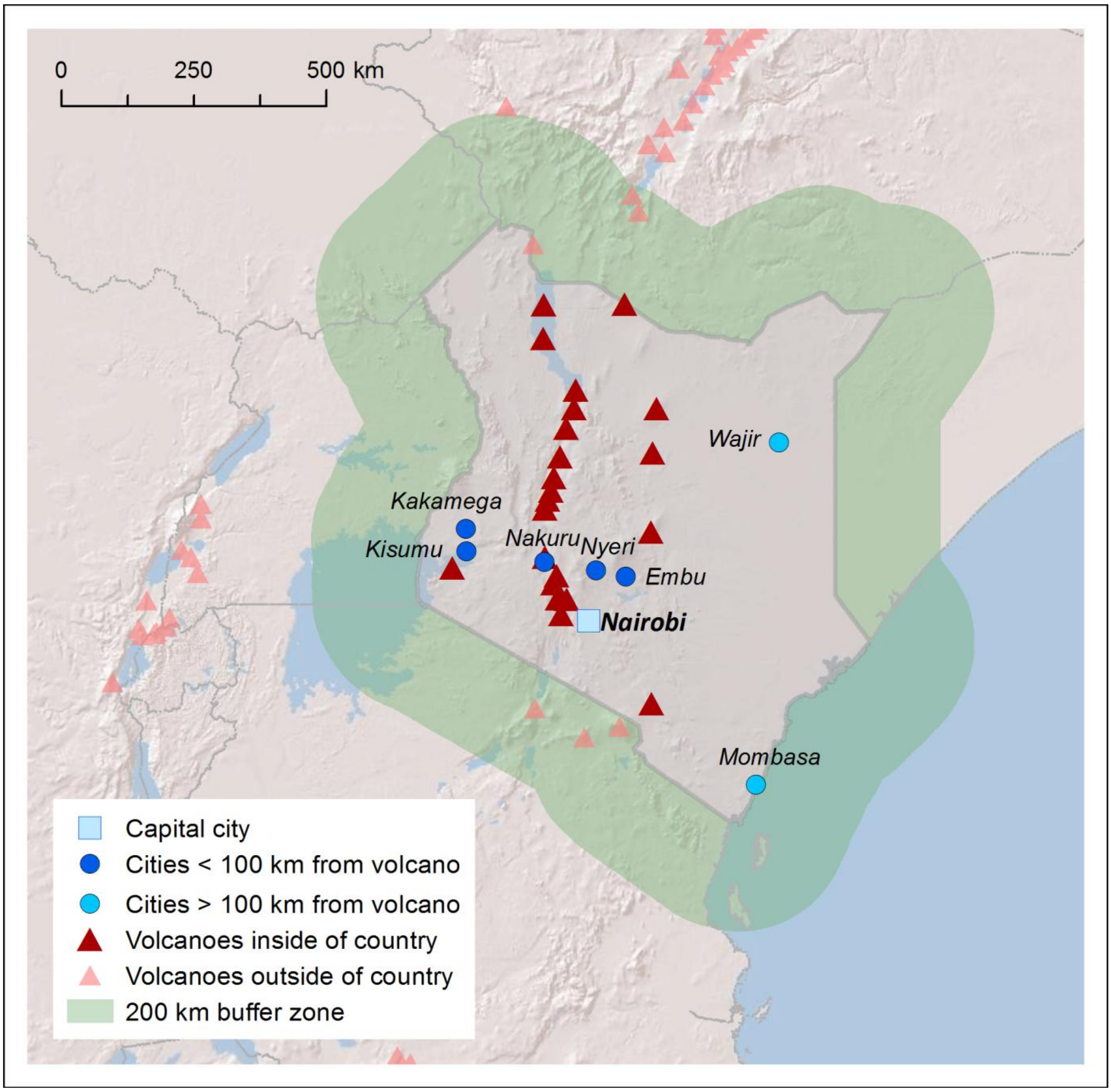


Figure 61: Location of Kenya's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Kenya.

Kenya has 21 Holocene volcanoes plus one on the border with Ethiopia, the Mega Basalt Field. The majority lie along the Rift Valley in a roughly N-S orientation, while five of them (Segererua Plateau, Marsabit, Nyambeni Hills and Chyulu Hills) lie to the east and one (Homa Mountain) lies to the west of the Rift Valley. Eleven of the volcanoes are basaltic to trachytic shield volcanoes, while the others comprise stratovolcanoes, pyroclastic cones, tuff cones, pumice cones and a volcanic field. Only two are felsic in composition: the rhyolitic Ol Doinyo Eburru volcanic complex, along the Rift Valley, south of Nakuru; and the Olkaria pumice cone, approximately 29 km SE of Ol Doinyo Eburru.

Only six of the volcanoes have recorded historical eruptions. The last know eruptions of these are: Olkaria in 1770; Chyulu Hills in 1855; Longonot in 1863; South Island in 1888; Emuruangogolak in 1919; and The Barrier in 1921.

Olikaria is a felsic volcanic complex comprising up to 80 individual centres within an 11 km wide caldera formed c.20,000 years ago that produced welded ignimbrites. The youngest known eruption was in 1770, producing a pumice cone and a lava flow that travelled c.5 km to SW. Olkaria is a large (50 km^2) high-temperature geothermal field.

The Chyulu Hills volcanic field is c.150 km east of the Rift Valley in southern Kenya, and comprises several hundred small cones and lava flows, including numerous recent cinder cones. The Holocene cones are found in the SE of the volcanic field. The most recent eruptions occurred in the mid-19th Century from two cinder cones, Shaitani and Chainu.

Longonot is a trachytic stratovolcano located in the Gregory Rift, SE of Lake Naivasha. Longonot comprises a 8×12 km caldera, formed c.21,000 years ago, within which sits a large central cone. According to Masai records, the last known eruption occurred from a satellite cone on the NE flank of the volcano in the 19th Century.

South Island is the largest and southernmost of the three volcanic islands in Lake Turkana in northern Kenya. The island comprises basaltic lava flows that erupted from a 11 km long N-S trending fissure, and a tuff cone. The last known eruption was in 1888, when eruption from a scoria cone was observed.

Emuruangogolak is a broad shield volcano in the Gregory Rift Valley. A 5 km wide summit caldera formed c.38,000 years ago. Trachytic and basaltic lava flows have since erupted on the northern and southern flanks, and within the caldera. Parasitic cones also erupted along rift-parallel faults that intersected the volcano. The last know eruption occurred in 1910, producing a trachytic lava flow. Active fumaroles occur along NNE trending fissures within the caldera and along the lower NW flanks.

The Barrier is the most recently active of Kenya's volcanoes, with its last known eruption recorded in 1921, which produced basaltic lava flows. The Barrier volcanic complex comprises four overlapping shield volcanoes. The youngest one lies over the axis of the East African Rift. Early Holocene scoria cones and lava flows erupted on the youngest volcano's southern and northern flanks.

Shompole (also Shombole) volcano lies on the border with Tanzania, at the northern end of Lake Natron. No Holocene activity is recorded at this volcano, however recent increased seismicity has been recorded in the area. A temporary seismic network has been installed to monitor this activity.

Volcano Facts

Number of Holocene volcanoes	22, inclusive of one on the border with Ethiopia
Number of Pleistocene volcanoes with M≥4 eruptions	8

Number of volcanoes generating pyroclastic flows	3
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	5
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Rift-zone
Largest recorded Pleistocene eruption	The M6.8 eruption of Menengai at 12,345 BP with the Ruplax Tuff eruption.
Largest recorded Holocene eruption	The M6.8 Caldera 2 eruption of Menengai is the largest recorded eruption in Kenya during the Holocene, occurring at 8985 BP.
Number of Holocene eruptions	34 confirmed eruptions. 3 uncertain eruptions.
Recorded Holocene VEI range	0 – 6 and unknown.
Number of historically active volcanoes	6
Number of historical eruptions	12

Number of volcanoes	Primary volcano type	Dominant rock type
4	Large cone(s)	Basaltic (1), Foiditic (1), Rhyolitic (1), Trachytic / Andesitic (1)
11	Shield(s)	Basaltic (4), Phonolitic (1), Trachytic / Andesitic (6)
7	Small cone(s)	Andesitic (1), Basaltic (5), Rhyolitic (1)

Table 61: The number of volcanoes in Kenya, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	43,323,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	1,507
Gross National Income (GNI) per capita (2005 PPP $)	1,541
Human Development Index (HDI) (2012)	0.519 (Low)

Population Exposure

Capital city	Nairobi
Distance from capital city to nearest Holocene volcano	53.3 km
Total population (2011)	41,943,504
Number (percentage) of people living within 10 km of a Holocene volcano	568,572 (1.4%)
Number (percentage) of people living within 30 km of a Holocene volcano	3,968,357 (9.5%)
Number (percentage) of people living within 100 km of a Holocene volcano	29,950,855 (71.4%)

Largest cities, as measured by population, and populations:

Nairobi	2,750,547
Mombasa	799,668
Nakuru	259,903
Kisumu	216,479
Kakamega	63,426
Nyeri	51,084
Wajir	45,771
Embu	34,922

Infrastructure Exposure

Number of airports within 100 km of a volcano	3
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	3,395
Total length of railroads within 100 km of a volcano (km)	763

Many of Kenya's volcanoes are located in the Rift Valley stretching roughly north to south across the country, whilst others are located east and west of this and on the border with Ethiopia. The number of volcanoes here means that a large portion of the country lies within 100 km of a volcano, including five of the largest cities in Kenya and the capital, Nairobi. As such, much of the critical infrastucture here is within 100 km of the volcanoes, inclusive of three airports and an extensive road and rail network. Being located inland, the volcanoes are distal to the ports on the Kenya coastline, though Homa Mountain lies on the shore of Lake Victoria. Areas of Ethiopia, Tanzania and Uganda lie within 100 km of the Kenyan volcanoes.

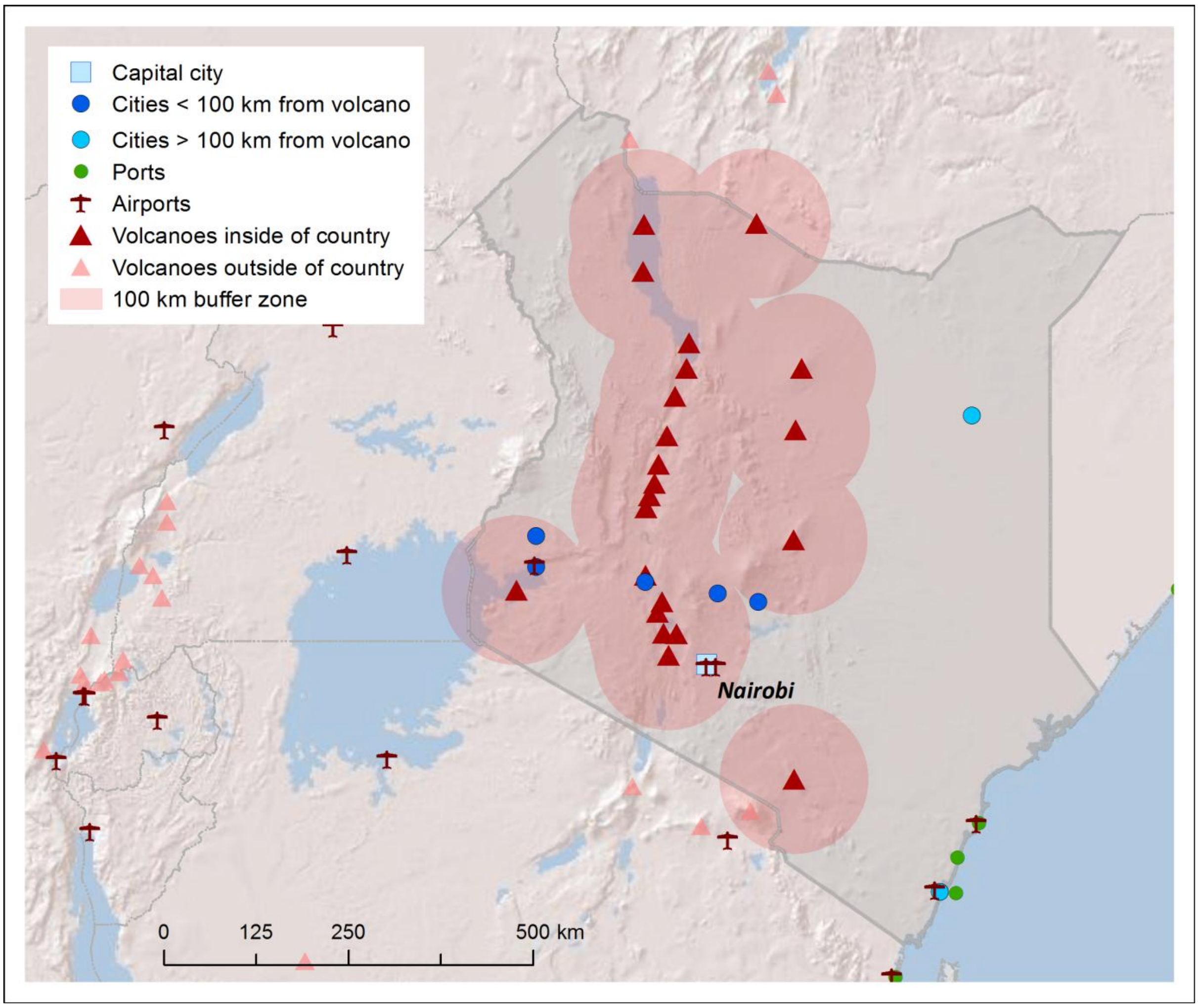


Figure 62: The location of Kenya's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

With the exception of The Barrier, all volcanoes in Kenya have eruption records which are too sparse to use to determine a Hazard Level without significant uncertainties. These are therefore unclassified in both hazard and risk. Of these unclassified volcanoes, twelve have no confirmed Holocene eruptions. Five have historical (post 1500 AD) eruptions, including a 1910 eruption at Emuruangogolak. The Barrier has an extensive Holocene and historical record of eruptions of a known size, and the hazard is therefore calculated. The low explosivity of this volcano in part results in the assignment of Hazard Level I.

PEI ranges from low to high in Kenya, with most volcanoes categorised at moderate and high PEIs.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I		The Barrier					
UNCLASSIFIED	**U – HHR**		South Island; **Emuruangogolak**		Chyulu Hills	Olkaria; Longonot		
	U- HR		Namarunu	Silali; Paka			Menengai	
	U- NHHR		North Island; **Central Island**	Mega Basalt Field; Segererua Plateau	Marsabit; Korosi; Ol Kokwe; Suswa	Homa Mountain; Eburru, Ol Doinyo	Nyambeni Hills; Elmenteita Badlands	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 62: Identity of Kenya's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Barrier, The	2	I

Table 63: Classified volcanoes of Kenya ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

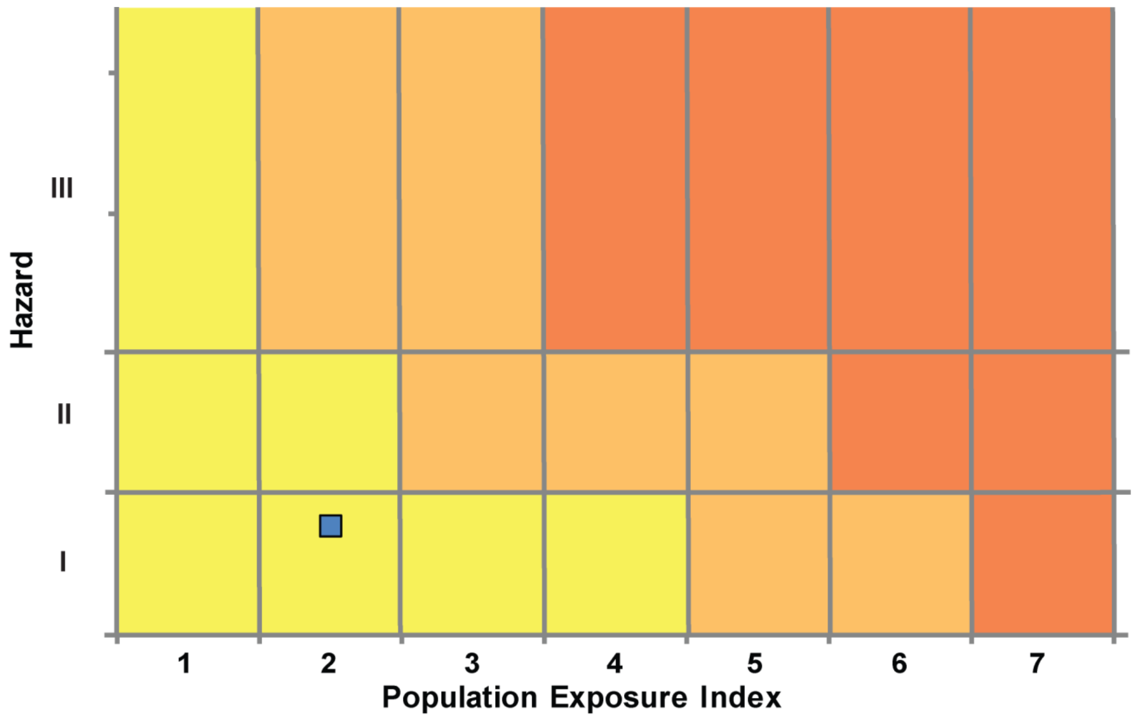


Figure 63: Distribution of Kenya's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Six volcanoes have historical eruption records in Kenya. No information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any of the volcanoes in Kenya.

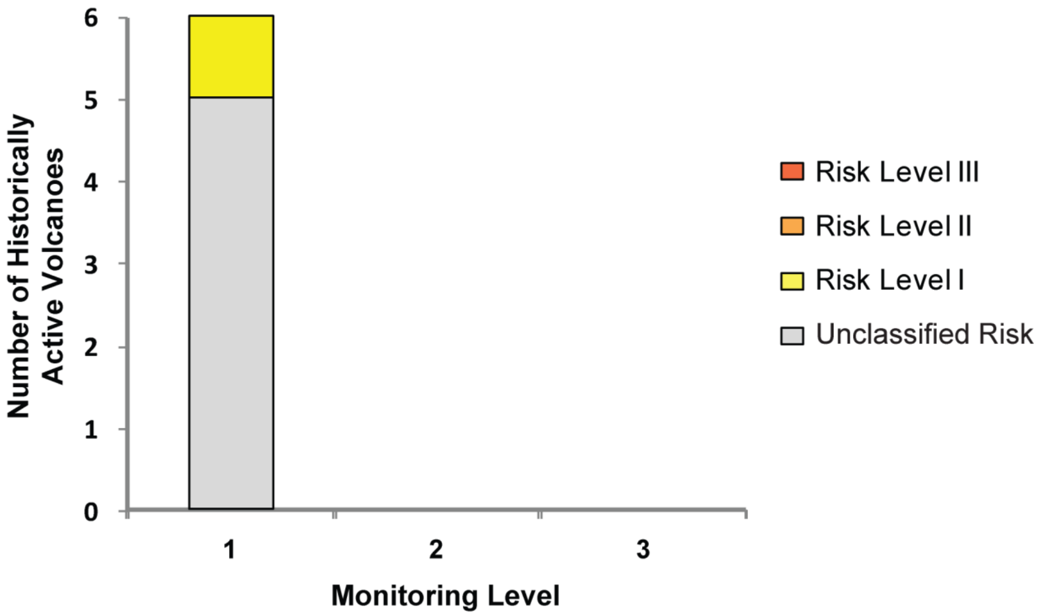


Figure 64: The monitoring and risk levels of the historically active volcanoes in Kenya. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Libya

Description

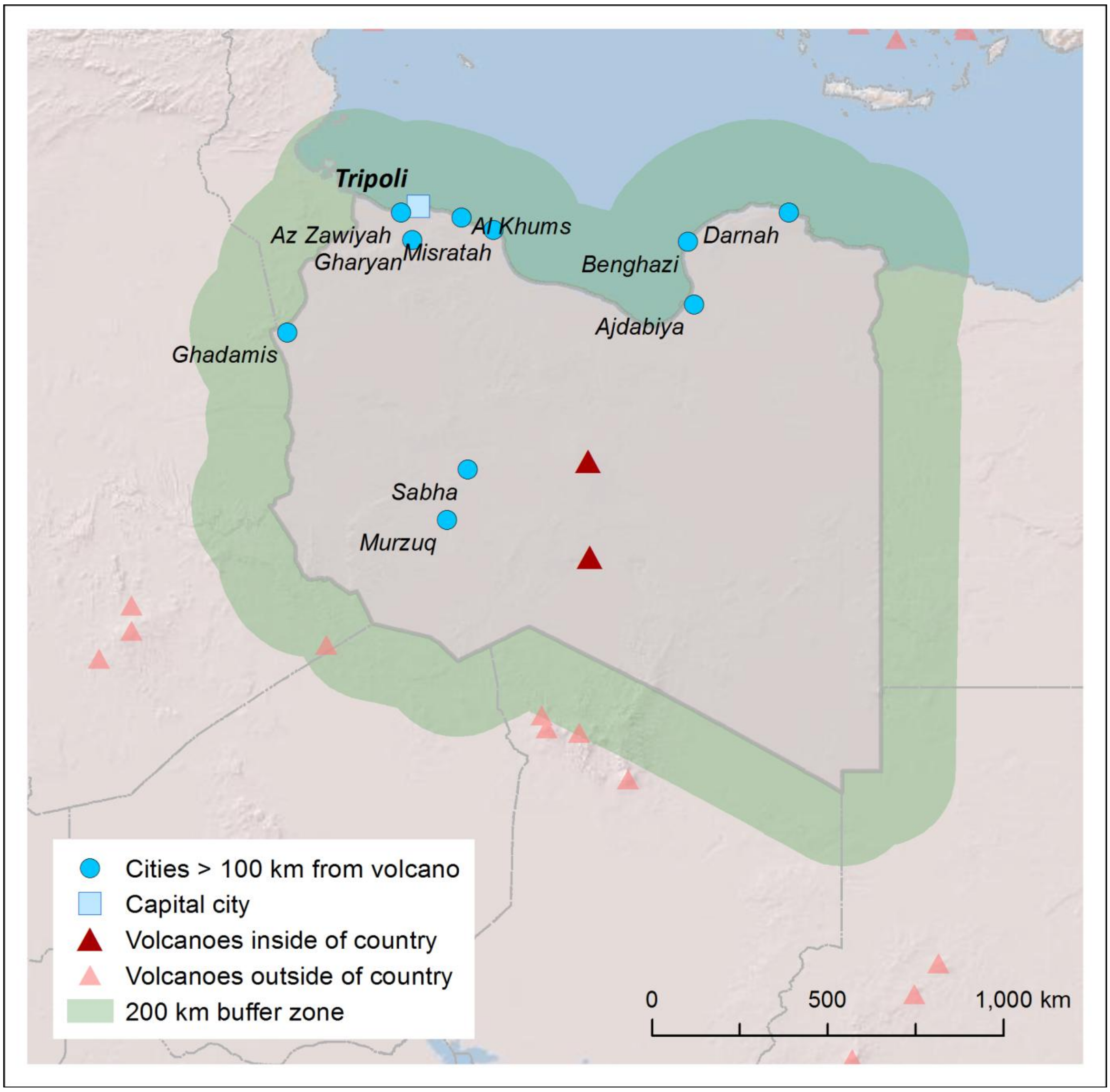


Figure 65: Location of Libya's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Libya.

Two Holocene volcanoes are located in the centre of Libya. These volcanoes are related to intra-plate processes.

The Haruj volcano is a basaltic volcanic field comprising numerous basaltic scoria cones, lava flows and explosion craters. The Wau-en-Namus volcano comprises a caldera and post-caldera basaltic scoria cone. Neither volcanoes have a record of Holocene eruptions, but both are considered to have had Holocene activity.

Both Libyan volcanoes are remote with fewer than 100 people living within 30 km of these volcanoes. Just over 2,000 people live within the 100 km radii. Assessment of hazard at these volcanoes is poorly constrained due to the absence of a detailed eruptive history.

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	-
Number of Holocene eruptions	-
Recorded Holocene VEI range	-
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
1	Caldera(s)	Basaltic (1)
1	Small cone(s)	Basaltic (1)

Table 64: The number of volcanoes in Libya, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	6,175,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	15,361
Gross National Income (GNI) per capita (2005 PPP $)	13,765
Human Development Index (HDI) (2012)	0.769 (High)

Population Exposure

Capital city	Tripoli
Distance from capital city to nearest Holocene volcano	444.2 km
Total population (2011)	6,597,960
Number (percentage) of people living within 10 km of a Holocene volcano	2 (<1%)

Number (percentage) of people living within 30 km of a Holocene volcano	98 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	2,193 (<1%)

Ten largest cities, as measured by population, and populations:

Benghazi	650,629
Misratah	386,120
Al Khums	201,943
Ajdabiya	134,358
Darnah	78,782
Murzuq	43,732
Az Zawiyah	4,917
Ghadamis	<50,000
Gharyan	<50,000
Sabha	<50,000

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	248
Total length of railroads within 100 km of a volcano (km)	0

Haruj and Wau-en-Namus volcanoes are located in central Libya. Being inland volcanoes, none of the ports along the northern coastline lie within 100 km. Many of the largest cities, including the capital Tripoli are concentrated along the coast, and as such are distal to the volcanoes. Indeed, no large settlements or infrastructure are located within 100 km of these remote volcanoes.

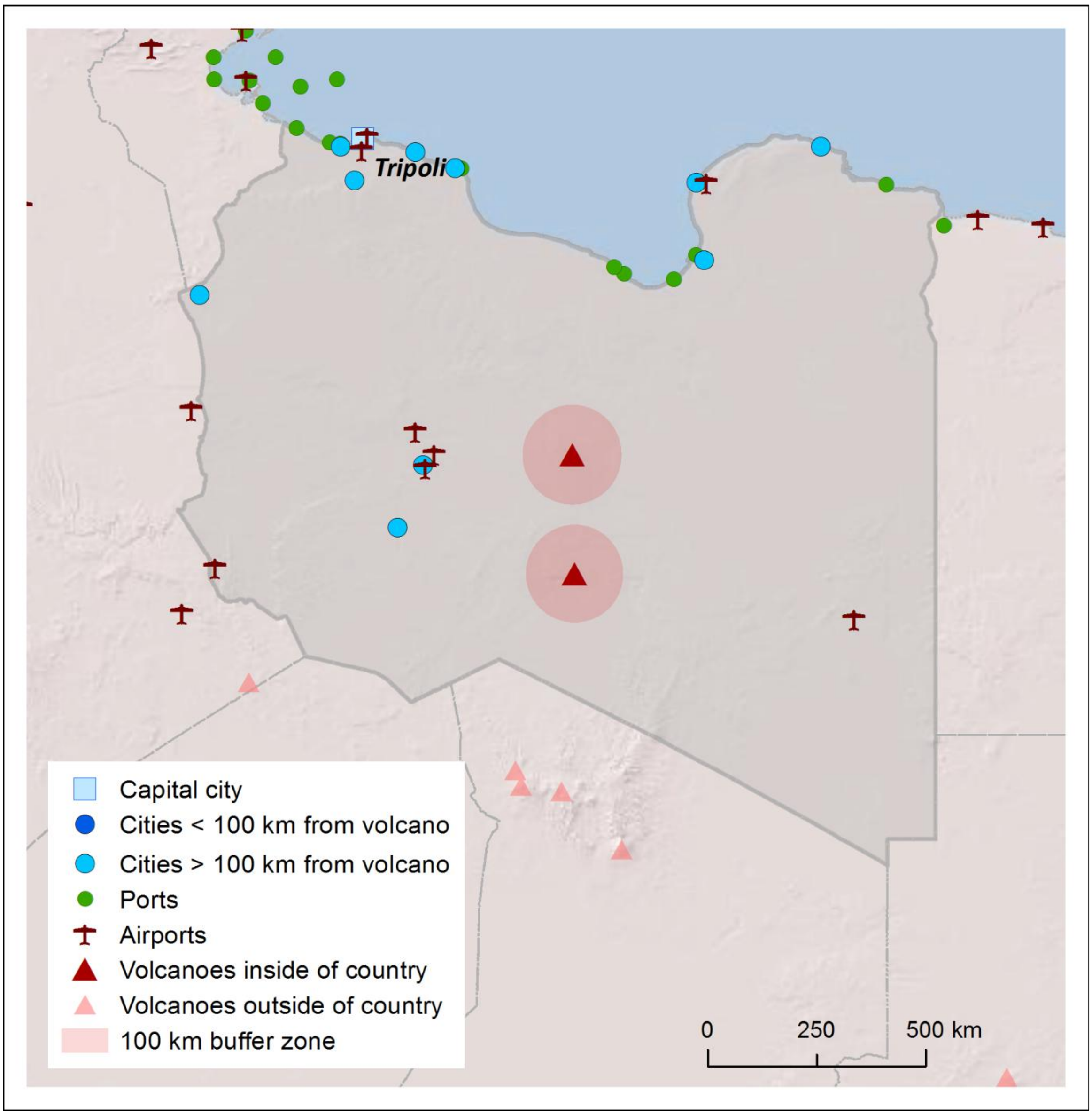


Figure 66: The location of Libya's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Neither of the volcanoes in Libya have confirmed Holocene eruptions. Without a comprehensive eruptive history, the hazard cannot be calculated and these volcanoes are therefore unclassified in both hazard and risk. The PEI at Libya's volcanoes is low, at PEI 2.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR							
	U- NHHR		Haruj; Wau-en-Namus					
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 65: Identity of Libya's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Libya have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Libya.

Mali

Description

One Holocene volcano is identified in Mali, located close to the border with Algeria and Niger. This volcano is related to intra-plate hot spot processes.

The Tin Zaouatene Volcanic Field is a small, basaltic volcanic field. No eruptions are recorded in the Holocene, however Holocene activity is suspected.

Only a very small population live within 100 km of this volcano, as much of the infrastructure and population in Mali is located in the south of the country, distal to this volcano, and therefore minimal risk is indicated here. However, the hazard is poorly constrained with the absence of an eruptive history. The 100km radius of this volcano extends beyond the borders into Algeria.

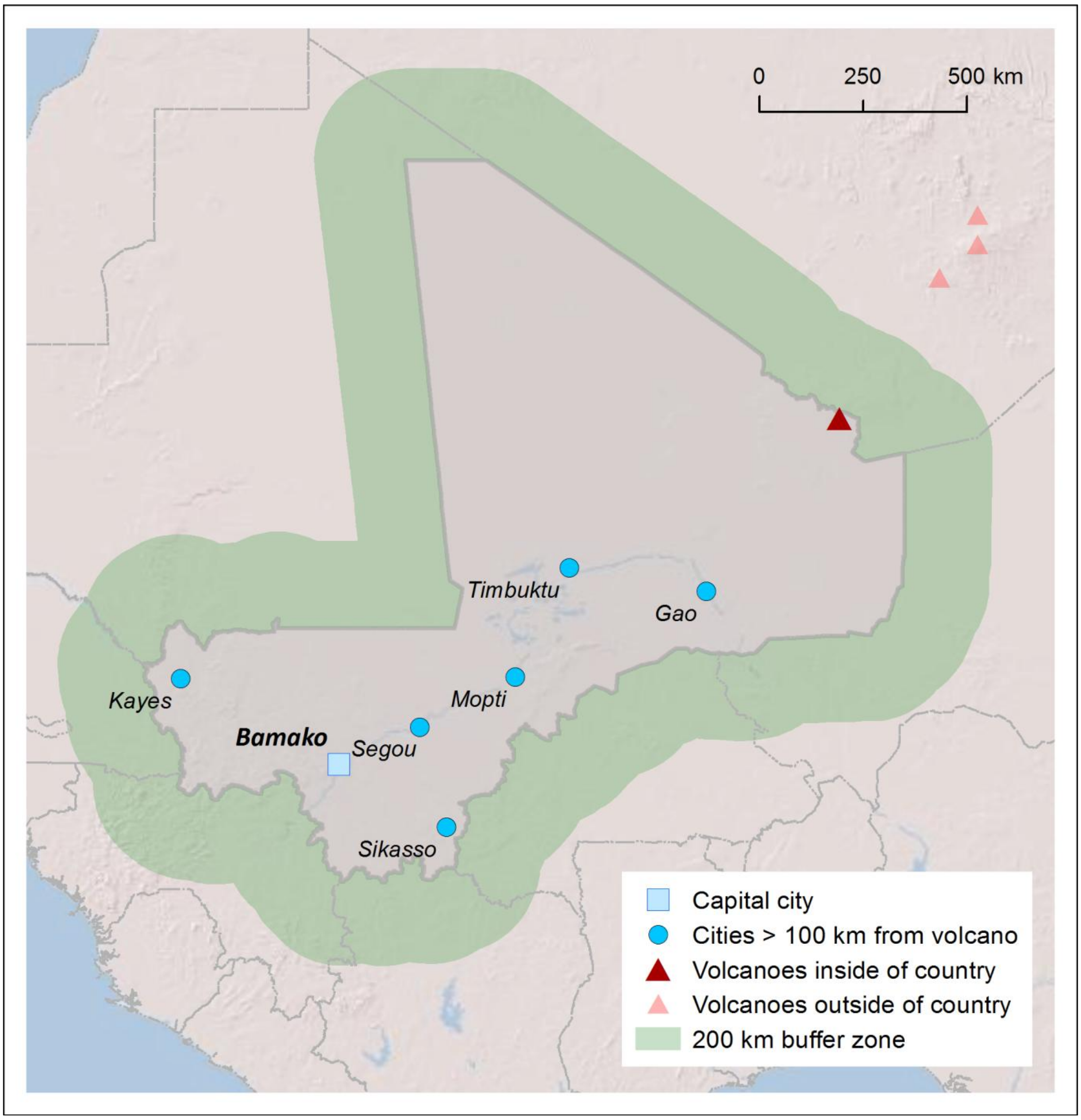


Figure 67: Location of Mali's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Mali.

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	-
Number of Holocene eruptions	-
Recorded Holocene VEI range	-
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
1	Small cone(s)	Basaltic (1)

Table 66: The number of volcanoes in Mali, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	14,850,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	964
Gross National Income (GNI) per capita (2005 PPP $)	853
Human Development Index (HDI) (2012)	0.344 (Low)

Population Exposure

Capital city	Bamako
Distance from capital city to nearest Holocene volcano	1404.2 km
Total population (2011)	14,159,904
Number (percentage) of people living within 10 km of a	101 (<1%)

Holocene volcano

Number (percentage) of people living within 30 km of a Holocene volcano	661 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	5,159 (<1%)

Largest cities, as measured by population, and populations:

Bamako	1,297,281
Sikasso	144,786
Mopti	108,456
Kayes	97,464
Segou	92,552
Gao	57,978
Timbuktu	32,460

Infrastructure Exposure

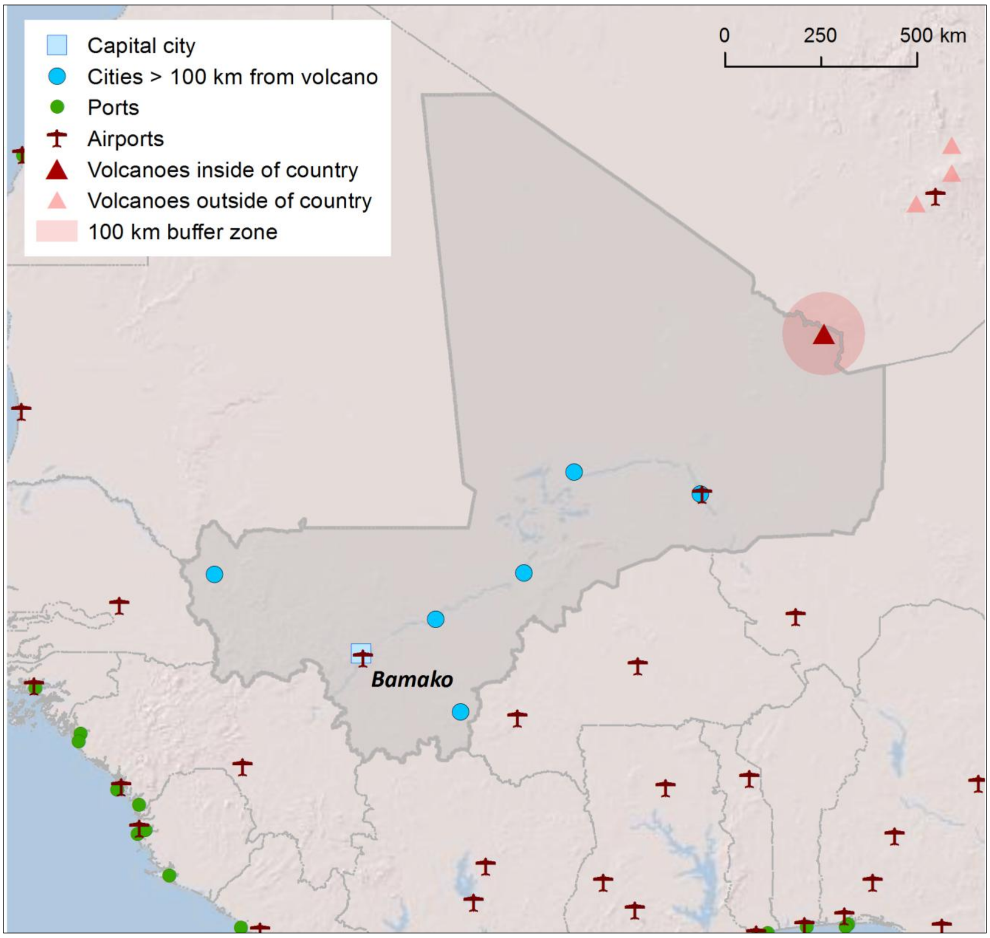


Figure 68: The location of Mali's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

Much of the infrastructure and population of Mali is located in the south of the country, with the Sahara desert making up much of northern Mali. As such, with the Tin Zaouatene Volcanic Field lying in the north on the border with Algeria, much of the critical infrastructure of Mali, including the largest cities and the capital, Bamako, lie distal to the volcano.

Hazard, Uncertainty and Exposure Assessments

The Tin Zaouatene Volcanic Field has no confirmed Holocene eruptions recorded in VOTW4.22. The absence of a detailed eruption history means that the hazard level cannot be calculated and therefore this volcano is unclassified in both hazard and risk. There is a small population living within 100 km of the Tin Zaouatene Volcanic Field, categorising this volcano at PEI 2.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR		Tin Zaouatene Volcanic Field					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 67: Identity of Mali's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Mali have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Mali.

Niger

Description

Two Holocene volcanoes are located in Niger. The Todra Volcanic Field is located in central Niger whilst the In Ezzane Volcanic Field lies on the border with Algeria. Both these volcanoes are related to intra-plate processes.

Both volcanic systems comprise small cones of basaltic composition; extensive lava flows surround the Todra cones. No Holocene eruptions are recorded at either volcanoes, however Holocene activity is suspected.

Only a very small population lives within 30 km of these volcanoes, however, the city of Agadez of over 128,000, lies within 100 km of the Todra Volcanic Field. The assessment of hazard is poorly constrained due to the absence of a detailed eruptive history.

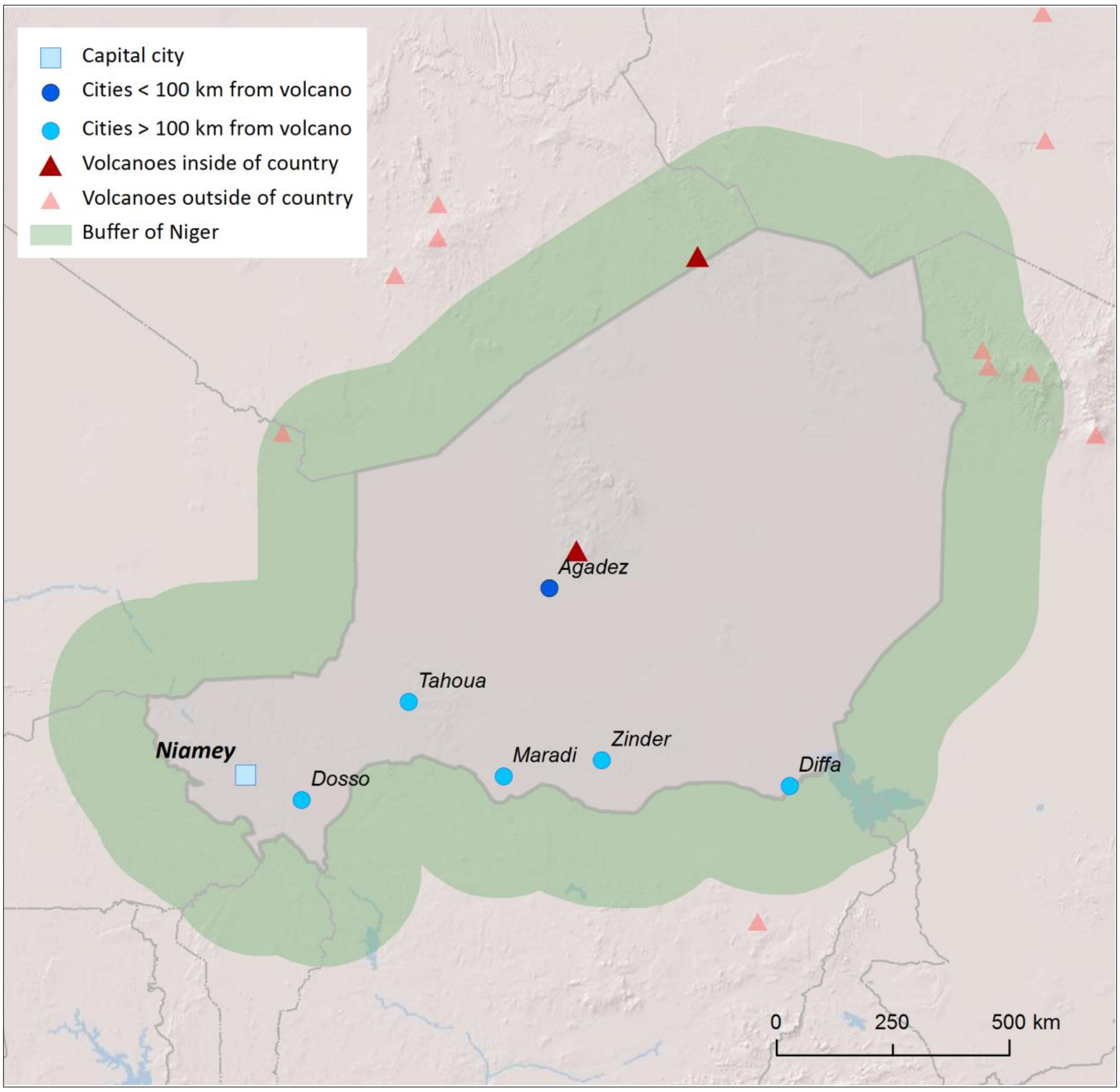


Figure 69: Location of Niger's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Niger.

Volcano Facts

Number of Holocene volcanoes	2, inclusive of one on the border with Algeria
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	-
Number of Holocene eruptions	-
Recorded Holocene VEI range	-
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
2	Small cone(s)	Basaltic (2)

Table 68: The number of volcanoes in Niger, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	17,153,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	642
Gross National Income (GNI) per capita (2005 PPP $)	701
Human Development Index (HDI) (2012)	0.304 (Low)

Population Exposure

Capital city	Niamey
Distance from capital city to nearest Holocene volcano	705.7 km

Total population (2011)	16,468,886
Number (percentage) of people living within 10 km of a Holocene volcano	87 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	1,704 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	199,595 (1.2%)

Largest cities, as measured by population, and populations:

Niamey	774,235
Zinder	191,424
Maradi	163,487
Agadez	128,324
Tahoua	80,425
Dosso	49,750
Diffa	27,948

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	114
Total length of railroads within 100 km of a volcano (km)	0

Much of the population and infrastructure in Niger is located in the south-west, away from the centrally located Todra Volcanic Field. However, the largest city in northern Niger, Agadez, lies within 100 km of this volcanic field.

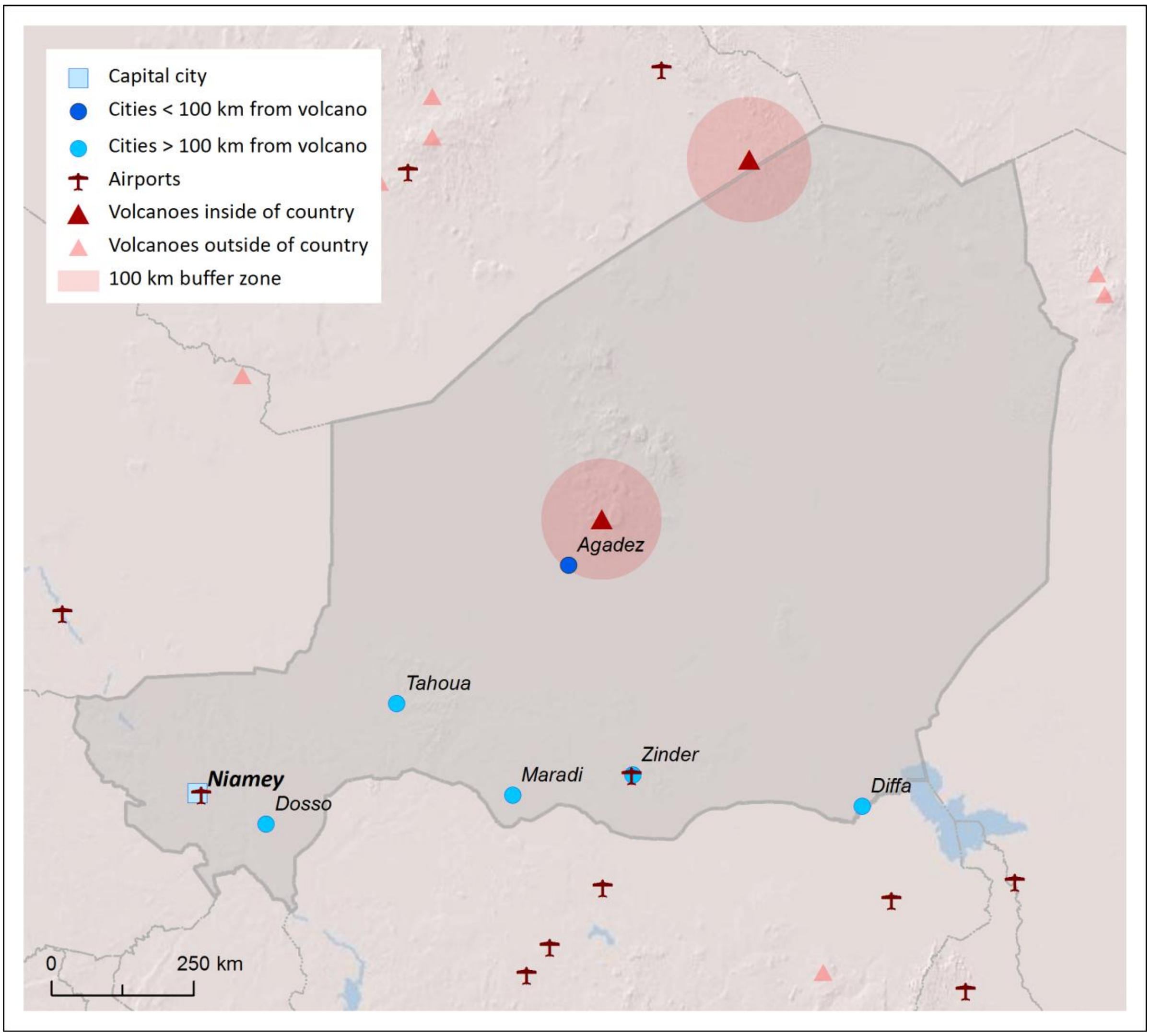


Figure 70: The location of Niger's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Neither the Todra Volcanic Field or the In Ezzane Volcanic Field have confirmed Holocene eruptions. This absence of a comprehensive eruption history means that the hazard level cannot be calculated and both the hazard and risk at these volcanoes are therefore unclassified.

The population within 30 km at both Niger volcanoes is small, growing to nearly 150,000 at the 100 km radius at the Todra Volcanic Field. The small proximal population categorises these volcanoes at PEI 2.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR							
	U- NHHR		Todra Volcanic Field; In Ezzane Volcanic Field					
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 69: Identity of Niger's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Niger have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Niger.

Nigeria

Description

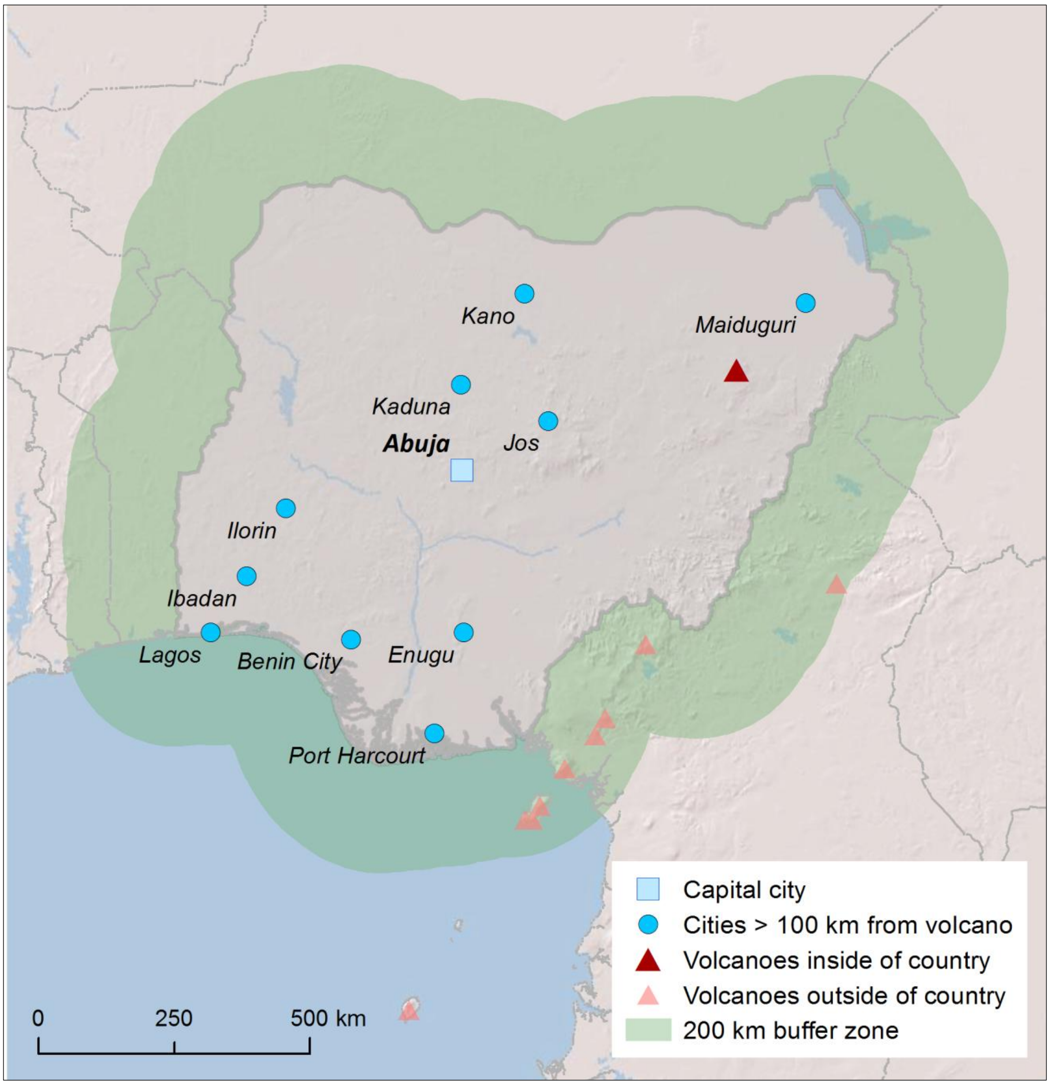


Figure 71: Location of Nigeria's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Nigeria.

One Holocene volcano is located in Nigeria, in the north-east of the country. The Biu Plateau is related to intra-plate processes and comprises a number of basaltic cinder cones and lava flows. No Holocene eruptions are recorded, however Holocene activity is suspected here.

None of the largest cities in Nigeria lie within 100 km of Biu Plateau, however, over 60,000 people live within 10 km of this volcano, rising to over 2 million within 100 km. Further population is exposed in the south-east of the country, as the 100 km radii of volcanoes in Cameroon extend a short distance into Nigeria.

The absence of a detailed eruptive history means hazard assessment here is poorly constrained and a risk level cannot be assigned, however there is a large proximal population who would be at risk from eruptive activity.

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	-
Number of Holocene eruptions	-
Recorded Holocene VEI range	-
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
1	Small cone(s)	Basaltic (1)

Table 70: The number of volcanoes in Nigeria, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	168,815,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	2,221
Gross National Income (GNI) per capita (2005 PPP $)	2,102
Human Development Index (HDI) (2012)	0.471 (Low)

Population Exposure

Capital city	Abuja
Distance from capital city to nearest Holocene volcano	462.6 km
Total population (2011)	165,822,569

Number (percentage) of people living within 10 km of a Holocene volcano	19,975 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	236,766 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	3,623,354 (2.2%)

Ten largest cities, as measured by population, and populations:

Lagos	9,000,000
Kano	3,626,068
Ibadan	3,565,108
Kaduna	1,582,102
Port Harcourt	1,148,665
Benin City	1,125,058
Maiduguri	1,112,449
Jos	816,824
Ilorin	814,192
Enugu	688,862

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	835
Total length of railroads within 100 km of a volcano (km)	216

The Biu Plateau volcano in north-eastern Nigeria is distal to the largest cities in Nigeria, including the capital, Abuja, which lies nearly 500 km away. Being an inland volcano, the ports and oilrigs along the southern coastline of the country are distal to this volcano and in fact lie closer to the volcanoes of Cameroon. Whilst no airports or ports are described within 100 km of the Biu Plateau, a road and rail network is affected and multiple towns are located within 100 km.

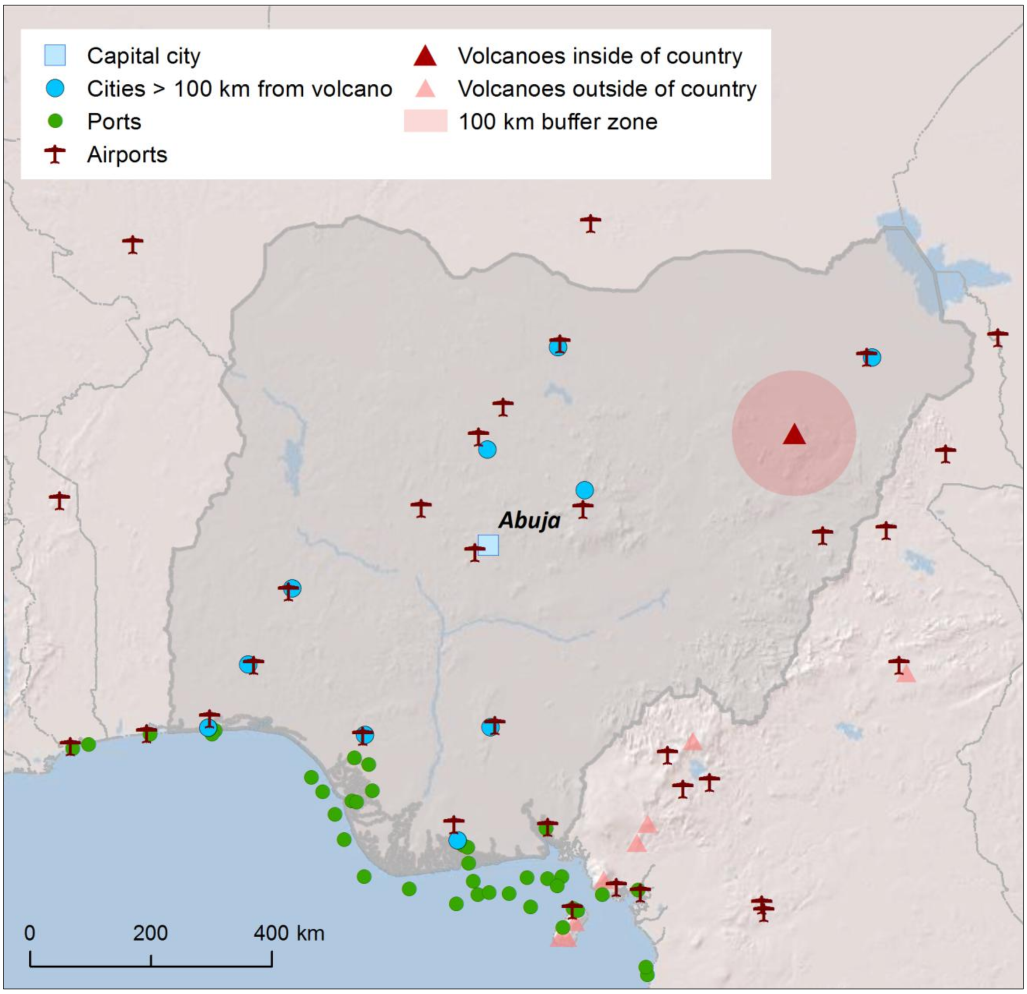


Figure 72: The location of Nigeria's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The Biu Plateau volcano in Nigeria has no confirmed Holocene eruptions. Without a comprehensive eruption history, an assessment of hazard cannot be undertaken and this volcano is unclassified in both hazard and risk.

The local population is quite large, with over 60,000 living within 10 km of this volcano and over 2 million within 100 km. The Biu Plateau is therefore categorised with a high PEI of 5.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR					Biu Plateau		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 71: Identity of Nigeria's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Nigeria have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Nigeria.

Rwanda

Description

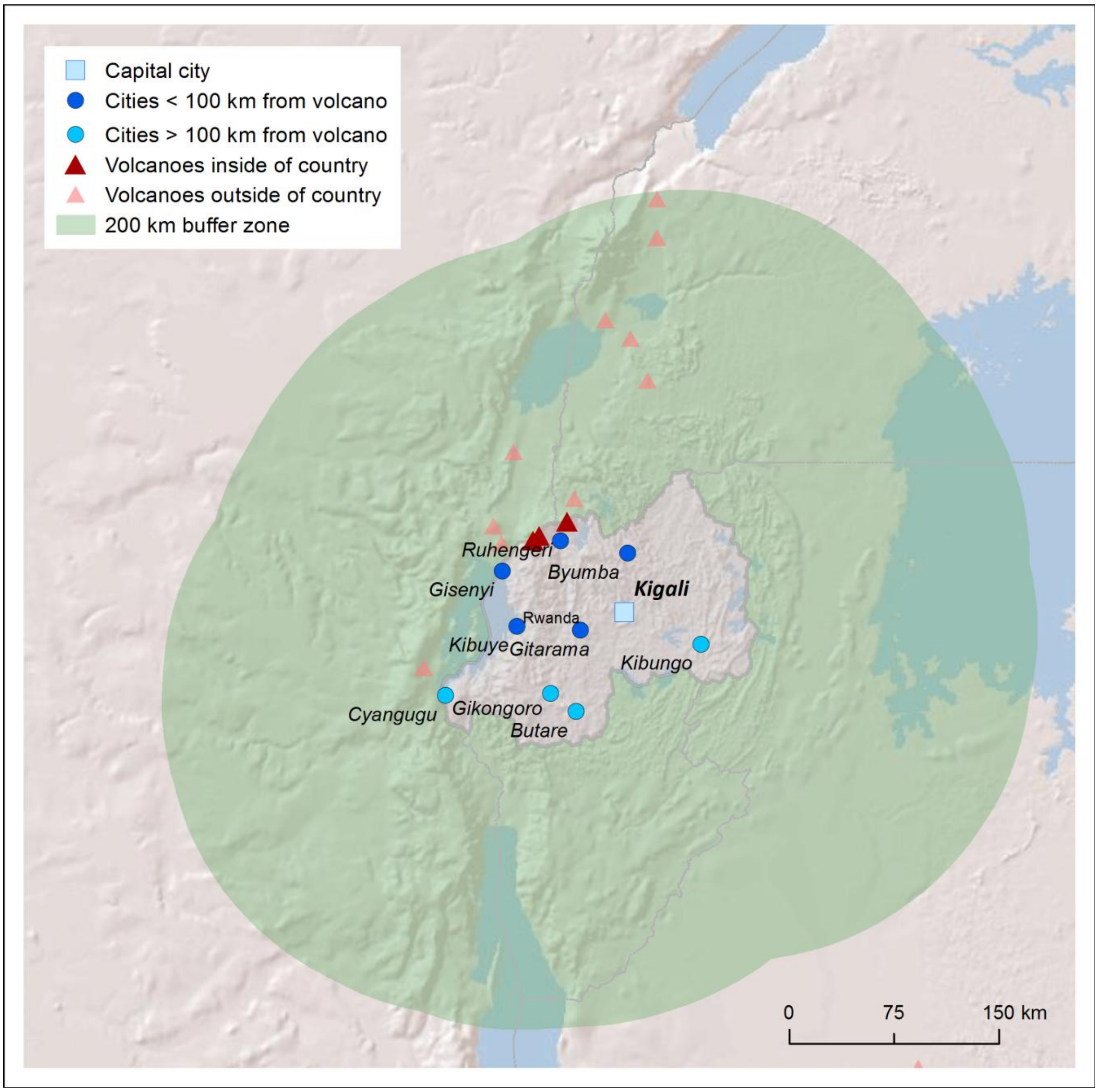


Figure 73: Location of Rwanda's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Rwanda.

Rwanda has three Holocene volcanoes: Karisimbi and Visoke which are on the border with the Democratic Republic of Congo (DRC), and Muhavura which is on the border with Uganda. All three are trachy-basaltic to trachy-andesitic stratovolcanoes belonging to the Virunga Range in the East Africa Rift Valley.

Muhavura is at the NE end of the Virunga Range, and is characterised by basanitic to trachyandesitic lavas. It has a 40 m wide lake in its summit crater. The last eruption of Muhavura is unknown; however, a small parasitic crater has been recently active.

Karisimbi is the highest of the Virunga Range, and is the southernmost of the Rwandan volcanoes. It comprises a trachy-basaltic stratovolcano with a 2 km wide caldera SE of the summit and a c.1.2 km wide crater south of the summit. The caldera is filled with lava flows and two explosion craters are apparent. A broad plain comprising lava flows and a chain of parasitic cones extends SW to the shores of Lake Kivo in DRC. The youngest eruptions of Karisimbi volcano formed parasitic vents east of the summit, which fed lava flows that travelled up to 12 km to the east. The last known eruption of Karisimbi was 8050 BC.

Visoke is a symmetrical stratovolcano with a 450 m wide crater lake. It lies 6.5 km to the NE of Karisimbi along the Virunga Range. The last known eruption occurred in 1957 forming two small cones on the northern flank of Visoke, 11 km from the summit. There is only one previous known historic eruption in 1891. Numerous cinder cones lie along a NE-SW trending fissure zone NE of Visoke.

Volcano Facts

Number of Holocene volcanoes	3, inclusive of two on the border with the DRC and one on the border with Uganda
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	2
Number of fatalities caused by volcanic eruptions	50?
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The VEI 1 eruption of Visoke in 1957.
Number of Holocene eruptions	3 confirmed eruption
Recorded Holocene VEI range	1 and unknown.
Number of historically active volcanoes	1
Number of historical eruptions	2

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
3	Large cone(s)	Andesitic (1), Basaltic (2)

Table 72: The number of volcanoes in Rwanda, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	11,507,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	1,097
Gross National Income (GNI) per capita (2005 PPP $)	1,147
Human Development Index (HDI) (2012)	0.434 (Low)

Population Exposure

Capital city	Kigali
Distance from capital city to nearest Holocene volcano	76.5 km
Total population (2011)	11,370,425
Number (percentage) of people living within 10 km of a Holocene volcano	275,793 (2.4%)
Number (percentage) of people living within 30 km of a Holocene volcano	1,935,583 (17%)
Number (percentage) of people living within 100 km of a Holocene volcano	8,808,864 (77.5%)

Ten largest cities, as measured by population, and populations:

Kigali	745,261
Butare	89,600
Gitarama	87,613
Ruhengeri	86,685
Gisenyi	83,623
Byumba	70,593
Cyangugu	63,883
Kibuye	48,024
Kibungo	46,240
Gikongoro	<50,000

Infrastructure Exposure

Number of airports within 100 km of a volcano	2

Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	768
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes of Rwanda are located on the borders with Uganda and the DRC. Being only a small country, measuring less than 300 km across, much of the country lies within 100 km of these volcanoes, including several of the largest cities and the capital, Kigali. This places critical infrastructure within this radius, including the Kigali International Airport and an extensive road network. The radii of these border volcanoes also affect the DRC and Uganda.

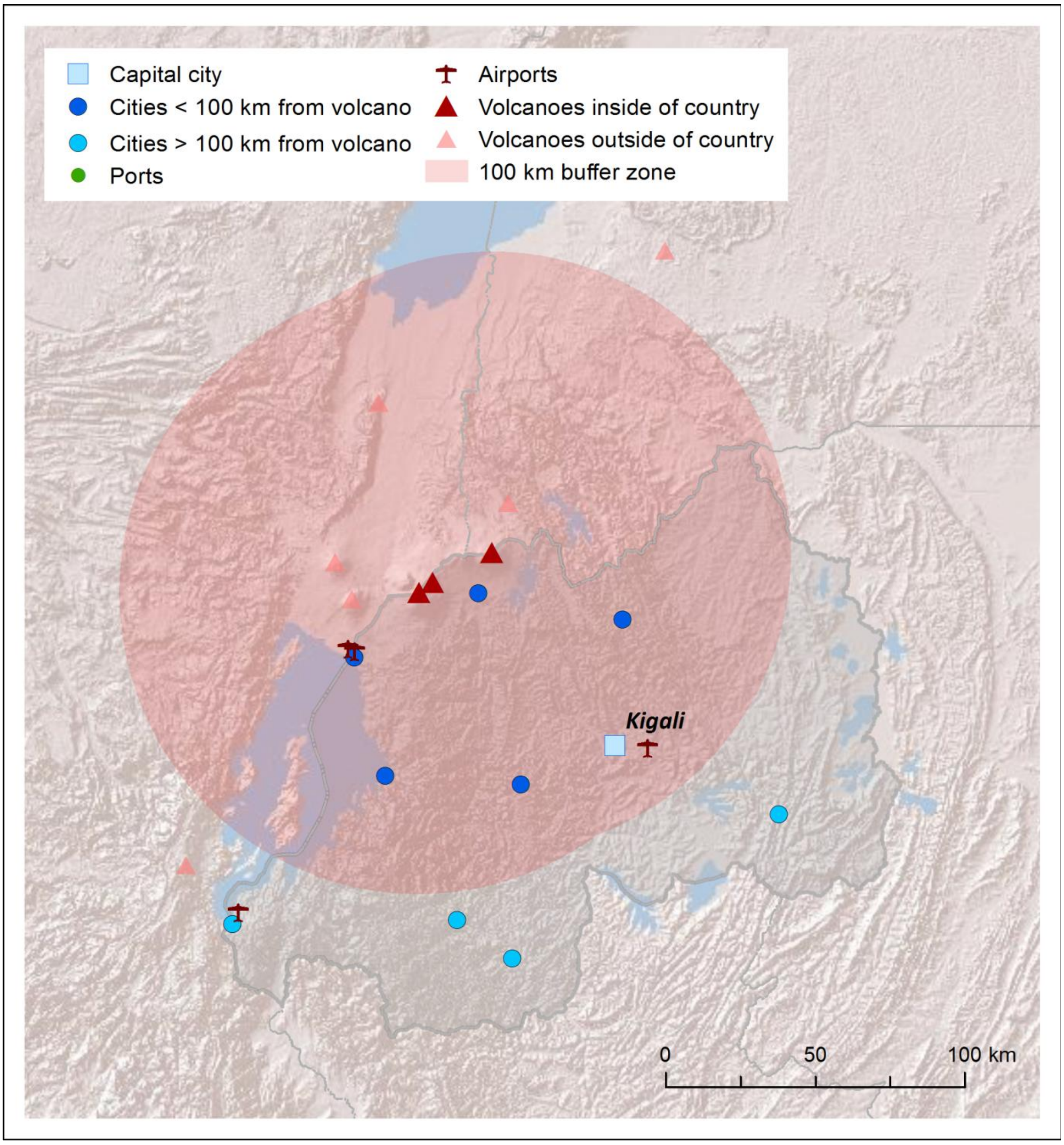


Figure 74: The location of Rwanda's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

All three volcanoes in Rwanda have a high degree of uncertainty associated with the classification of the Hazard Index due to the absence of extensive eruption histories. These volcanoes are therefore unclassified. Of the three volcanoes, only Visoke has a historical record of eruptions, with eruptions as recently as 1957. Karisimbi has a Holocene eruption record, but Muhavura has no confirmed Holocene eruptions.

There is a large local population at all three volcanoes on Rwanda's borders, with over 80,000 within 10 km at Karisimbi and Visoke, and nearly 200,000 within 10 km of Muhavura. This categorises these volcanoes at a high PEI of 6. These high local populations indicate Risk Levels of II to III would be applicable dependent on the hazard.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**						Visoke	
	U- HR						Karisimbi	
	U- NHHR						Muhavura	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 73: Identity of Rwanda's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Just Visoke on the border with the DRC has records of historical activity. In the DRC the Goma Volcano Observatory would have responsibility for this volcano, though at the time of the writing of this report no information is available to indicate that regular dedicated ground-based monitoring is undertaken at this unclassified volcano.

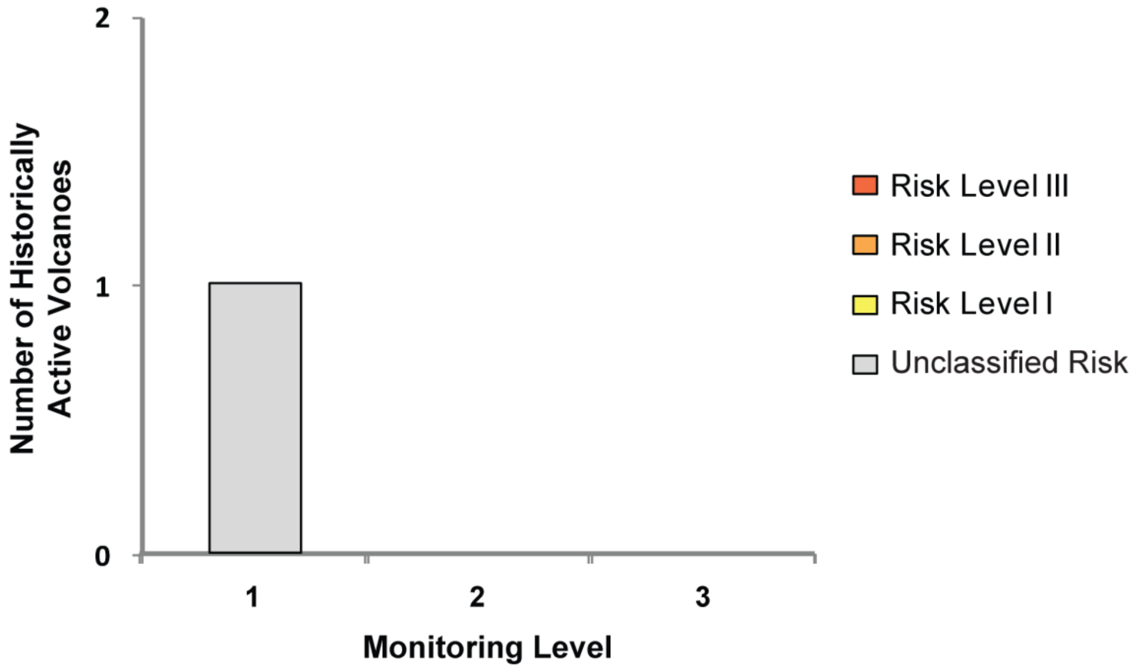


Figure 75: The monitoring and risk levels of the historically active volcanoes in Rwanda. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Sao Tome and Principe

Description

One Holocene volcano is located in the country of Sao Tome and Principe. Sao Tome volcano is located on the island of the same name, the largest island in the country. This volcano is a basaltic shield, related to intra-plate processes.

No Holocene eruptions are recorded, however activity of a Holocene age is suspected. The absence of a detailed eruptive history means that assessment of hazard here has large associated uncertainties.

Sao Tome island measures abound 50 km across, with only a small population located on the Principe islands distal to Sao Tome, therefore nearly 100% of the population of Sao Tome and Principe lies within 100 km of the Sao Tome volcano.

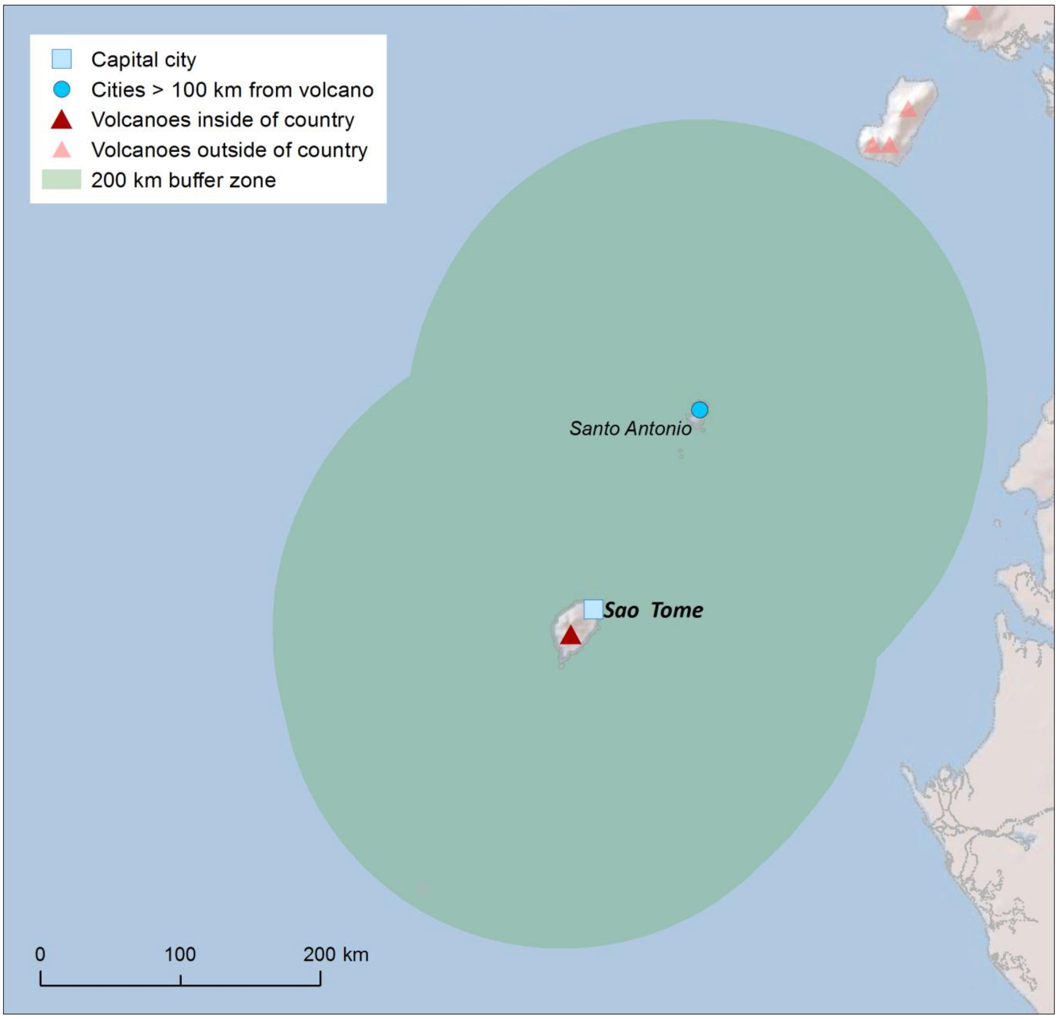


Figure 76: Location of Sao Tome and Principe's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Sao Tome.

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	-
Number of Holocene eruptions	-
Recorded Holocene VEI range	-
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
1	Shield(s)	Basaltic (1)

Table 74: The number of volcanoes in Sao Tome and Principe, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	189,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	1,805
Gross National Income (GNI) per capita (2005 PPP $)	1,864
Human Development Index (HDI) (2012)	0.525 (Low)

Population Exposure

Capital city	São Tomé
Distance from capital city to nearest Holocene volcano	24.4 km
Total population (2011)	179,506

Number (percentage) of people living within 10 km of a Holocene volcano	7,887 (4.4%)
Number (percentage) of people living within 30 km of a Holocene volcano	175,005 (97.5%)
Number (percentage) of people living within 100 km of a Holocene volcano	175,005 (97.5%)

Largest cities, as measured by population, and populations:

Sao Tome	53,300
Santo Antonio	12,529

Infrastructure Exposure

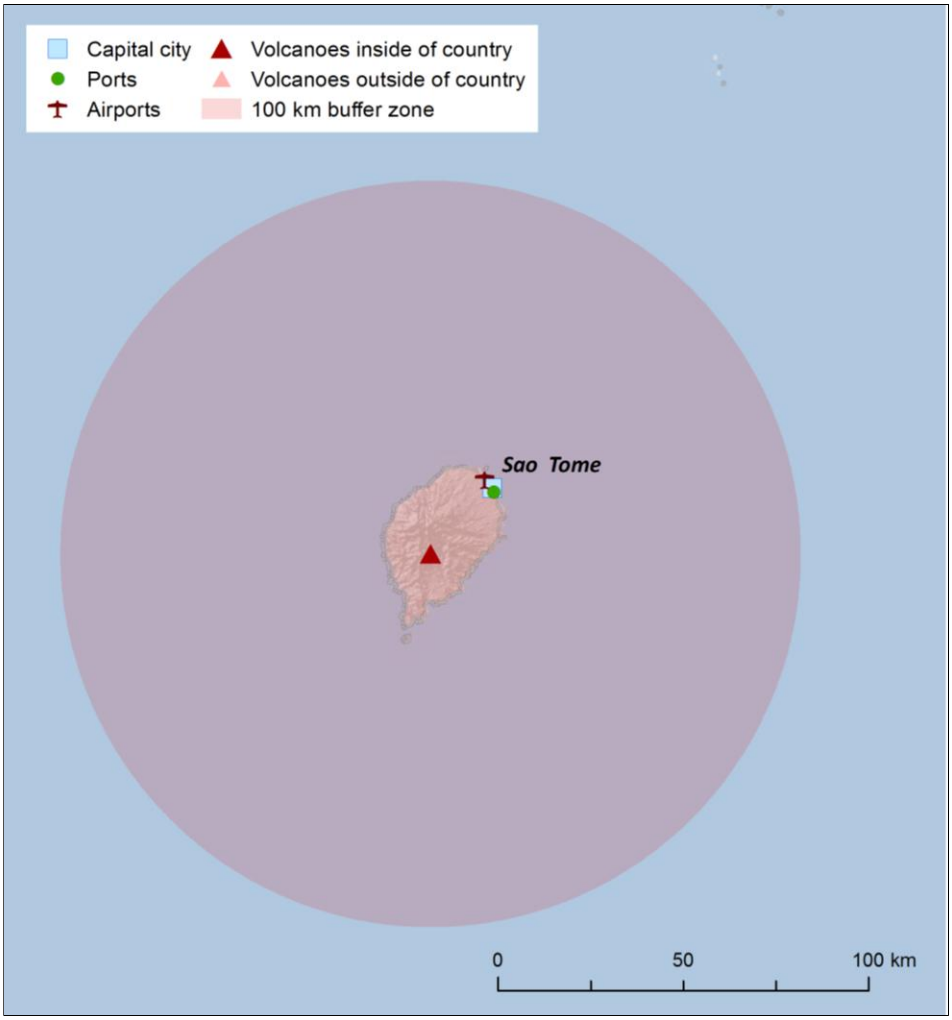


Figure 77: The location of Sao Tome and Principe's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	2
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The island Sao Tome, the largest island in Sao Tome and Principe is a volcanic island, comprising the large shield volcano Sao Tome. Being a small island, all infrastructure lies in its entirety within the 100 km radius and hence is exposed. The 100 km radius does not extend to the other islands of this country.

Hazard, Uncertainty and Exposure Assessments

The Sao Tome volcano has no confirmed eruptions recorded in the Holocene. This absence of a comprehensive eruptive history means that the hazard cannot be calculated and Sao Tome is therefore unclassified in both hazard and risk. The PEI at Sao Tome is classed as moderate, at PEI 4.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR				Sao Tome			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 75: Identity of Sao Tome and Principe's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Sao Tome and Principe have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Sao Tome and Principe.

Sudan

Description

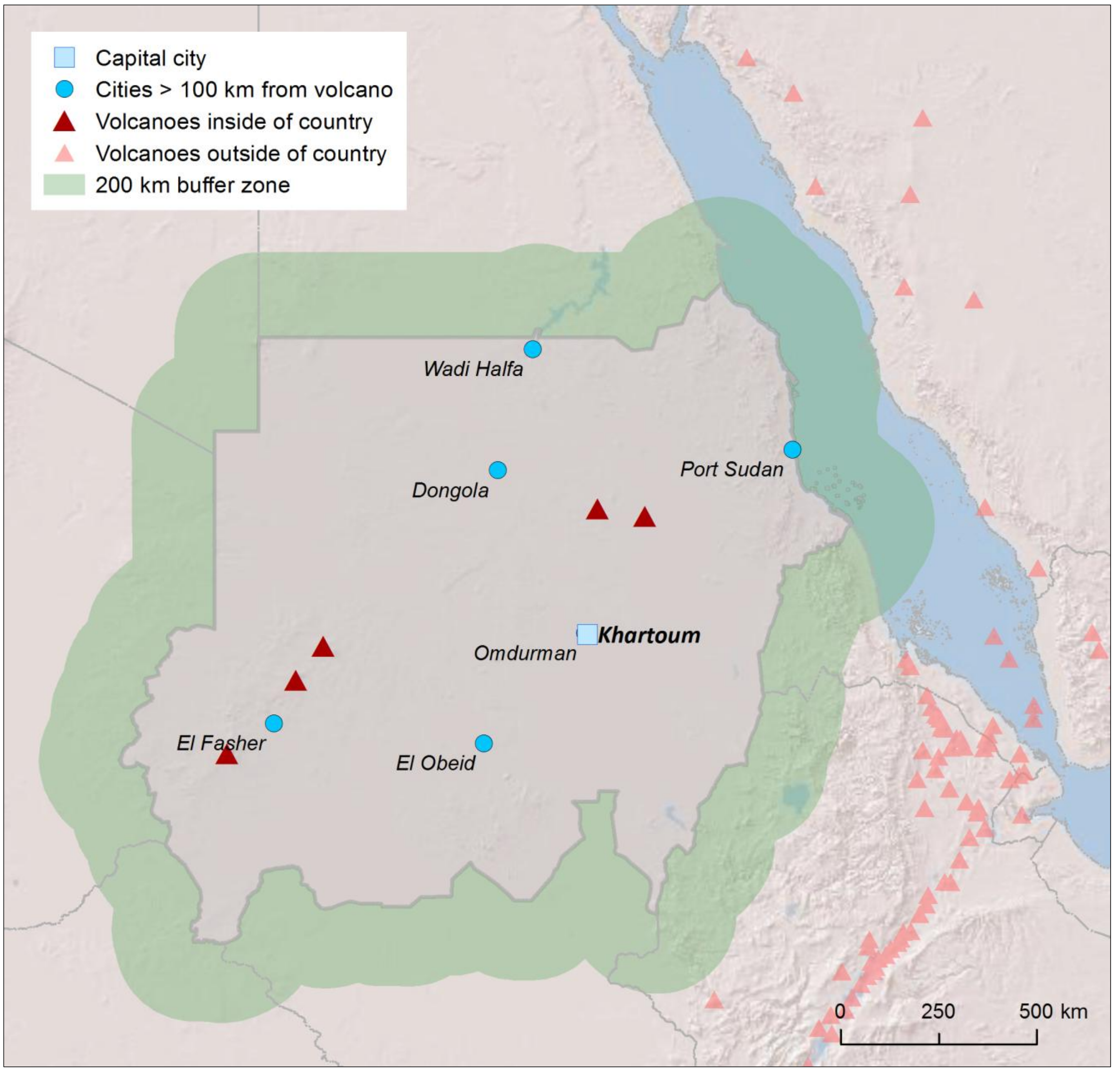


Figure 78: Location of Sudan's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Sudan.

Five volcanoes are located in Sudan. Two are situated in east central Sudan, and another three in the south-west. Volcanoes here are related to intra-plate processes and are dominantly basaltic, forming as four groups of scoria cones in volcanic fields and a shield volcano.

Three volcanoes in Sudan have a Holocene eruption record of eight eruptions ranging in size from VEI 0 to 4. Five of these eruptions of Jebel Marra and Meidob Volcanic Field were VEI 4, with three eruptions of the latter generating pyroclastic flows. No historical eruptions are recorded, with the most recent volcanic activity in Sudan being the 850 AD eruption of Bayuda Volcanic Field in the north-east of the country.

Although the capital, Khartoum, and the most populous cities in Sudan are distal to the volcanoes, numerous small settlements lie within 100 km of one or more Holocene volcano, in which over 2.5 million people reside.

The eruption histories are poorly constrained at all but the Meidob Volcanic Field, making assessment of hazard here difficult. Focussed research is required to better understand the ages and sizes of eruptions in Sudan.

Volcano Facts

Number of Holocene volcanoes	5
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	2
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The M6.7 eruption of Jebel Marra. This eruption formed the Deriba Caldera and occurred at 3950 BP.
Number of Holocene eruptions	8 confirmed eruptions.
Recorded Holocene VEI range	0 – 4
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
1	Shield(s)	Basaltic (1)
4	Small cone(s)	Basaltic (4)

Table 76: The number of volcanoes in Sudan, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	37,320,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	1,878
Gross National Income (GNI) per capita (2005 PPP $)	1,848
Human Development Index (HDI) (2012)	0.414 (Low)

Population Exposure

Capital city	Khartoum
Distance from capital city to nearest Holocene volcano	305.6 km
Total population (2011)	35,604,595
Number (percentage) of people living within 10 km of a Holocene volcano	11,752 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	314,097 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	2,527,778 (7.1%)

Largest cities, as measured by population, and populations:

Khartoum	1,974,647
Omdurman	1,200,000
Port Sudan	489,725
El Obeid	393,311
El Fasher	252,609
Wadi Halfa	<50,000
Dongola	<50,000

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	1,456
Total length of railroads within 100 km of a volcano (km)	252

The Sudanese volcanoes are located inland, away from the ports on the north-eastern coastline of the Red Sea. None of the largest cities are situated within 100 km of the volcanoes, and the capital, Khartoum, lies over 300 km away. An extensive road and rail network is proximal to the volcanoes, and numerous cities lie within 100 km of the volcanoes, including settlements along the River Nile which runs around the Bayuda Volcanic Field.

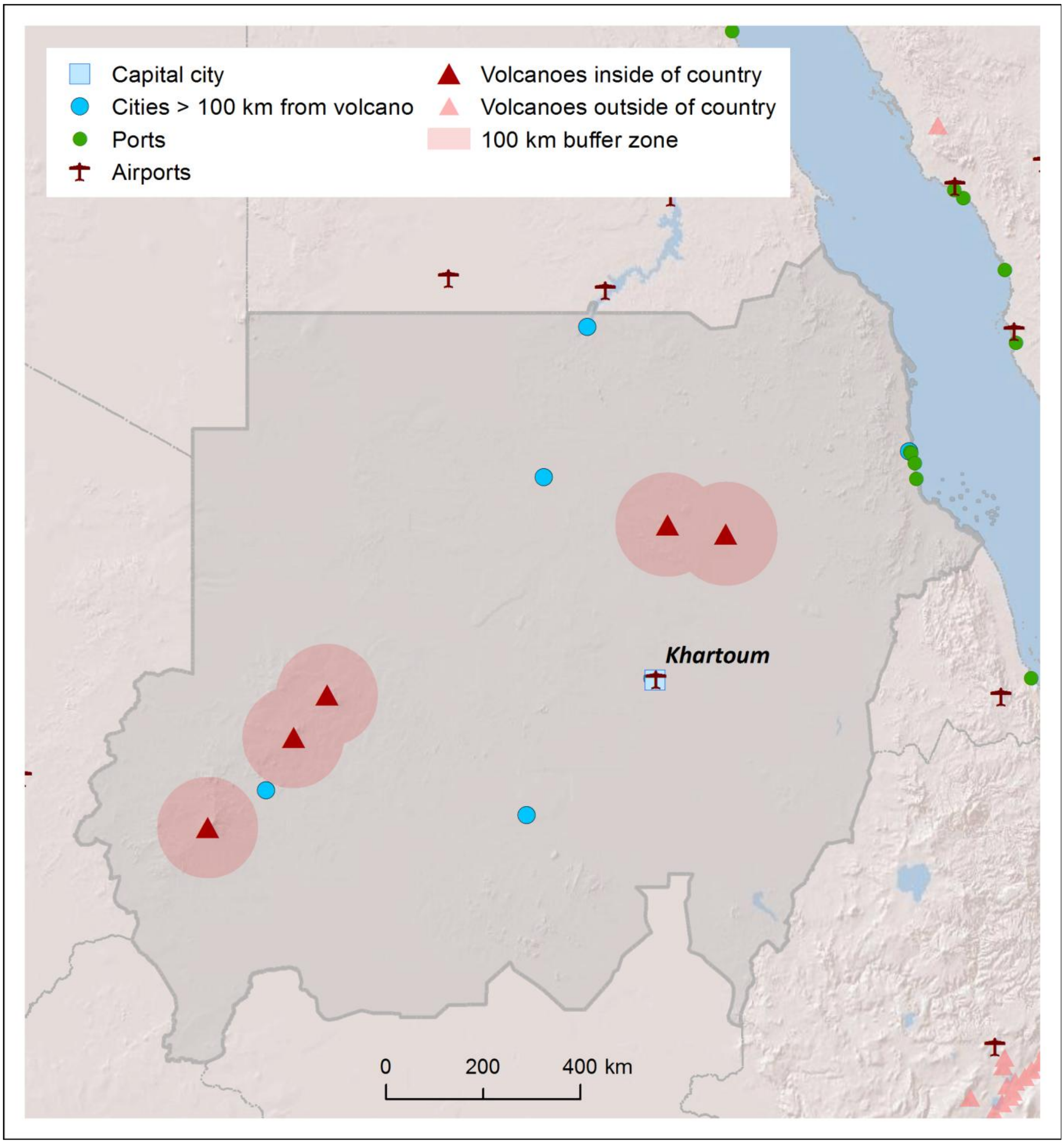


Figure 79: The location of Sudan's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

All but one volcano in Sudan, the Meidob Volcanic Field, have large uncertainties associated with the calculation of the Hazard Level and these are therefore unclassified. Of these four unclassified volcanoes, two, Kutum Volcanic Field and Jebel Umm Arafieb have no confirmed Holocene eruptions. Bayuda Volcanic Field and Jebel Marra have Holocene eruptions recorded. The Jebel Marra eruption was VEI 4 in 850 AD.

The Meidob Volcanic Field has six confirmed Holocene eruptions, four of which were VEI 4 in size. This history of large explosive eruptions results in a Hazard Level of III being calculated.

In Sudan the PEI ranges from low to high, from PEI 2 to PEI 5. With no hazard classification at most of Sudan's volcanoes, the risk levels cannot be classified. At Meidob Volcanic Field, a risk level of II is assigned on the basis of a moderate local population.

CLASSIFIED	**Hazard III**			Meidob Volcanic Field				
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR		Bayuda Volcanic Field		Marra, Jebel			
	U- NHHR				Kutum Volcanic Field	Umm Arafieb, Jebel		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 77: Identity of Sudan's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Meidob Volcanic Field	3	II

Table 78: Classified volcanoes of Sudan ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 1 volcano; Risk Level III – 0 volcanoes.

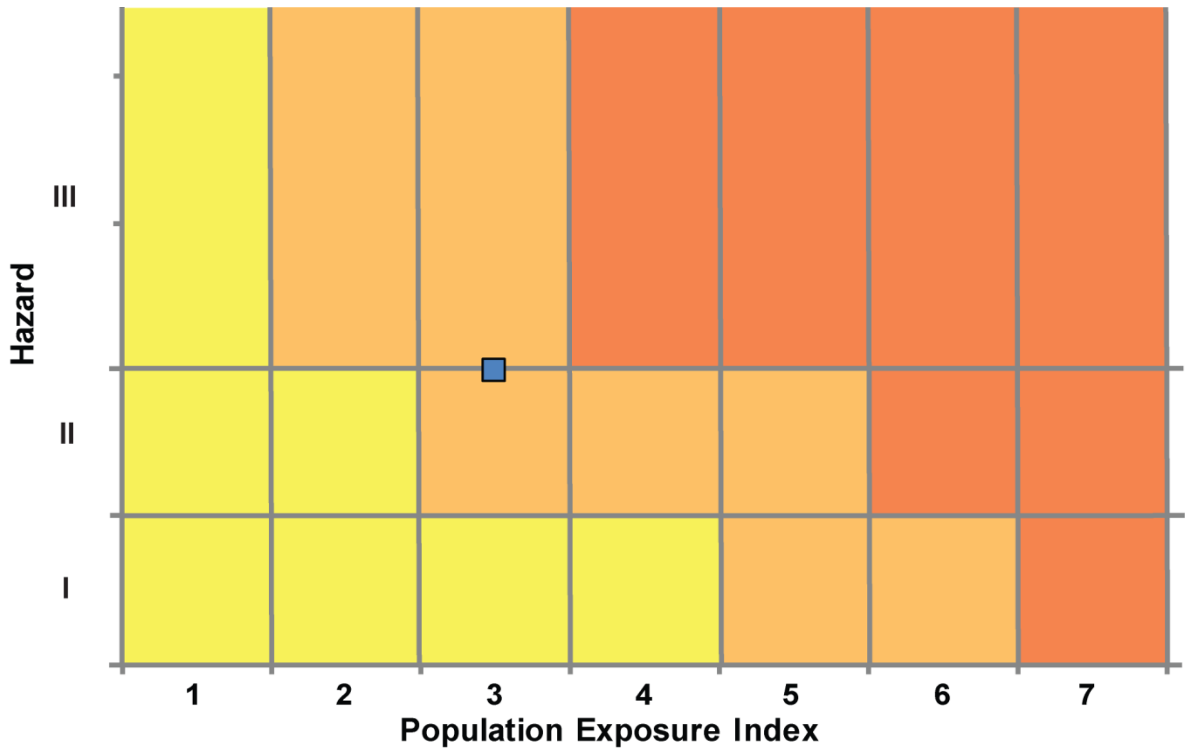


Figure 80: Distribution of Sudan's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

No volcanoes in Sudan have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Sudan.

Tanzania

Description

There are ten Holocene volcanoes in Tanzania. These form two clusters in the northern and southern parts of the country marking the southern portion of the East African Rift Valley. The northern volcanoes are Mt Kilimanjaro, Mt Meru and Ol Doinyo Lengai, while the southern volcanoes are clustered around Rungwe Volcanic Province. Of Tanzania's Holocene volcanoes, only the carbonatite volcano of Ol Doinyo Lengai is known to be currently active. However, at the time of writing, the lack of volcano monitoring in proximity to any of these volcanoes means that any state of unrest is unreported and the potential for an eruption may be underestimated.

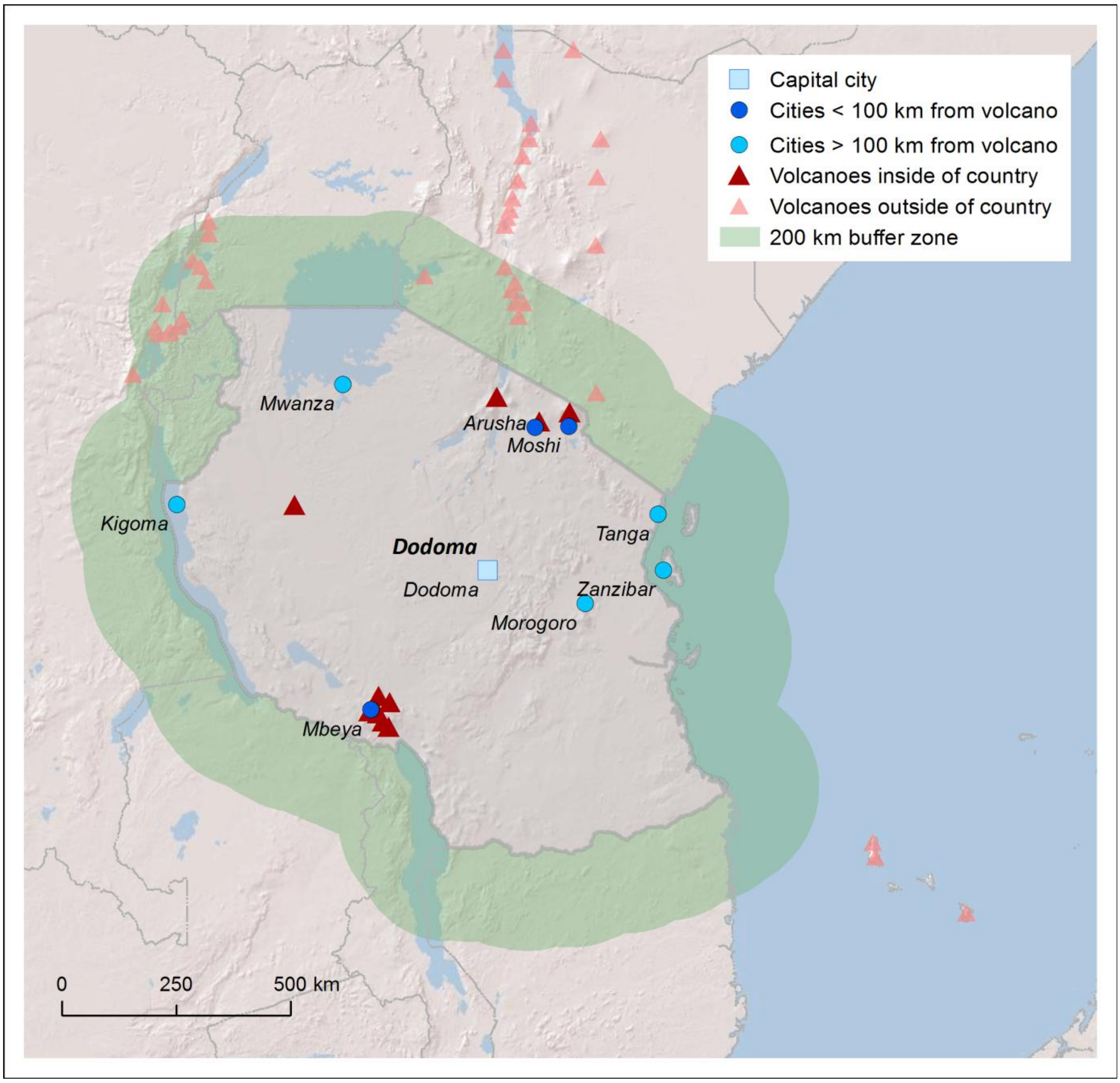


Figure 81: Location of Tanzania's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Tanzania.

The majority of Tanzania's Holocene volcanoes are explosive in nature, with effusive lava dome growth and lava flows. The three northern volcanoes (Mt Meru, Mt Kilimanjaro and Ol Doinyo

Lengai), and Mt Rungwe and Mt Kyejo in the south, are stratovolcanoes characterised by pyroclastic cones and lava domes. Mt Kilimanjaro and Mt Meru also have craters resulting from edifice collapse. Three of the southern volcanoes (Igwisi Hills, Izumbwe-Mpoli and an unnamed volcano) are pyroclastic and tuff cones. Mt Ngozi is a shield volcano with a summit caldera. Only SW Usangu Basin is entirely effusive, characterised by lava dome growth.

Although Tanzania's largest cities are situated more than 30 km from the volcanic centres, the prevalence of numerous rural communities in Tanzania mean that seven of the Holocene volcanic centres have more than 100,000 people living within a 30 km radius. Of these, two have more than 300,000 people within a 10 km radius (Source: Smithsonian Institute GVP 2013).

There is no record of fatalities as a result of volcanic activity although there are reports of injuries and loss of livestock associated with the 2007 eruption of Ol Doinyo Lengai. The Disaster Management Unit (DMU) of Tanzania wrote a report to the Prime Minister's Office in response to this eruption, recommending a series of restrictions on access, regulation of official local guides, first aid stations and shelters be implemented on Ol Doinyo Lengai. At the time of writing those recommendations have yet to be actioned. The lack of fatalities known as a result of past eruptions may be due to recording and epistemic uncertainty that requires consideration when analysing the impact of past eruptions.

Volcano Facts

Number of Holocene volcanoes	10
Number of Pleistocene volcanoes with M≥4 eruptions	3
Number of volcanoes generating pyroclastic flows	2
Number of volcanoes generating lahars	2
Number of volcanoes generating lava flows	3
Number of fatalities caused by volcanic eruptions	?15
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	The M5.9 eruption of the Kitulo pumice with caldera formation at Ngozi at 10.2 ka.
Largest recorded Holocene eruption	The M5 eruption of the Rungwe pumice from Rungwe at 4 ka.
Number of Holocene eruptions	33 confirmed eruptions. 1 uncertain eruption and 2 discredited.
Recorded Holocene VEI range	0 – 5 and unknown
Number of historically active volcanoes	3
Number of historical eruptions	23

Number of volcanoes	Primary volcano type	Dominant rock type
1	Caldera(s)	Trachytic / Andesitic (1)
5	Large cone(s)	Foiditic (1), Phonolitic (2), Trachytic / Andesitic (2)
1	Lava dome(s)	Phonolitic (1)
3	Small cone(s)	Basaltic (1), Foiditic (2)

Table 79: The number of volcanoes in Tanzania, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	47,911,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	1,334
Gross National Income (GNI) per capita (2005 PPP $)	1,383
Human Development Index (HDI) (2012)	0.476 (Low)

Population Exposure

Capital city	Dodoma
Distance from capital city to nearest Holocene volcano	343.4 km
Total population (2011)	42,746,620
Number (percentage) of people living within 10 km of a Holocene volcano	532,918 (1.3%)
Number (percentage) of people living within 30 km of a Holocene volcano	2,604,862 (6.1%)
Number (percentage) of people living within 100 km of a Holocene volcano	6,997,614 (16.4%)

Ten largest cities, as measured by population, and populations:

Dar es Salaam	2,698,652
Mwanza	436,801
Zanzibar	403,658
Arusha	341,136
Mbeya	291,649
Morogoro	250,902
Tanga	224,876
Dodoma	180,541

Kigoma	164,268
Moshi	156,959

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	1,273
Total length of railroads within 100 km of a volcano (km)	734

The volcanoes of Tanzania are located in three areas, south near the border with Malawi and Zambia, north on the border with Kenya and in the west. Being inland volcanoes, these are located away from the ports along the eastern coastline of Tanzania. They also lie over 300 km away from the capital, Dodoma, however several of the largest cities in Tanzania are situated within 100 km of these volcanoes. The location of these cities close to the volcanoes means that considerable infrastructure is exposed to the volcanic hazard, including an extensive road and rail network. The 100 km radii surrounding the volcanoes extends into Kenya and Malawi, and affects the Karonga Airport across the border in Malawi.

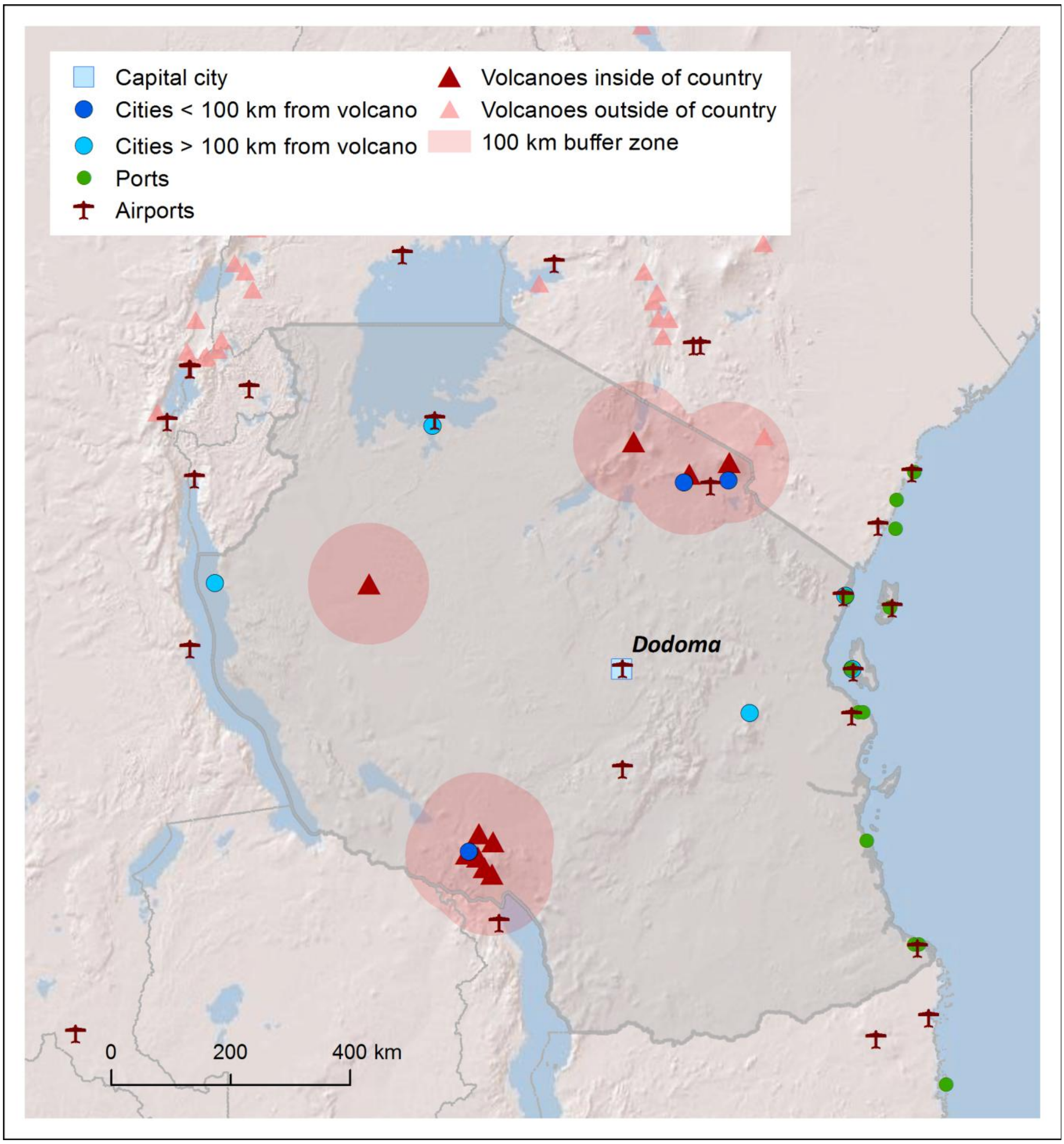


Figure 82: The location of Tanzania's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

All but one volcano in Tanzania have considerable uncertainties associated with the classification of the Hazard Levels, and these are therefore unclassified. Of these unclassified volcanoes, five have no confirmed Holocene eruptions; two have Holocene activity records and Meru and Kyejo have historic activity as recently as 1910. Meru, Rungwe and Ngozi have Holocene records of large magnitude eruptions of VEI ≥4.

Ol Doinyo Lengai has 23 Holocene eruptions recorded in VOTW4.22, with most of these recorded historically. All historical eruptions at this volcano are of a known size, with activity commonly being effusive to moderately explosive. This volcano is therefore classified at Hazard Level II.

The PEI in Tanzania ranges from moderate to very high, at PEIs of 3 to 7. Most volcanoes are classed as PEI 5, with a high proximal population. Ngozi has the largest population in Tanzania living within 10 km, with over 450,000 people in this radius, whilst Kilimanjaro has the largest population within 100 km at over 2.6 million. At a hazard level of II and PEI of 3, Ol Doinyo Lengai is classified at Risk Level II.

CLASSIFIED	**Hazard III**							
	Hazard II			Ol Doinyo Lengai				
	Hazard I							
UNCLASSIFIED	**U – HHR**					**Meru**; Kyejo		
	U- HR					Rungwe		Ngozi
	U- NHHR				Kilimanjaro; Unnamed	Igwisi Hills; SW Usangu Basin		Izumbwe-Mpoli
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 80: Identity of Tanzania's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Ol Doinyo Lengai	3	II

Table 81: Classified volcanoes of Tanzania ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 1 volcano; Risk Level III – 0 volcanoes.

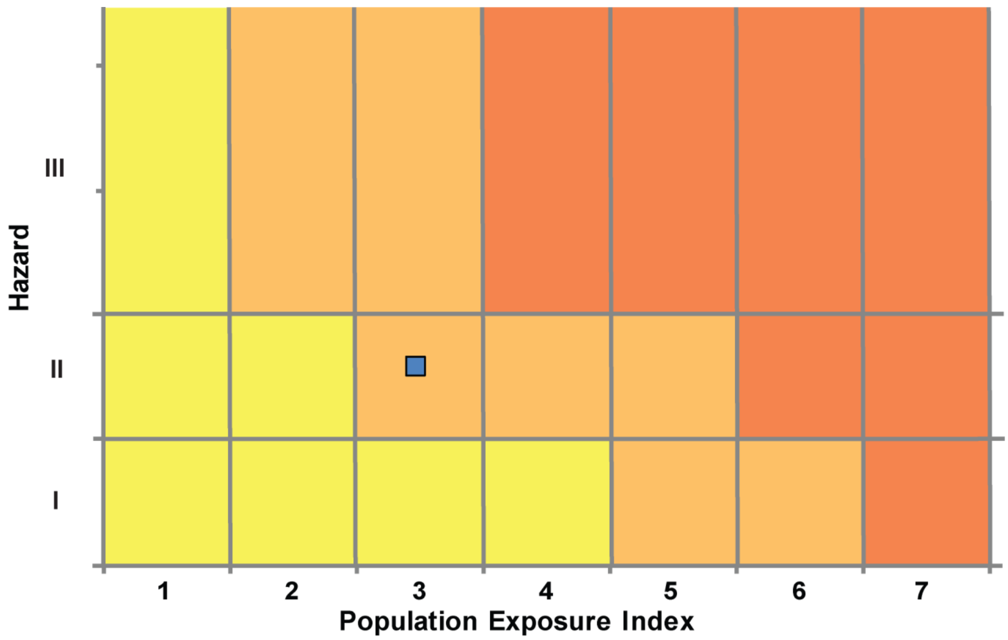


Figure 83: Distribution of Tanzania's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Three volcanoes have been historically active in Tanzania. The Geological Survey of Tanzania is responsible for these volcanoes, and have operated a system of temporary seismics at the Risk Level II Ol Doinyo Lengai. Meru and Kyejo do not currently have a dedicated ground-based monitoring system.

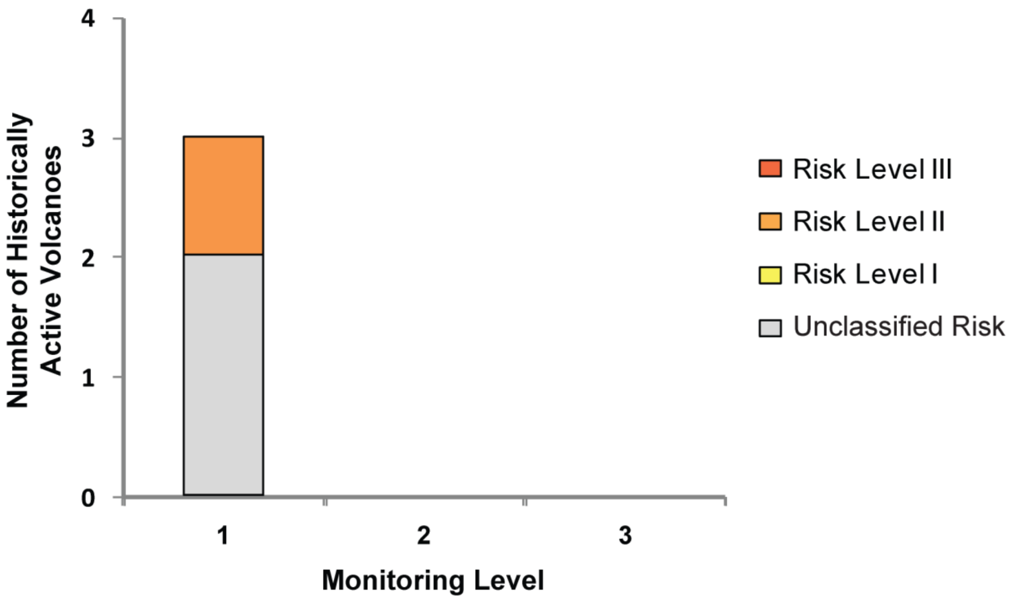


Figure 84: The monitoring and risk levels of the historically active volcanoes in Tanzania. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Uganda

Description

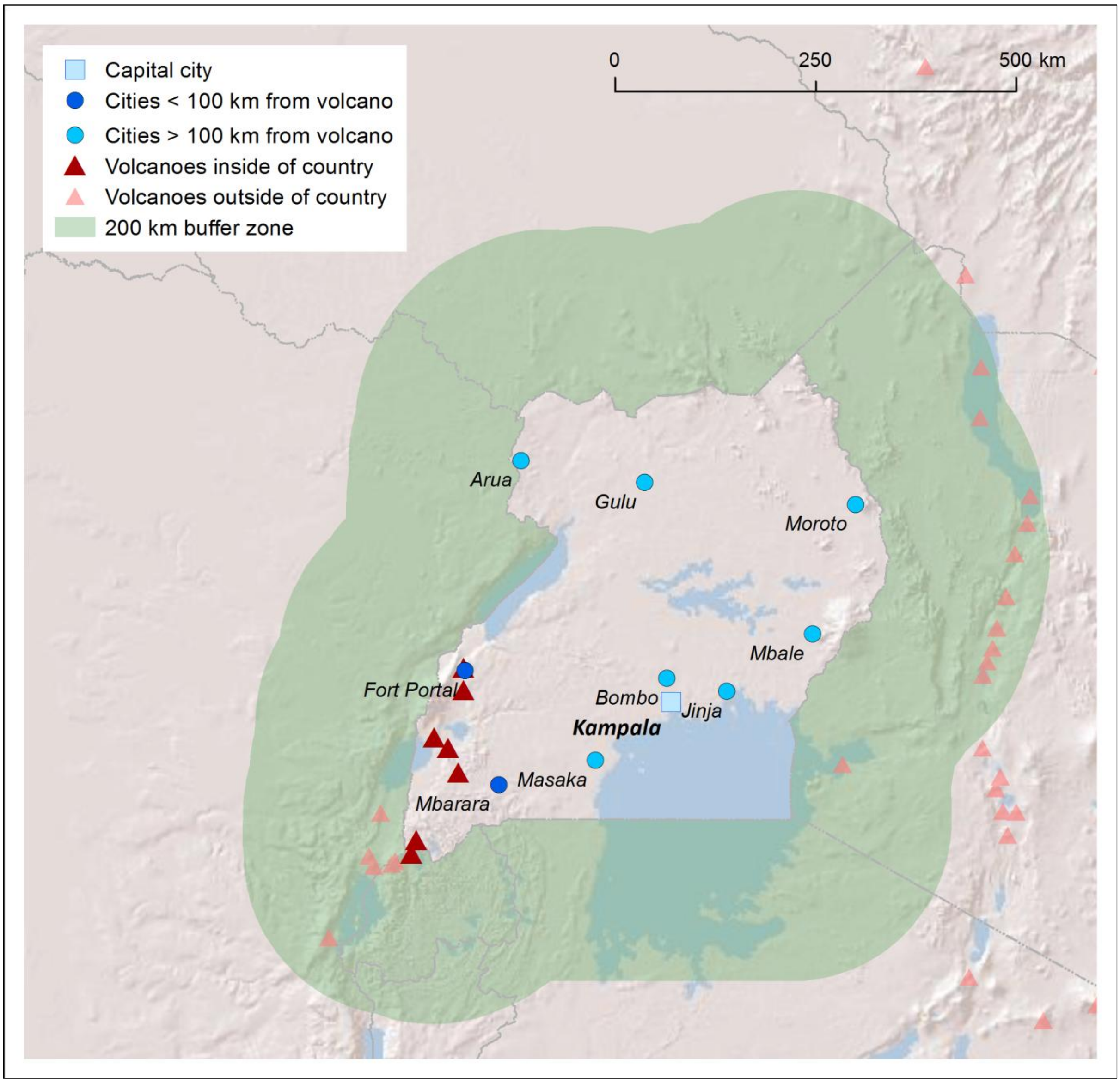


Figure 85: Location of Uganda's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Uganda.

Seven Holocene volcanoes are located in the south-west of Uganda and on the border with Rwanda. These volcanoes are the product of rift zone volcanism, which has formed dominantly Foiditic tuff cones and one basaltic stratovolcano – Muhavura.

Two Holocene eruptions are recorded at the Fort Portal tuff cones in 2120 and 2750 BC. The size of these eruptions is unknown though ash deposits have been identified. No historical eruptions are recorded in Uganda, however historical activity may have occurred at Fort Portal.

Uganda’s volcanoes are largely located near the borders with Rwanda and the Democratic Republic of Congo, so eruptions here may affect these countries. Multiple volcanoes in these neighbouring countries and Kenya are located within 200 km of Uganda.

Large proximal populations exist at all of Uganda’s volcanoes. Nearly 450,000 live within 10 km of Katwe-Kikorongo, and over 240,000 at Fort Portal. All have over 4 million within 100 km.

The absence of detailed eruptive histories at Uganda’s volcanoes makes assessment of hazard difficult, with large associated uncertainties. Further research is required to more fully understand the past activity.

Volcano Facts

Number of Holocene volcanoes	7, inclusive of one on the border with Rwanda
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Two eruptions with unknown VEI at Fort Portal.
Number of Holocene eruptions	2 confirmed eruptions.
Recorded Holocene VEI range	Unknown
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Basaltic (1)
6	Small cone(s)	Foiditic (5), Phonolitic (1)

Table 82: The number of volcanoes in Uganda, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	36,484,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	1,188
Gross National Income (GNI) per capita (2005 PPP $)	1,168
Human Development Index (HDI) (2012)	0.456 (Low)

Population Exposure

Capital city	Kampala
Distance from capital city to nearest Holocene volcano	227.2 km
Total population (2011)	34,612,250
Number (percentage) of people living within 10 km of a Holocene volcano	817,080 (2.4%)
Number (percentage) of people living within 30 km of a Holocene volcano	3,087,519 (8.9%)
Number (percentage) of people living within 100 km of a Holocene volcano	7,968,612 (23%)

Ten largest cities, as measured by population, and populations:

Kampala	1,353,189
Gulu	146,858
Jinja	93,061
Mbale	76,493
Masaka	65,373
Arua	55,585
Fort Portal	42,670
Bombo	<50,000
Moroto	<50,000
Mbarara	<50,000

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	1,278
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes are located in western Uganda, along the border with the Democratic Republic of Congo and Rwanda. As such, the 100 km radii extend into all three countries and affect a number of lakes along the borders. The capital of Uganda, Kampala, is distal to these volcanoes, lying over 200 km away, however two of the largest cities fall within 100 km – Mbarara and Fort Portal, therefore placing considerable infrastructure in this exposure zone including an extensive road network. Several airports across the border are affected by these volcanoes.

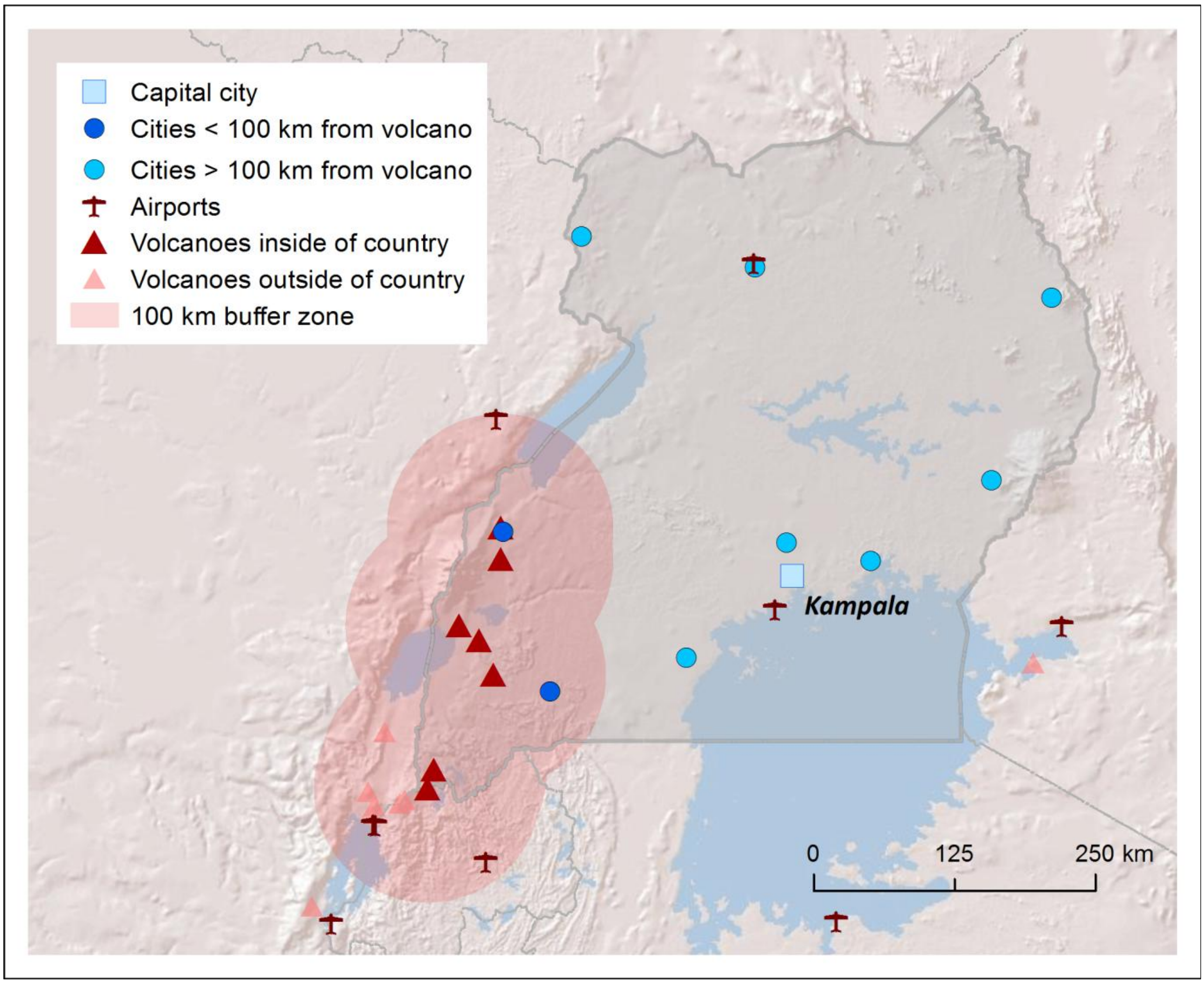


Figure 86: The location of Uganda's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The eruptive history for all of Uganda's volcanoes is lacking, which means that an assessment of hazard cannot be undertaken without large uncertainties. Indeed, only Fort Portal has confirmed Holocene eruptions, whilst the remaining six volcanoes are of suspected Holocene age.

The PEI in Uganda is very high, with all volcanoes categorised at PEI 6 and 7 with a population of over 140,000 within 10 km at all volcanoes. Whilst the risk levels are unassigned given the absence of hazard data, these high local populations indicate that the risk would be categorised at Risk Level II or III at all of Uganda's volcanoes.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR						Fort Portal	
	U- NHHR						Kyatwa; Bunyaruguru; Katunga; Muhavura	Katwe-Kikorongo; Bufumbira
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 83: Identity of Uganda's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Uganda have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Uganda.

Region 3: Middle East and Indian Ocean

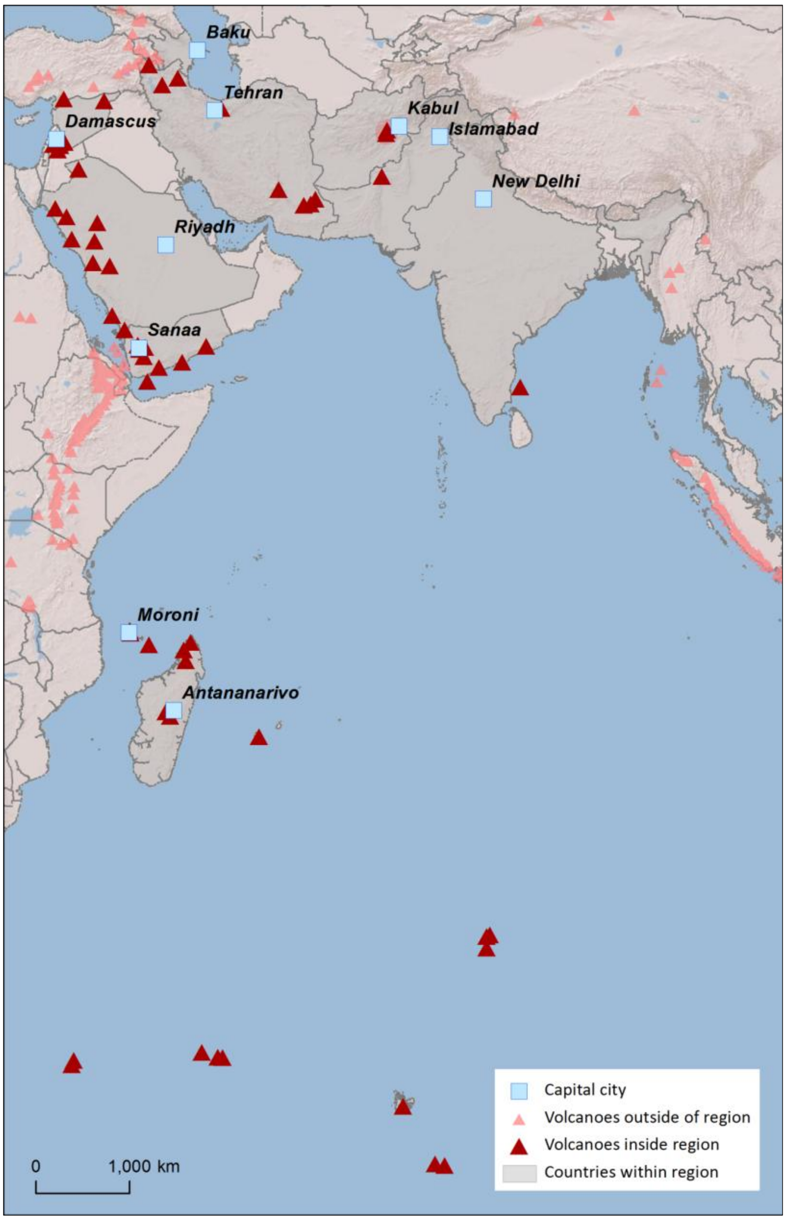


Figure 87: The distribution of Holocene volcanoes through the Middle East and Indian Ocean region. The capital cities of the constituent countries are shown.

Description

Region 3: The Middle East and Indian Ocean comprises volcanoes throughout the Middle East, Madagascar and much of the west and south Indian Ocean. Twelve countries are represented in this region. All are included in this regional discussion. For individual country profiles for Australia see Region 5 and for India see Region 6.

Country	Number of volcanoes
Afghanistan	2
Australia (See Region 5)	2
Comoros	2
France	9
India (See Region 6)	1
Iran	8
Madagascar	5
Pakistan	1
Saudi Arabia	10
South Africa	2
Syria	6
Yemen	8 + 4 from Region 2

Table 84: The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

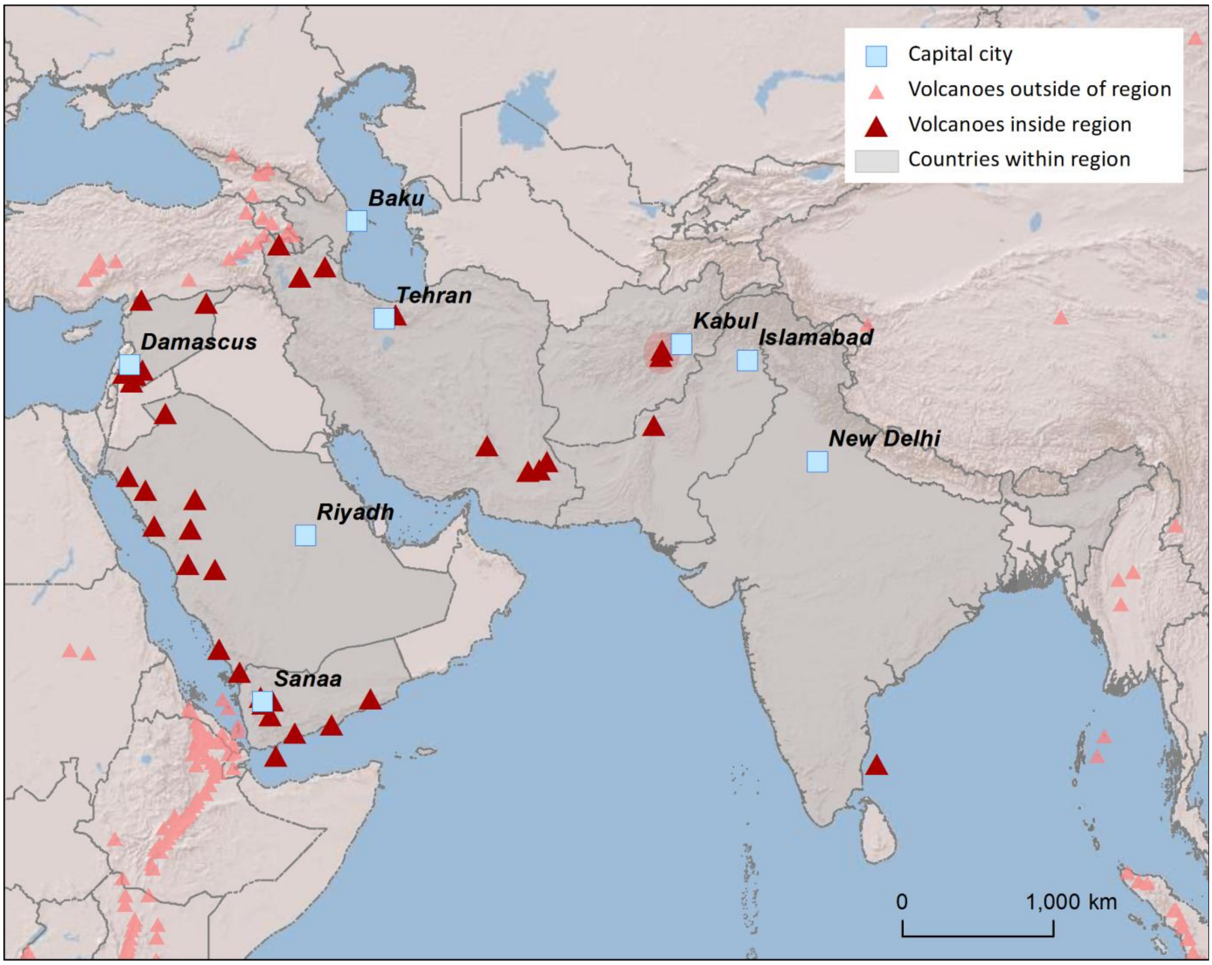


Figure 88: The Middle East section of Region 3.

Fifty-six Holocene volcanoes are located in the Middle East and Indian Ocean. Most of these volcanoes are in Saudi Arabia (10), and indeed, most volcanoes are Middle Eastern, with fewer in the

Indian Ocean. A range of tectonic settings are represented here, from dominantly rift-related volcanism in the Middle East to intra-plate hotspot volcanoes in the Indian Ocean.

Volcanoes with a range of morphologies are present in this region, with small cones dominating throughout Syria, Saudi Arabia, Yemen and Madagascar. Large cones, mainly stratovolcanoes, dominate in Iran and the French and Australian Indian Ocean islands. 36 out of 56 volcanoes are of basaltic composition.

A range of activity has been recorded in the Middle East and Indian Ocean during the Holocene. 252 confirmed eruptions are recorded in this region, of VEI 0 to 5, representing small to large explosive eruptions. However, about 97% of eruptions have been small VEI 0 to 2 size events, with less than 1% of eruptions (just 1 event) being VEI ≥4. This VEI 5 event was the 2700 BC eruption of Piton de la Fournaise on the French island of Réunion. The absence of more VEI ≥4 eruptions may represent the limited geological stratigraphic studies of the volcanoes.

Eleven volcanoes have historical records of 225 eruptions, of which 223 were recorded through direct observations. 76% of these eruptions have records of producing lava flows. No pyroclastic flows are recorded historically and just one lahar is recorded, at Karthala in the Comoros in 2005. The eruption record is dominated by historical events and eruptions of Piton de la Fournaise and Karthala, which make up 90% of the historical record.

Just 2% of historical eruptions have resulted in loss of life. This is likely due to the small nature of most eruptions here, with lava flows rarely being the cause of fatalities. The size of the local population at the volcanoes of this region varies from low to high, with a corresponding range of assigned risk levels. Assessment of hazard (VHI) for all but four volcanoes is complicated by large uncertainties due to sparse eruption records.

The two most frequently active volcanoes in this region, Karthala and Piton de la Fournaise have monitoring systems in place.

Volcano facts

Number of Holocene volcanoes	56
Number of Pleistocene volcanoes with M≥4 eruptions	4
Number of volcanoes generating pyroclastic flows	1 (1 eruption)
Number of volcanoes generating lahars	1 (1 eruption)
Number of volcanoes generating lava flows	15 (187 eruptions)
Number of eruptions with fatalities	5
Number of fatalities attributed to eruptions	53
Largest recorded Pleistocene eruption	The largest recorded explosive eruption in this region occurred at 26 ka, with the M6.7 Trachytic Ignimbrite eruption in the Kerguelen Islands. The

	Kerguelen Islands are a French territory.
Largest recorded Holocene eruption	The largest Holocene eruption was that of Piton de la Fournaise with the M5.3 Bellecombe Ash eruption of 4650 BP.
Number of Holocene eruptions	252 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 5 and unknown.
Number of historically active volcanoes	11
Number of historical eruptions	225

Number of volcanoes	Primary volcano type	Dominant rock type
6	Large cone(s)	Andesitic (5), Basaltic (1)
1	Lava dome(s)	Andesitic (1)
6	Shield(s)	Basaltic (6)
33	Small cone(s)	Basaltic (29), Dacitic (1), Foiditic (1), Trachytic/Andesitic (1), Unknown (1)
1	Submarine	Unknown (1)

Table 85: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	

Table 86: Average recurrence interval (years between eruptions) for small and large eruptions in the Middle East and Indian Ocean.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 ocurr in this region with an average recurrence interval (ARI) of about a year

Eruption Size

Eruptions of VEI 0 to 5 are recorded through the Middle East and Indian Ocean, representing a range of eruption styles from gentle effusive events, to large explosive eruptions. VEI 2 events dominate the record, with nearly 60% of all Holocene eruptions classed as such. Indeed, less than 1% of eruptions here are explosive at VEI≥4.

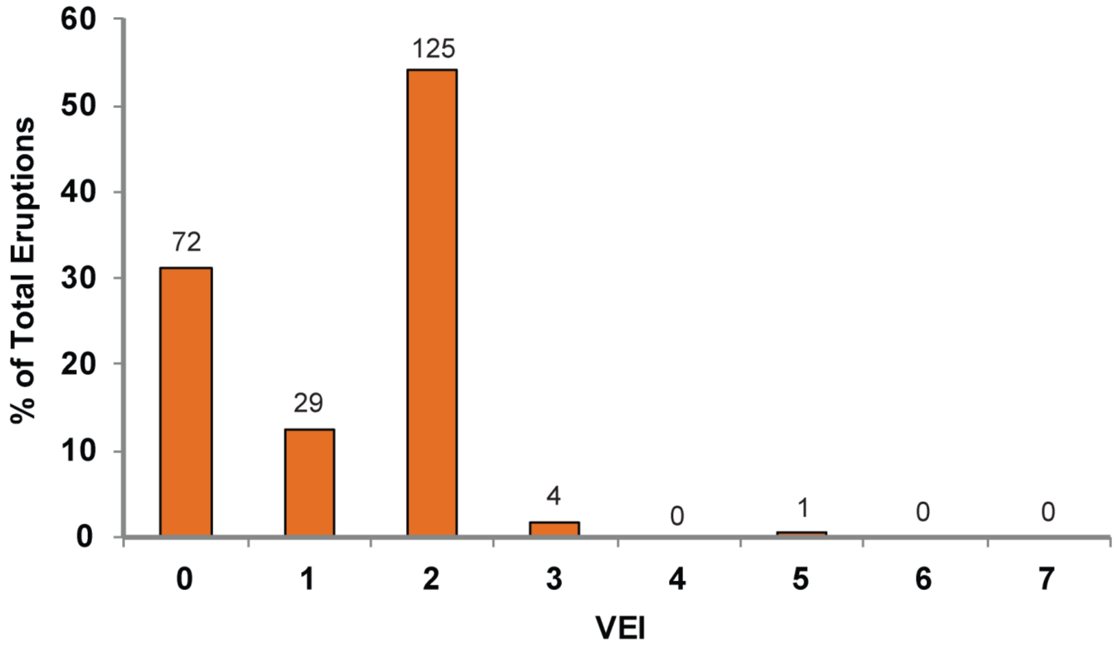


Figure 89: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 21 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	391,186,408
Gross Domestic Product (GDP) per capita (2005 PPP $)	853 – 21,430
	(Mean 5,504)
Gross National Income (GNI) per capita (2005 PPP $)	828 – 22,616
	(Mean 5,648)
Human Development Index (HDI) (2012)	0.374 – 0.782 (Low to High: Mean 0.554 Medium)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	1,337,541 (0.34 %)
Number (percentage) of people living within 30 km of a Holocene volcano	8,242,589 (2.11 %)
Number (percentage) of people living within 100 km of a Holocene volcano	67,324,540 (17.21 %)

CLASSIFIED	**Hazard III**							
	Hazard II					Fournaise, Piton de la		
	Hazard I	Heard; McDonald Islands					Karthala	
UNCLASSIFIED	**U – HHR**	**Tor Zawar; Boomerang Seamount**; St. Paul; **Marion Island**					Es Safa; Yar, Jabal	**Dhamar, Harras of**
	U- HR	Mayotte Island	'Uwayrid, Harrat; **Lunayyir, Harrat**		Khaybar, Harrat	Sawâd, Harra es-; Damavand	Unnamed; Unnamed; Haylan, Jabal; Itasy Volcanic Field	Rahat, Harrat; Arhab, Harra of
	U- NHHR	Amsterdam Island; Kerguelen Islands; Est, Ile de l'; Possession, Ile de la; Cochons, Ile aux; Prince Edward Island	Rahah, Harrat ar; Unnamed; Bir Borhut; Bazman; **Taftan**; Unnamed	Ithnayn, Harrat; Kishb, Harrat; Bal Haf, Harra of; Sabalan; Qal'eh Hasan Ali; Unnamed	Sahand; Ambre-Bobaomby; Nosy-Be; Ankaizina Field	Birk, Harrat al; Unnamed; Dacht-i-Navar Group; Vakak Group	Sharat Kovakab; Harrah, Al; Marha, Jabal el-; Grille, La; Ankaratra Field	Golan Heights; Druze, Jabal ad
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 87: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
5	7
12	6
7	5
5	4
6	3
8	2
13	1

Table 88: The number of volcanoes in the Middle East and Indian Ocean classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
0	III
2	II
2	I
52	Unclassified

Table 89: The number of volcanoes in the Middle East and Indian Ocean region classified at each Risk Level.

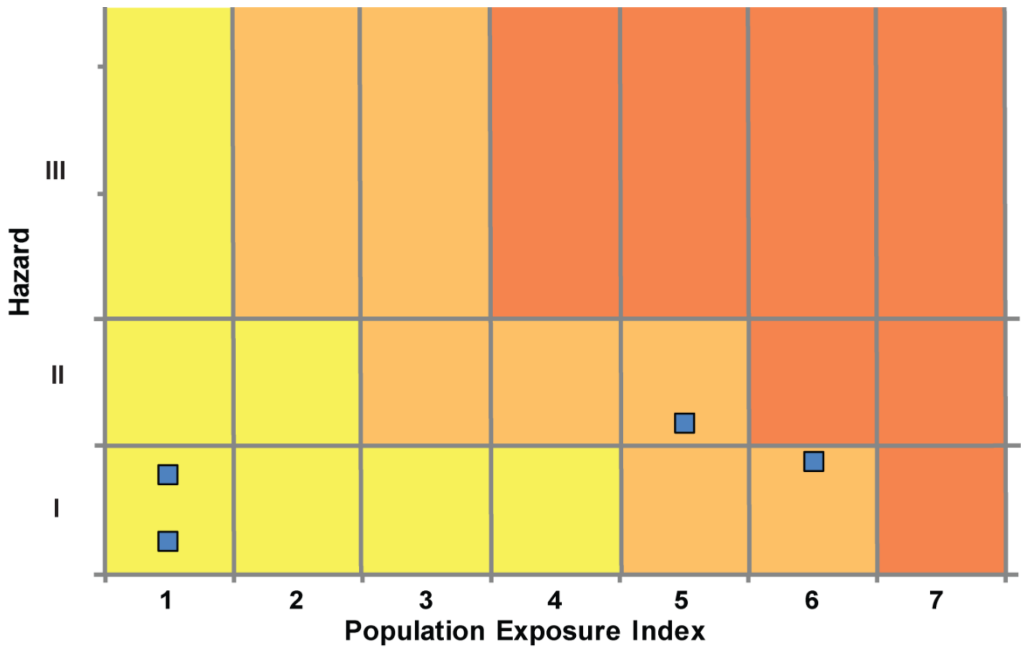


Figure 90: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

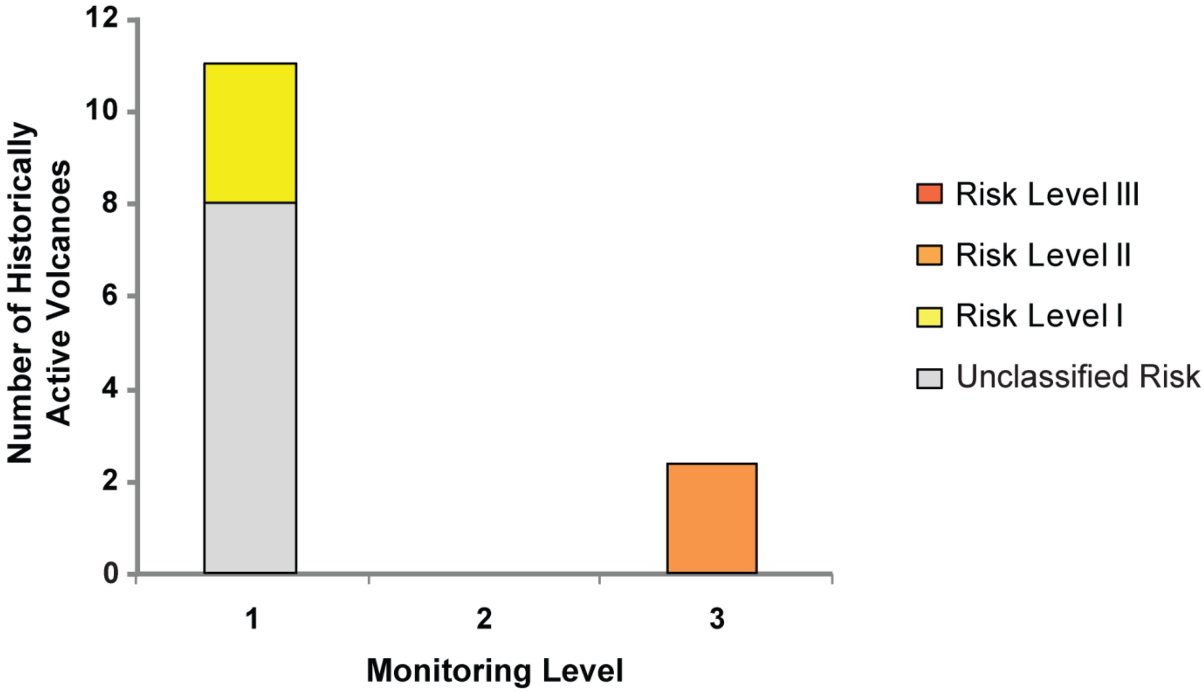


Figure 91: The monitoring and risk levels of the historically active volcanoes in the Middle East and Indian Ocean. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Afghanistan

Description

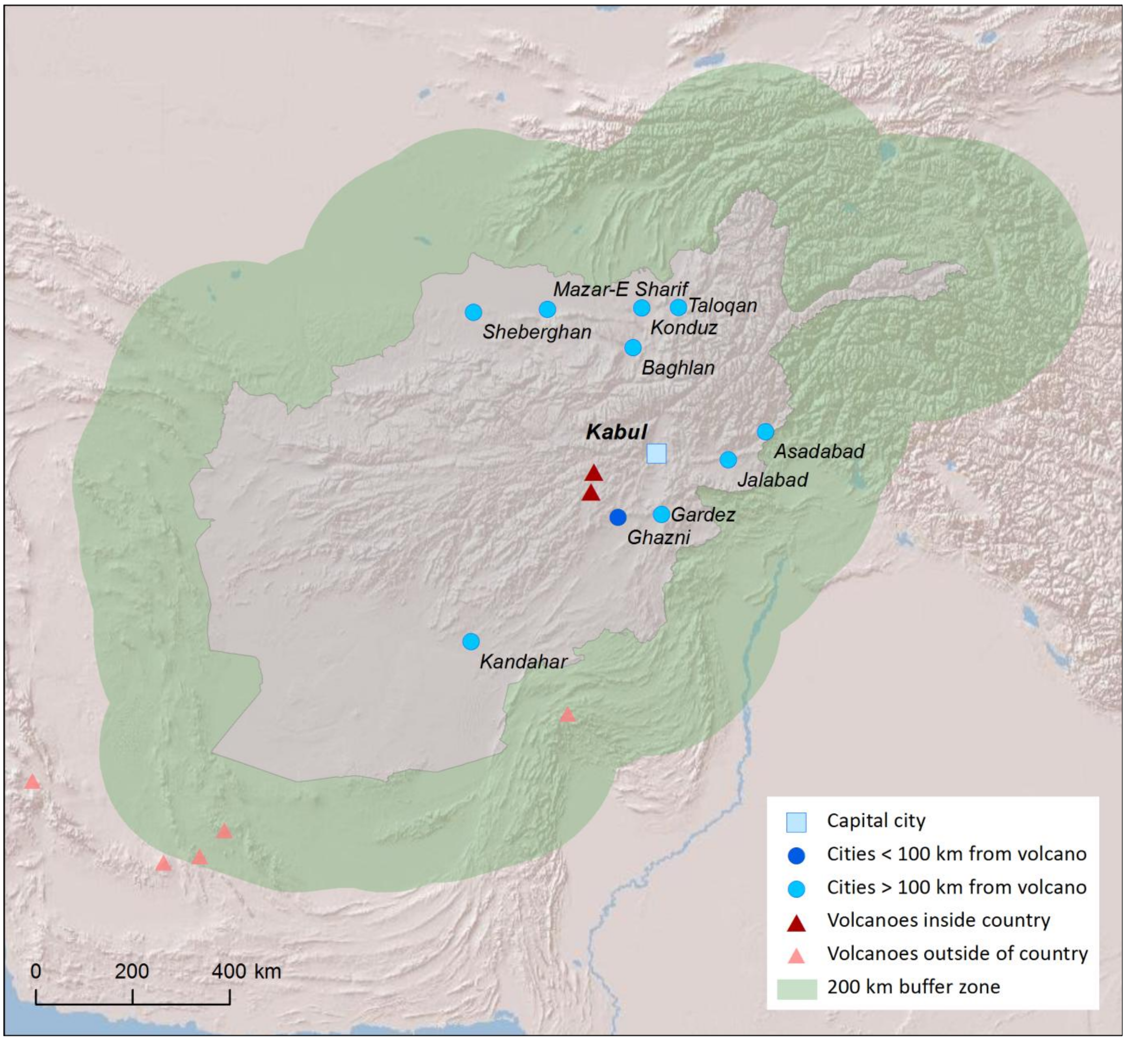


Figure 92: Location of Afghanistan's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Afghanistan.

Two Holocene volcanoes are located in east-central Afghanistan: the Dacht-i-Navar volcanic field and the Vakak Group. The collision zone between the Eurasian and Indian Plates is located within 500 km of these volcanoes, but volcanism here is a result of intra-plate activity.

The Dacht-i-Navar volcanic field comprises a group of trachyandesitic lava domes, while the Vakak Group comprises a more felsic group of lava domes. There are no precisely dated eruptions in either group, however Holocene activity is suspected. With no detailed eruptive history, assessing the hazard at Afghanistan's volcanoes is difficult and associated with considerable uncertainty. Only a small population resides within 10 km of the volcanoes, however over 2.3 million live within 100 km of these volcanoes thus exposing considerable infrastructure and population. Further research is required to better understand the hazard and risk at these volcanoes, which currently do not appear to be subject to regular dedicated ground-based monitoring.

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	-
Number of Holocene eruptions	-
Recorded Holocene VEI range	-
Number of historically active volcanoes	-
Number of historic eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
1	Lava dome(s)	Andesitic (1)
1	Small cone(s)	Dacitic (1)

Table 902: The number of volcanoes in Afghanistan, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	30,156,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	1,083
Gross National Income (GNI) per capita (2005 PPP $)	1,000
Human Development Index (HDI) (2012)	0.374 (Low)

Population Exposure

Capital city	Kabul
Distance from capital city to nearest Holocene volcano	114.7 km

Total population (2011)	29,757,566
Number (percentage) of people living within 10 km of a Holocene volcano	20,734 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	157,606 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	2,320,646 (7.8%)

Ten largest cities, as measured by population, and populations:

Kabul	3,043,532
Kandahar	391,190
Mazar-E Sharif	303,282
Jalabad	200,331
Konduz	161,902
Ghazni	141,000
Baghlan	108,449
Gardez	103,601
Taloqan	64,256
Asadabad	59,617

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	912
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes in Afghanistan are located to the south-west of the capital, Kabul. This city lies just outside of the 100 km radii at 114 km. One of the largest cities in Afghanistan, Ghazni, lies within about 60 km of the Dacht-i-Navar Group, exposing significant infrastructure to the volcanic hazard. Multiple small settlements lie within 100 km of the two volcanoes, and an extensive road network is exposed.

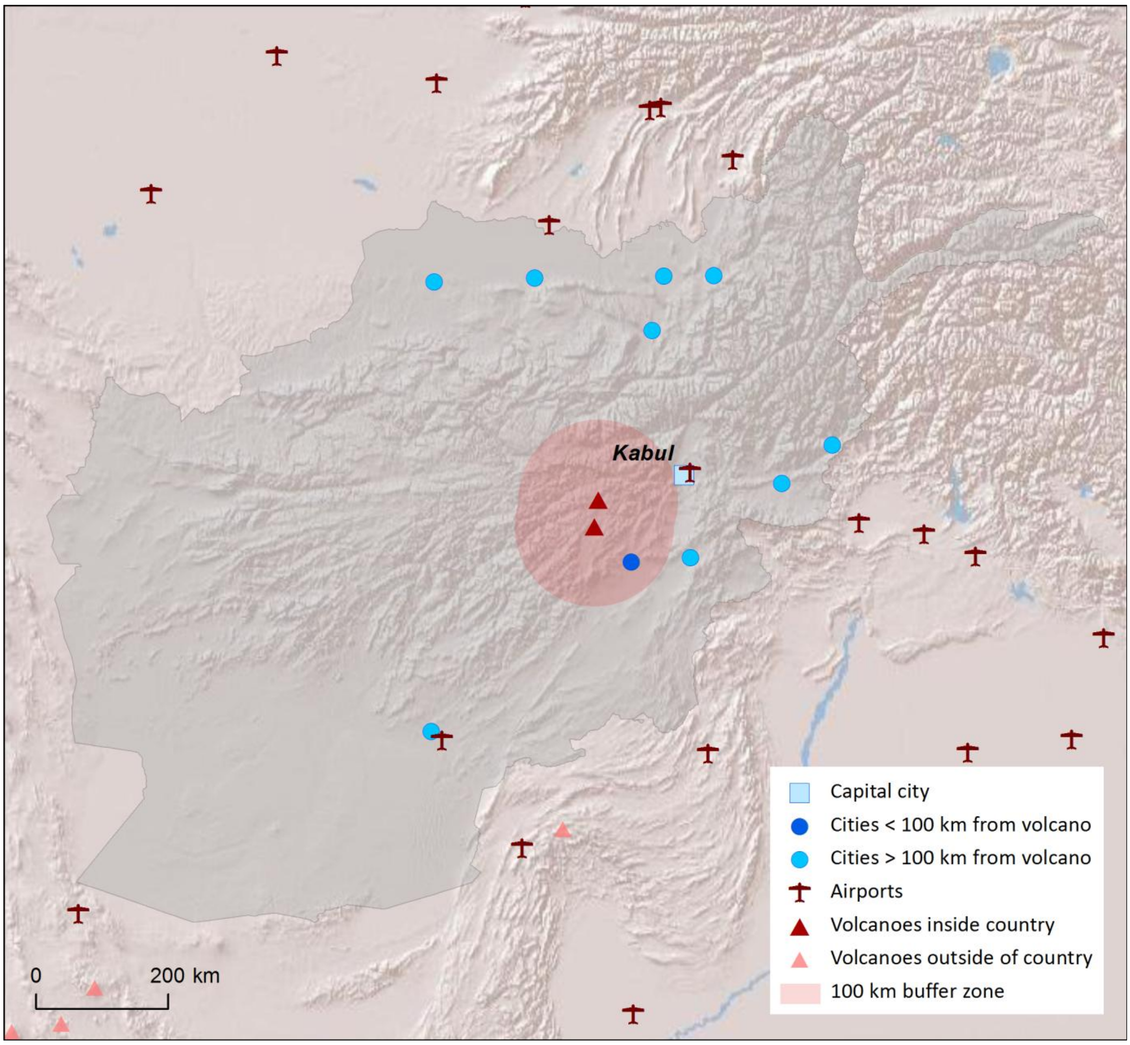


Figure 93: The location of Afghanistan's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are no confirmed Holocene eruptions recorded at either of the volcanoes in Afghanistan. The absence of a comprehensive eruptive history means that the hazard cannot be calculated and these are therefore unclassified in both hazard and risk. The PEI of 5 indicates a high local population near both volcanoes.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR							
	U- NHHR					Dacht-i-Navar Group; Vakak Group		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 91: Identity of Afghanistan's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Afghanistan have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Afghanistan.

Comoros

Description

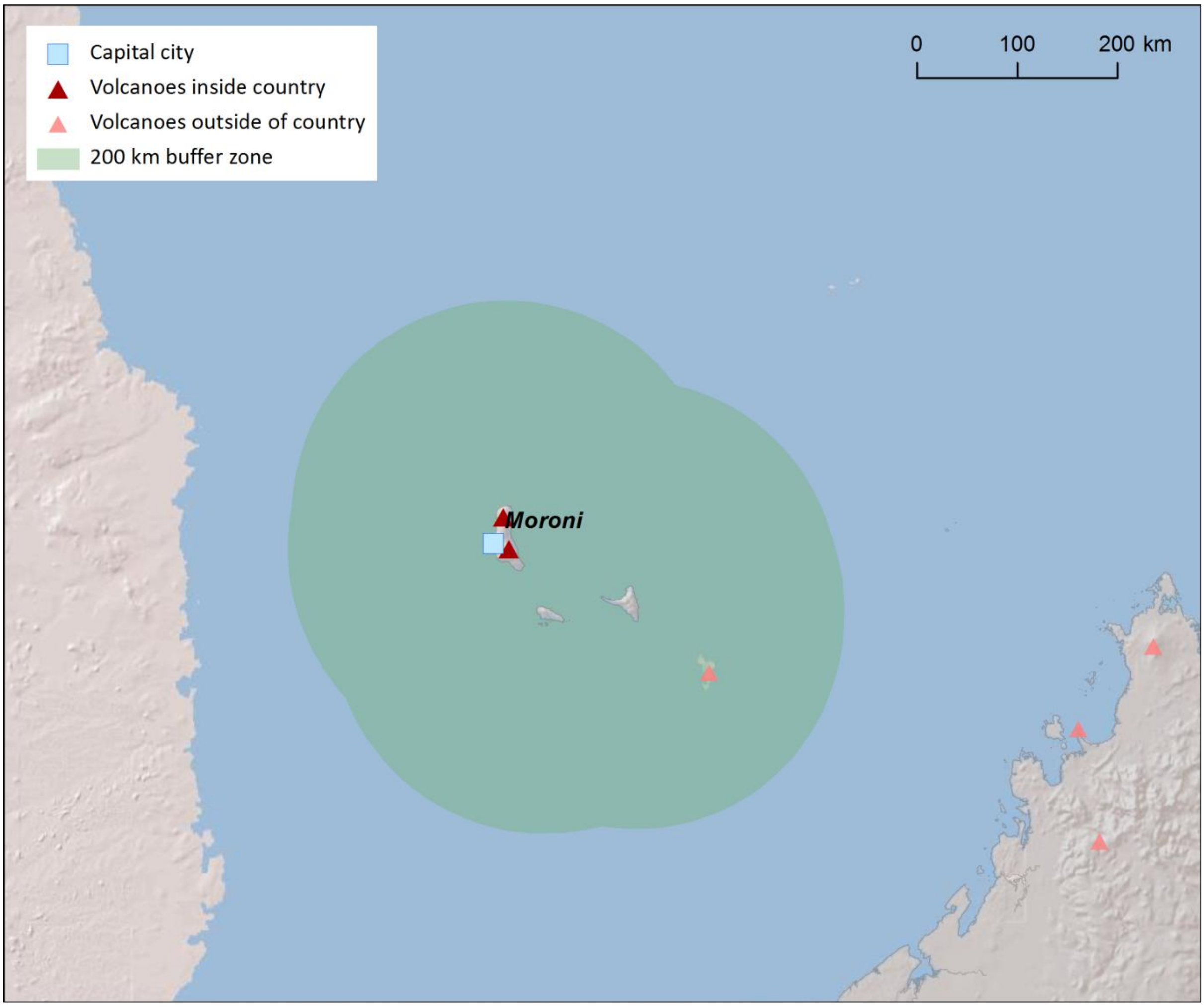


Figure 94: Location of the Comoros volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Comoros.

Comoros has two Holocene volcanoes: Karthala and La Grille. Both are basaltic shield volcanoes. La Grille has numerous pyroclastic cones erupted along fissures paralleling the summit ridge in a N-S direction. The last eruption is unknown; however, there are morphologically young lava flows that reached the sea from fissures on the lower western, northern and eastern flanks.

Kartharla is the southernmost and largest of the two Holocene volcanoes. It is an asymmetrical shield volcano with steeper slopes to the south, formed from NNW-SSE orientated rift zones and a repeated collapses forming a summit caldera. Historic eruptions numbering more than 20 in the 19th Century are recorded from both the summit and flank vents with lava flows reaching the sea and the capital city, Moroni.

In May 2012, incandescence from the summit was observed. Prior to that, activity was recorded in January 2007. Two VEI 3 eruptions occurred in 1918 and 2005.

The Observatoire Volcanologique du Karthala is responsible for monitoring volcanic activity on Comoros using a seismic and GPS network.

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	?35
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Two eruptions at VEI 3 at Karthala, in 1918 and 2005.
Number of Holocene eruptions	34 confirmed eruptions. 1 uncertain eruption.
Recorded Holocene VEI range	0 – 3 and unknown.
Number of historically active volcanoes	1
Number of historic eruptions	33

Number of volcanoes	Primary volcano type	Dominant rock type
2	Shield(s)	Basaltic (2)

Table 92: The number of volcanoes in the Comoros, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	719,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	980
Gross National Income (GNI) per capita (2005 PPP $)	986
Human Development Index (HDI) (2012)	0.429 (Low)

Population Exposure

Capital city	Moroni
Distance from capital city to nearest Holocene volcano	16.2 km
Total population (2011)	721,886
Number (percentage) of people living within 10 km of a Holocene volcano	90,332 (12.5%)
Number (percentage) of people living within 30 km of a Holocene volcano	350,743 (48.6%)
Number (percentage) of people living within 100 km of a Holocene volcano	429,243 (59.5%)

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	2
Total length of roads within 100 km of a volcano (km)	195
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes of the Comoros are located on the country's main and largest island, Grande Comore. Being a small island measuring less than 100 km across, this island and Moheli island are within the 100 km radii of the volcanoes in their entirety, exposing much of the critical infrastructure of the country, including ports, airports and the road network. Nzwani Island is located just outside of the 100 km radius of Karthala. The capital, Moroni, lies at less than 20 km from Karthala.

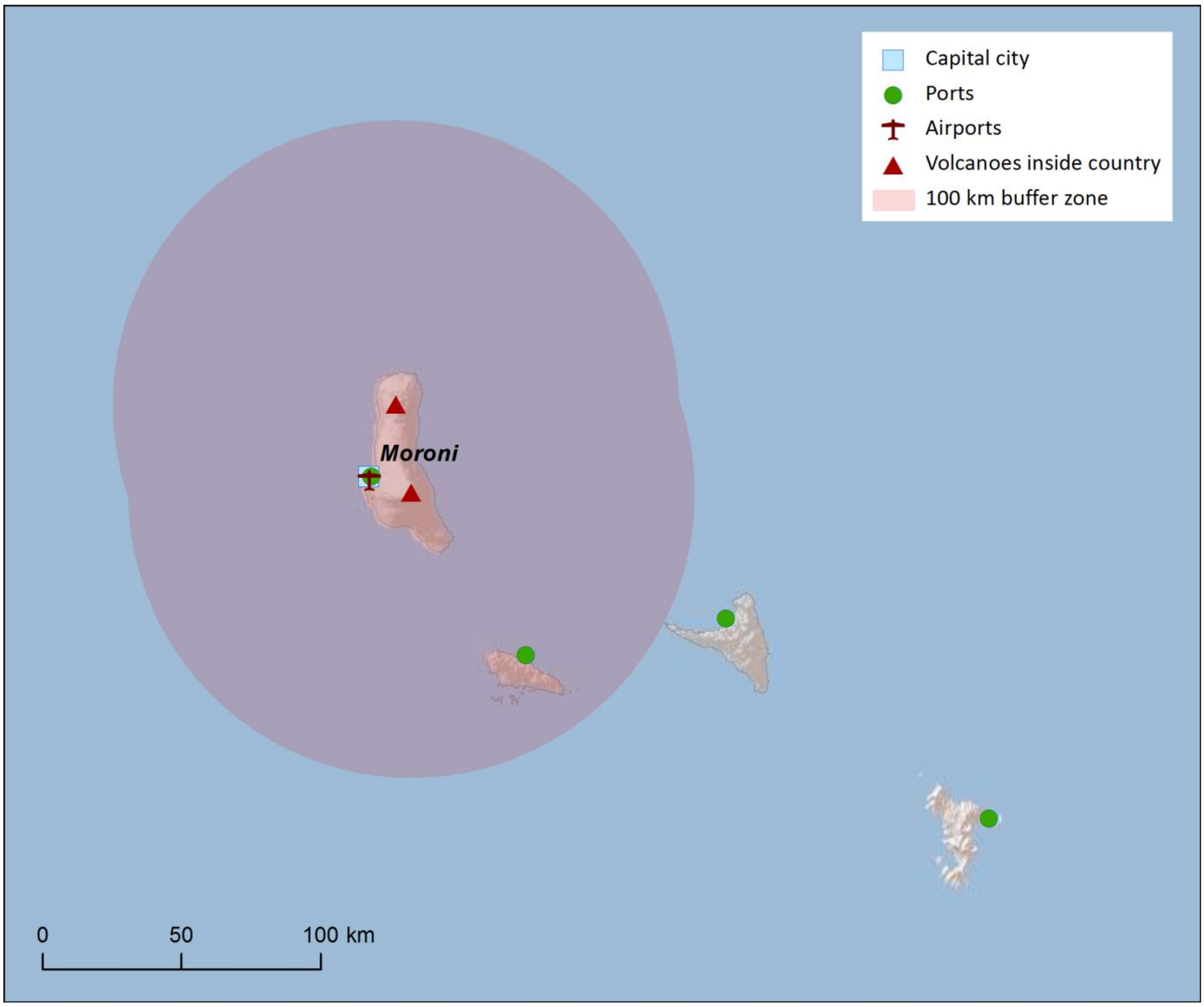


Figure 95: The location of the Comoros' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Karthala volcano in the Comoros has 34 eruptions recorded in the Holocene, all but one of which was recorded since 1800. The majority of these historical eruptions have a known VEI and therefore it has been possible to calculate a hazard score, placing Karthala at Hazard level I with activity being dominantly effusive to moderately explosive.

La Grille volcano has no recorded Holocene eruptions, meaning the hazard level cannot be assigned here.

Both Karthala and La Grille have high local populations, with over 225,000 and over 150,000 within 10 km due in part to the location of these volcanoes on a small ocean island. This large population size coupled with a hazard level of I classifies Karthala at Risk Level I. La Grille's risk level cannot be classified.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I						Karthala	
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR						La Grille	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 93: Identity of the volcanoes of the Comoros in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Karthala	6	II

Table 94: Classified volcanoes of the Comoros ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 1 volcano; Risk Level III – 0 volcanoes.

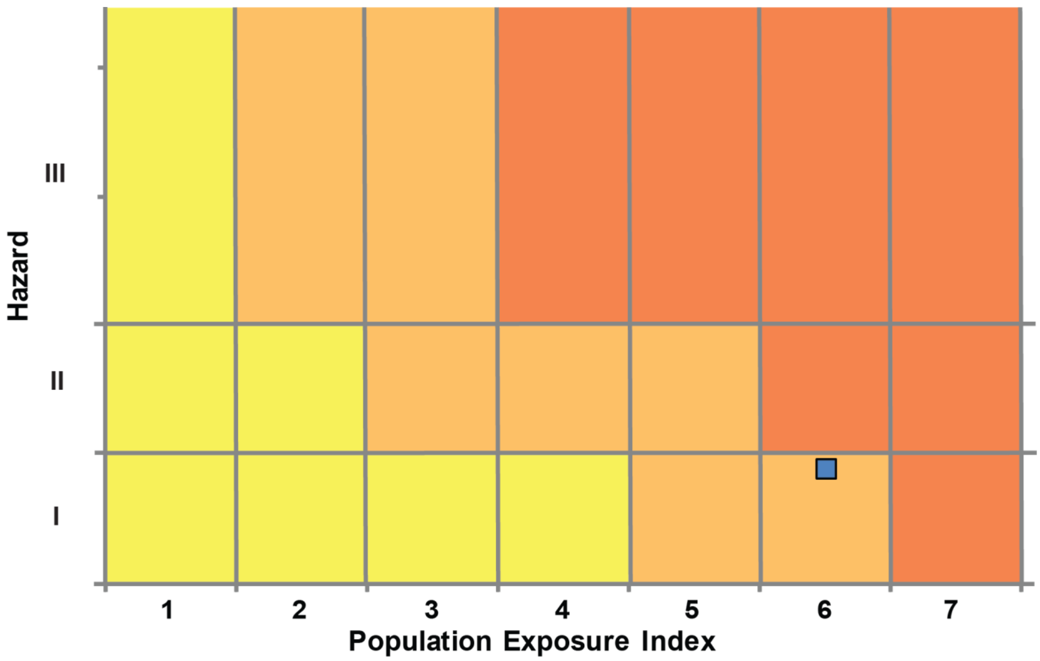


Figure 96: Distribution of the Comoros' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Karthala is the only volcano in the Comoros to have a record of historical activity. This Risk Level II volcano is monitored by the Observatoire Volcanologique du Karthala using a dedicated seismic and deformation network.

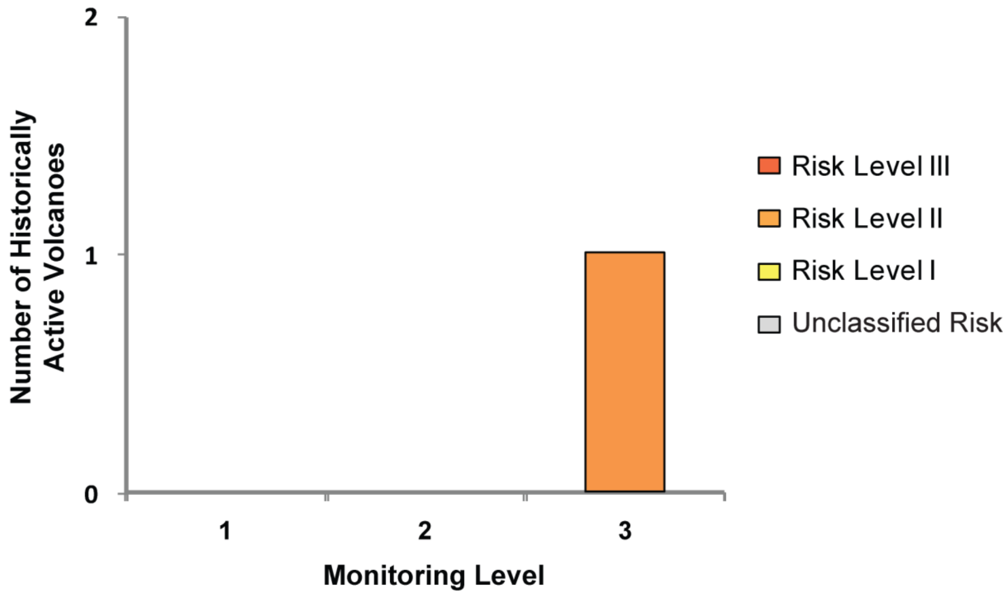


Figure 97: The monitoring and risk levels of the historically active volcanoes in the Comoros. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

France – Multiple islands in the Indian Ocean

Note that here we discuss the overseas territories of France located in the Indian Ocean, including the volcanoes: Mayotte Island, Piton de la Fournaise, Boomerang Seamount, Amsterdam Island, St. Paul, Kerguelen Islands, Ile de l'Est, Ile de la Possession and Ile aux Cochons. See Region 1 for Mainland France and Region 16 for the French territories in the West Indies.

Description

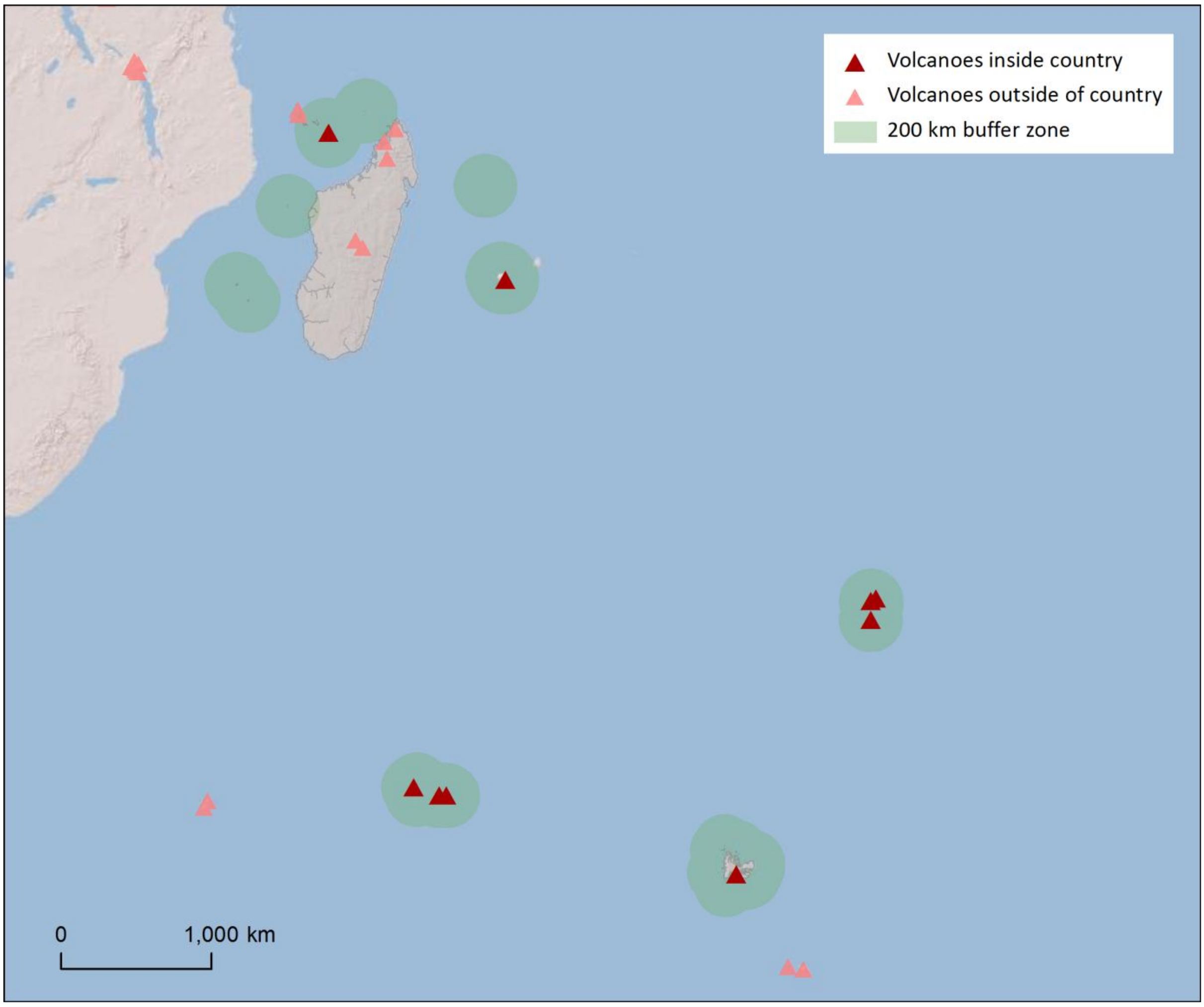


Figure 98: Location of the Indian Ocean French territories volcanoes. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect these islands.

Nine individual Holocene volcanoes are located on islands of French overseas territories in the southern and eastern Indian Ocean. Volcanoes here are due to both rifting and intra-plate hotspot processes.

Four volcanoes have produced 183 confirmed Holocene eruptions. The remaining five volcanoes have activity of suspected Holocene age. Eruptions here ranged in size from VEI 0 to 5, indicating a variety of activity from mild largely effusive events to large explosive activity. However, over 99% of eruptions were VEI 0 to 2. Many of these small eruptions involved the production of lava flows, with lavas being recorded in 151 eruptions. Just one eruption, that of Piton de la Fournaise on Reunion in 2700 BC, was a VEI 5 eruption, producing pyroclastic flows, tephra and a debris avalanche.

Only three volcanoes have recorded historical activity – Piton de la Fournaise, St. Paul and Boomerang Seamount. 171 eruptions are recorded since 1500 AD at these volcanoes, demonstrating the sparse nature of the record prior to historical times. Indeed, over 90% of eruptions here are dated through direct observations.

With the exception of Réunion, all of the French Southern overseas territories have no permanent population living within 100 km distance of the Holocene volcanoes. Piton de la Fournaise on Réunion has a high local population, with over 55,000 people living within 10 km. This is the only volcano with a well constrained hazard assessment (VHI) based on a populous eruption record, all others have considerable uncertainties associated with the calculation of VHI. Given the frequent activity of Piton de la Fournaise and the proximal population, this volcano has the highest risk ranking of the French islands in the Indian Ocean.

The Observatoire Volcanologique du Piton de la Fournaise (OVPF) was founded in 1980, as part of the Insitut de Physique du Globe de Paris (IPGP)). The OVPF monitors the activity on Réunion using seismic, deformation, and gas emission networks, in additional to other monitoring techniques such as radon gas detection and magnetic profile studies. In addition to ground-based monitoring systems, the OVPF-IPGP have access to Earth Observation data. An alarm system is operated to alert staff to activity outside of work hours and about three quarters of personnel at the OVPF have experience of responding to eruptions.

The OVPF-IPGP has developed set protocols to follow in the event of unrest or eruption. The Préfet (representative of the national government) is contacted by the OVPF for the declaration of alerts and the regional VAAC is contacted if necessary.

The OVPF are involved in a program of hazard education for the public and participate in risk assessments, management and mitigation of risk.

See also:

L'observatoire de la Réunion – OVPF, http://www.ipgp.fr/pages/03030809.php

Volcano Facts

Number of Holocene volcanoes	9
Number of Pleistocene volcanoes with M≥4 eruptions	2, also 1 in Kerguelen Islands
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	3
Tectonic setting	3 intra-plate, 6 rift zone

Largest recorded Pleistocene eruption	The 221 ka M6.3 Dalle Soudee Formation eruption of Piton des Nieges.
Largest recorded Holocene eruption	M5.3 Bellecombe Ash eruption at 4650 BP from Piton de la Fournaise.
Number of Holocene eruptions	183 confirmed eruptions
Recorded Holocene VEI range	0 – 5 and unknown.
Number of historically active volcanoes	3
Number of historic eruptions	171

Number of volcanoes	Primary volcano type	Dominant rock type
2	Shield(s)	Basaltic (2)
6	Large Cone(s)	Basaltic (6)
1	Submarine	Basaltic (1)

Table 95: The number of volcanoes in the French Islands of the Indian Ocean, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (from http://www.cartesfrance.fr/)	Reunion 2006: 781,962 Mayotte 2007: 186,452
Gross Domestic Product (GDP) per capita (2005 PPP $)	-
Gross National Income (GNI) per capita (2005 PPP $)	-
Human Development Index (HDI) (2012)	-

Population Exposure

Capital city	Saint-Denis, Réunion
Distance from capital city to nearest Holocene volcano	48.5 km (Réunion)
Population in 30km	246,792 (Réunion, Mayotte)

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	5
Total length of roads within 100 km of a volcano (km)	312
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes here are located on a number of islands across the west and south Indian Ocean. Being small islands, the 100 km radii of the volcanoes encompasses each in their entirety, with the exception of the most northerly tip of Kerguelen. Infrastructure including ports, an airport and road network are exposed on Mayotte and Réunion, and Port-aux-Français the capital settlement of Kerguelen is also exposed. All critical infrastructure is exposed on these French islands.

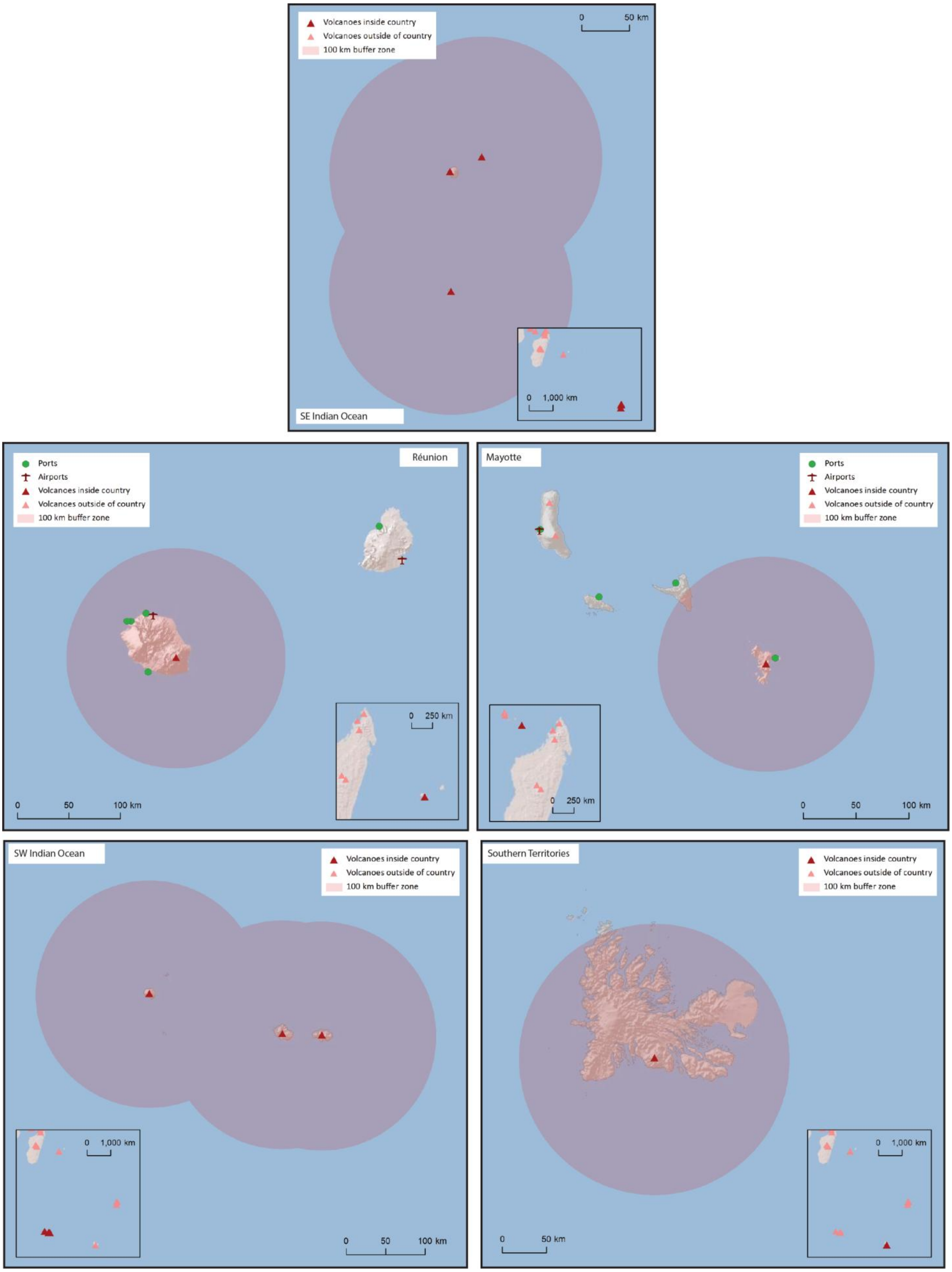


Figure 99: The location of France's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

With the exception of Piton de la Fournaise, where the eruptive history is quite detailed and hence the hazard score is well constrained, all volcanoes in this region are unclassified. Of these unclassified volcanoes, five have no confirmed eruptions in the Holocene. Mayotte Island has a Holocene eruptive record, and Boomerang Seamount and St Paul have historical eruptions. An eruption was recorded at Boomerang Seamount in 1995.

Piton de la Fournaise has a record of 178 Holocene eruptions, all but nine of which are recorded historically. Most of these eruptions were of VEI 2. This volcano is classed at Hazard Level II.

With the exception of Réunion, all of the French Southern territories have no permanent population living within 100 km distance of the Holocene volcanoes, and hence their PEI levels are low at PEI 1. Piton de la Fournaise on Réunion is assigned a high PEI of 5, with over 700,000 within 100 km and over 55,000 people living within 10 km and is therefore is categorised at Risk Level II.

CLASSIFIED	**Hazard III**							
	Hazard II					Piton de la Fournaise		
	Hazard I							
UNCLASSIFIED	**U – HHR**	**Boomerang Seamount**; St. Paul						
	U- HR	Mayotte Island						
	U- NHHR	Amsterdam Island; Kerguelen Islands; Est, Ile de l'; Possession, Ile de la; Cochons, Ile aux						
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 96: Identity of the volcanoes of the French territories in the Indian Ocean in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Fournaise, Piton de la	5	II

Table 97: Classified volcanoes of French territories in the Indian Ocean ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 1 volcano; Risk Level III – 0 volcanoes.

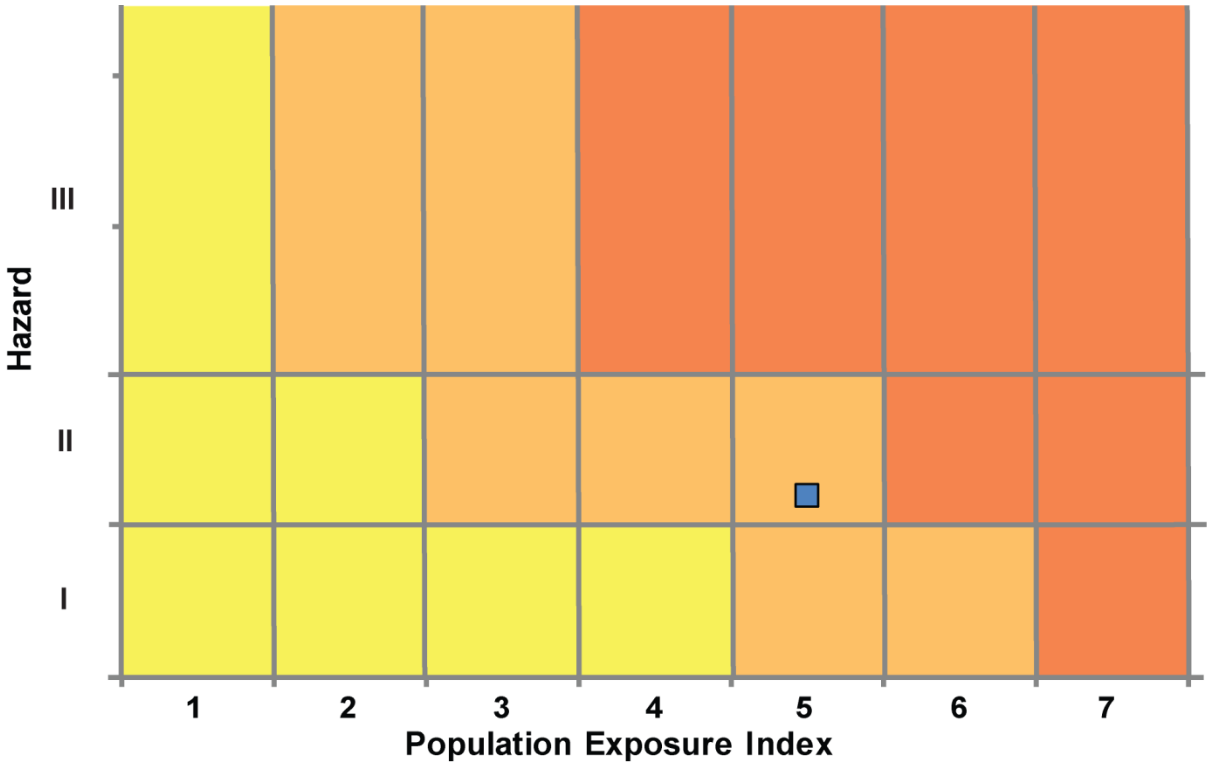


Figure 100: Distribution of the classified volcanoes of France's territories in the Indian Ocean across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Three volcanoes have historical records of activity, St.Paul, Piton de la Fournaise and the submarine Boomerang Seamount. Of these, no information is available at the time of the writing of this report to indicate that dedicated ground-based monitoring is present at the unclassified volcanoes (St.Paul and Boomerang Seamount). However, the Observatoire Volcanologique du Piton de la Fournaise extensively monitors the activity of the Risk Level II Piton de la Fournaise volcano using multiple monitoring systems including seismic, deformation and gas networks.

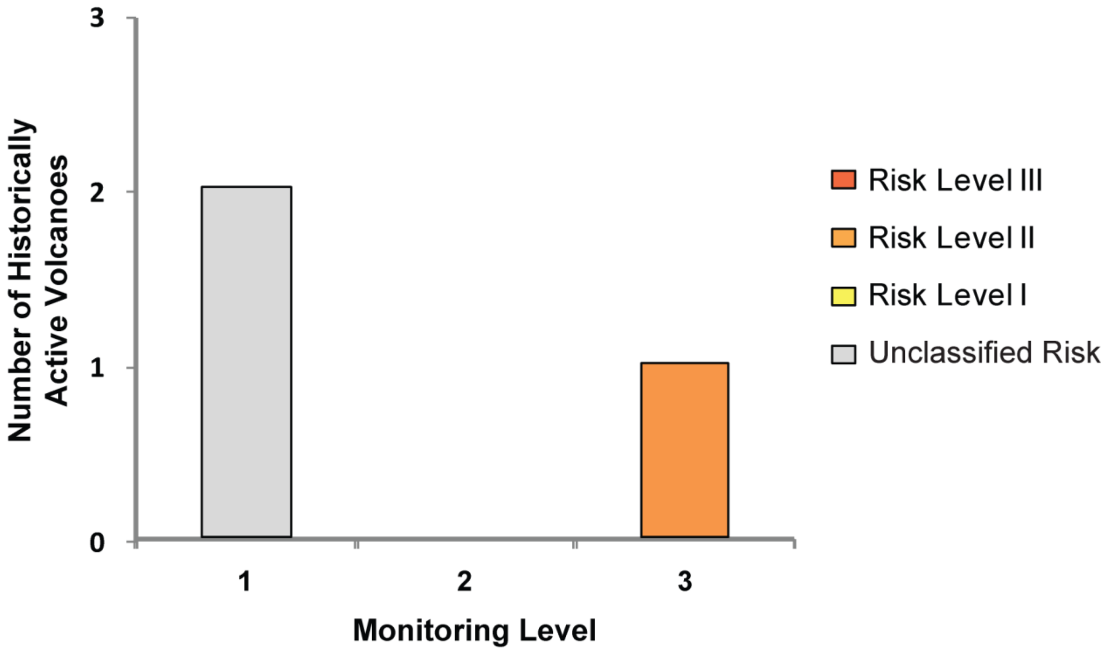


Figure 101: The monitoring and risk levels of the historically active volcanoes in the French territories in the Indian Ocean. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Iran

Description

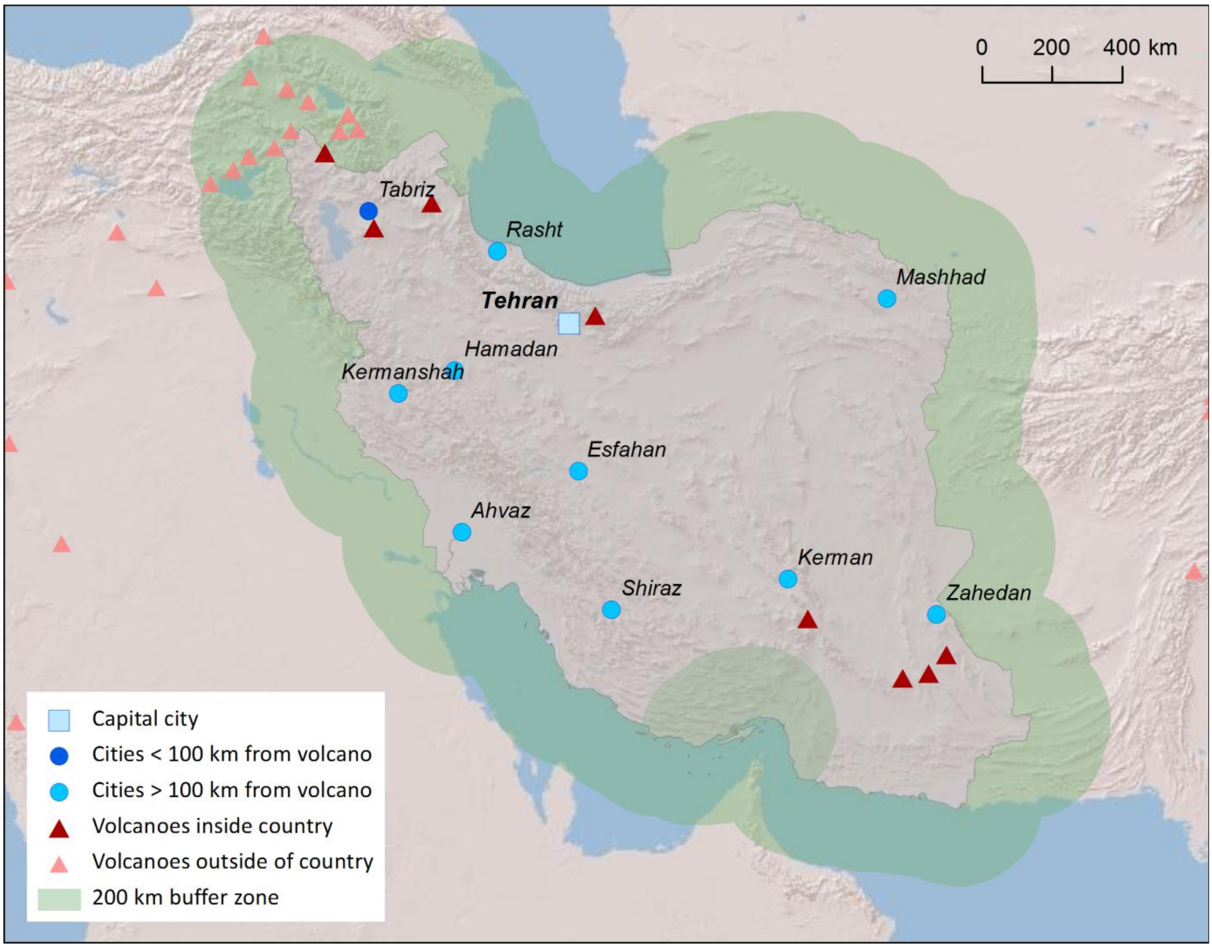


Figure 102: Location of Iran's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Iran.

Eight volcanoes are located in Iran, including one on the border with Azerbaijan. Iran's volcanism is due to intra-plate processes. All but one volcano, the Qal'eh Hasan Ali maar, are andesitic stratovolcanoes or basaltic volcanic fields.

Just one of these volcanoes has a Holocene record of confirmed eruptions. Damavand, a large stratovolcano that lies about 70 km northeast of Tehran, Iran's capital, had a VEI 0 eruption in 5350 BC. During this eruption effusion of lava flows occurred at the summit vent, covering the western flanks of the volcano. A large explosive eruption of Damavand is recorded in the Pleistocene, with the M5.4 eruption of the Ask Ignimbrite about 280,000 years ago.

Besides Damavand, none of the other volcanoes have a Holocene eruption record, however activity of this age is suspected. No historical activity is recorded anywhere in Iran, however unrest is recorded since 1900 at five of Iran's volcanoes, including the presence of fumaroles and hot springs at Damavand.

Given the very sparse eruption histories for volcanoes in Iran, all have large uncertainties associated with the assessment of hazard.

The size of the local population varies considerably at Iran's volcanoes, with small to large local populations. A large population is located within 100 km of Damavand, given the presence of Tehran within this distance.

The Asian Disaster Reduction Center (ADRC) produced a report on the hazards in Iran in 2013. In this they do not consider volcanic hazards, but describe the efforts in Iran in disaster preparedness and response capacity at national and local levels. See the ADRC report (listed below) for full details.

The National Disaster Management Organisation (NDMO) was formed in 2008 to respond to natural disasters and to develop a management system for development of plans and policies and coordination of research. They also are working to implement actions following the Hyogo Framework for Action (HFA).

See also:

Asian Disaster Reduction Center: Iran:
http://www.adrc.asia/nationinformation.php?NationCode=364&Lang=en&NationNum=38

National Disaster Management Organisation: http://www.ndmo.org/

Volcano Facts

Number of Holocene volcanoes	8, inclusive of one on the border with Azerbaijan
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	The M5.4 eruption of the Ask Ignimbrite from Damavand at 280 ka.
Largest recorded Holocene eruption	The VEI 0 eruption of Damavand in 5350 BC.
Number of Holocene eruptions	1 confirmed eruption. 2 uncertain eruptions.
Recorded Holocene VEI range	0
Number of historically active volcanoes	0
Number of historic eruptions	0

Number of volcanoes	Primary volcano type	Dominant rock type
5	Large cone(s)	Andesitic (5)
3	Small cone(s)	Basaltic (2), Unknown (1)

Table 98: The number of volcanoes in Iran, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	76,367,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	10,462
Gross National Income (GNI) per capita (2005 PPP $)	10,695
Human Development Index (HDI) (2012)	0.742 (High)

Population Exposure

Capital city	Tehran
Distance from capital city to nearest Holocene volcano	69.5 km
Total population (2011)	77,891,220
Number (percentage) of people living within 10 km of a Holocene volcano	7,639 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	366,121 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	20,032,430 (25.7%)

Ten largest cities, as measured by population, and populations:

Tehran	7,153,309
Mashhad	2,307,177
Esfahan	1,547,164
Tabriz	1,424,641
Shiraz	1,249,942
Ahvaz	841,145
Kermanshah	621,100
Rasht	594,590
Kerman	577,514
Zahedan	551,980

Infrastructure Exposure

Number of airports within 100 km of a volcano	4
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	6,574
Total length of railroads within 100 km of a volcano (km)	1,583

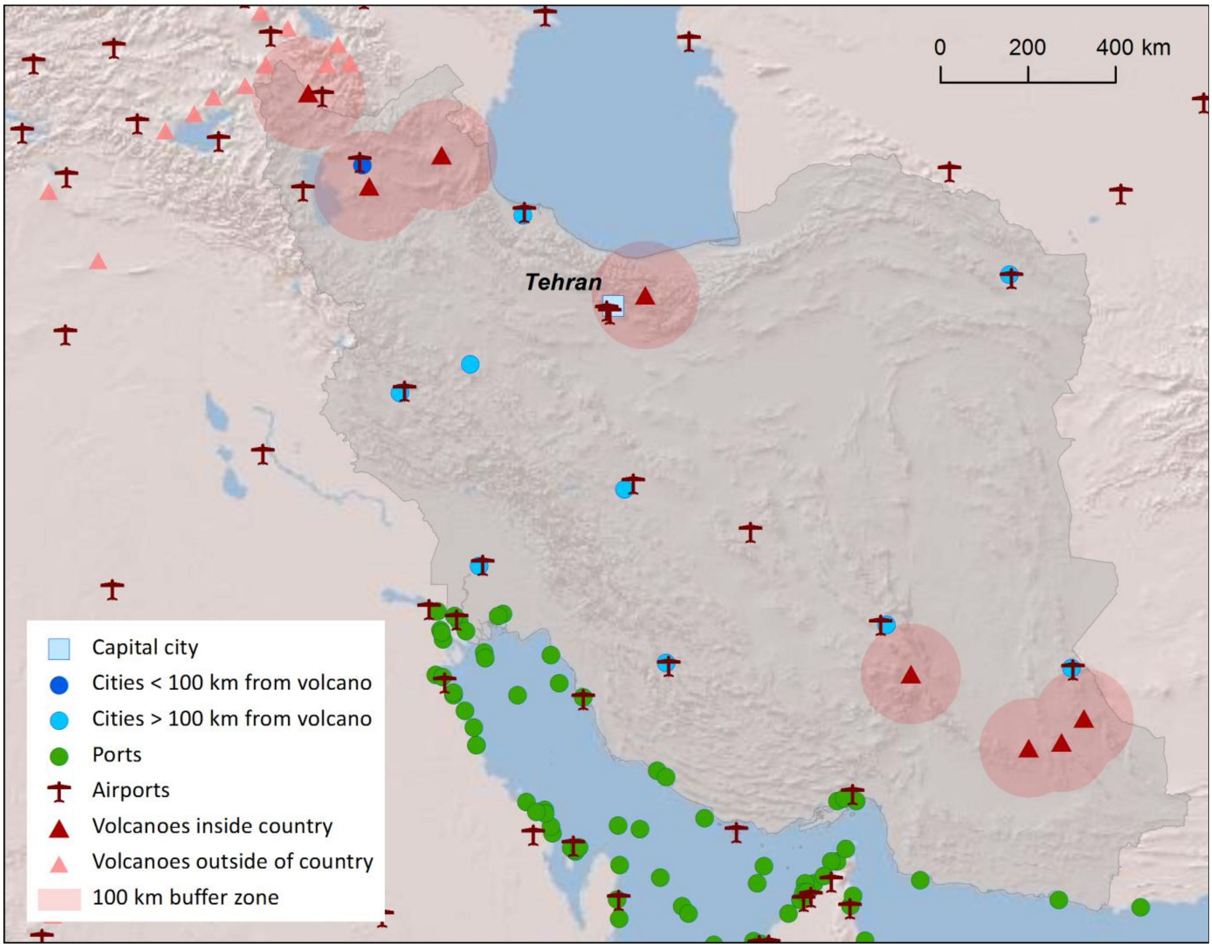


Figure 103: The location of Iran's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The volcanoes in Iran are distributed across the country, with a group located in the south and another in the north-west. Taftan volcano in the south is located near the border with Pakistan, and as such the 100 km radius around this volcano extends into Pakistan. The 100 km radius for Sabalan volcano in the north extends beyond the border into Azerbaijan. The Unnamed volcano on the border between Iran and Azerbaijan has a 100 km radius extending into both countries as well as Armenia and Turkey. Volcanoes close to the borders in these other countries also have radii extending into Iran, exposing infrastructure here. The capital of Iran, Tehran, is situated less than 70 km from Damavand volcano, exposing critical infrastructure, including airports and an extensive road and rail network. In addition to this, one of the other largest cities in Iran, Tabriz, is located within 40 km of Sahand volcano.

Hazard, Uncertainty and Exposure Assessments

Of all the volcanoes of Iran, only Damavand has a confirmed Holocene eruptive record, and this is of just one event. Taftan in SE Iran has periods of unrest described since 1900 AD comprising smoking, glow and a possible lava flow. The absence of an extensive eruptive history for these volcanoes means that assessment of hazard would be associated with large uncertainties, and as such these volcanoes are unclassified in both hazard and risk.

The PEI ranges from low to high, with Damavand and an unnamed volcano having PEI values of 5.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR					Damavand		
	U- NHHR		Bazman; **Taftan**	Sabalan; Qal'eh Hasan Ali; Unnamed (232040)	Sahand	Unnamed (232000)		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 99: Identity of Iran's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Iran have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Iran.

Madagascar

Description

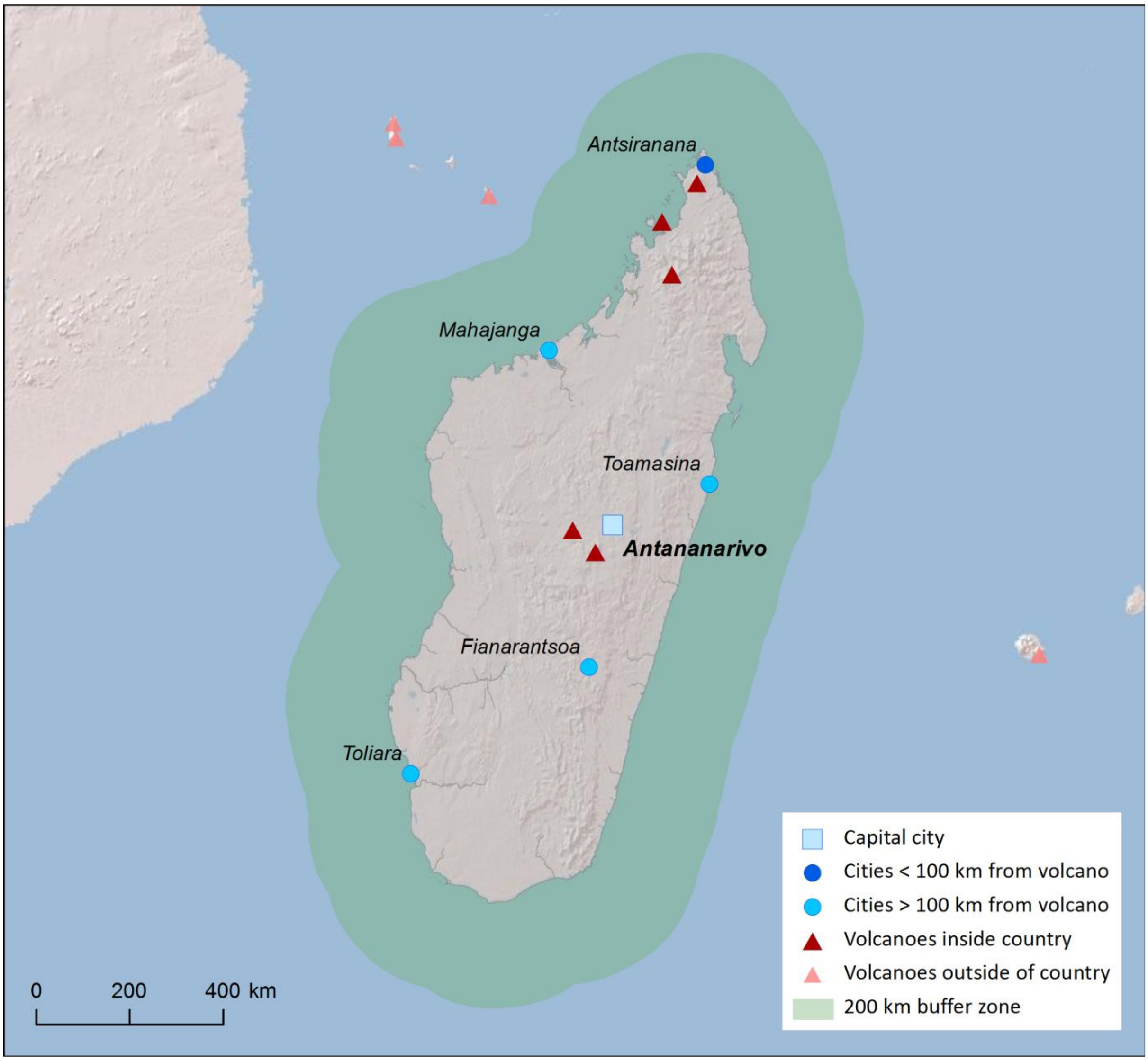


Figure 104: Location of Madagascar's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Madagascar.

Five Holocene volcanoes are located in Madagascar, due to the presence of an intra-plate volcanic hotspot off the south-east coast of Africa.

The volcanic field Ambre-Bobaomby and two groups of cinder cones – Nosy Be and Ankaizina Field lie in the north of the country. These volcanoes have suspected Holocene activity, but no confirmed eruptions. The more acidic Itasy Volcanic Field and Ankaratra Field are situated in the centre of Madagascar. Two confirmed Holocene eruptions are recorded in VOTW4.0 at Itasy Volcanic Field, with the most recent occurring in 6050 BC. However, there is evidence of recent activity in this field, with an eruption identified through satellite imagery as recently as 2000 or 2001 AD at Kassigie scoria cone[1].

Unrest has been recorded at Itasy Volcanic Field and Ankaratra Volcanic Field since 1900, with minor seismic activity and hot springs at both volcanic centres.

The capital of Madagascar, Antananarivo, is situated within about 70 km of both central volcanic fields. This places much of the critical infrastructure within the 100 km exposure radii of the volcanoes. Antisiranana, another of the largest cities in Madagascar, lies within 100 km of Ambre-Bobaomby volcano in the north. Around 30% of the total population in the country lives within 100 km of one or more Holocene volcano.

The assignment of hazard scores at Madagascar's volcanoes is associated with significant uncertainties due to the sparse eruptive history, and all volcanoes are classed at Hazard Level I, with both central volcanoes potentially increasing to Hazard Level III. Recent activity has been minor and only lava flows are recorded in the Holocene. However, over 120,000 people live within 5 km of Itasy and Akaratra Fields, and even minor effusions and explosions could rapidly impact on these populations. Lava flows are normally not a threat to life, however the large population suggests significant infrastructure here and even small eruptions could cause property damage and loss of livelihoods. Indeed, despite the current assignment of Hazard Level I to these volcanoes, they are ranked at Risk Level II to III.

Bibliography

[1] Universität Bern/Université d'Antananarivo press release. Active volcanism in Madagascar: The Kassigie eruptions in 2000/2001. Issued 16 March 2011. http://www.geo.unibe.ch/news/medien/madagaskar/PR110316_Madagascar_Schreurs_E.pdf

Volcano Facts

Number of Holocene volcanoes	5
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Both eruptions were of unknown VEI.
Number of Holocene eruptions	2 confirmed eruptions
Recorded Holocene VEI range	0

Number of historically active volcanoes	-
Number of historic eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
5	Small cone(s)	Basaltic (3), Foiditic (1), Trachytic / Andesitic (1)

Table 100: The number of volcanoes in Madagascar, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	22,360,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	853
Gross National Income (GNI) per capita (2005 PPP $)	828
Human Development Index (HDI) (2012)	0.483 (Low)

Population Exposure

Capital city	Antananarivo
Distance from capital city to nearest Holocene volcano	63.1 km
Total population (2011)	21,926,221
Number (percentage) of people living within 10 km of a Holocene volcano	50,873 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	709,349 (3.2%)
Number (percentage) of people living within 100 km of a Holocene volcano	6,769,724 (30.9%)

Largest cities, as measured by population, and populations:

Antananarivo	1,391,433
Toamasina	2,063,73
Fianarantsoa	167,227
Mahajanga	154,657
Toliara	115,319

Infrastructure Exposure

Number of airports within 100 km of a volcano	2

Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	2,398
Total length of railroads within 100 km of a volcano (km)	0

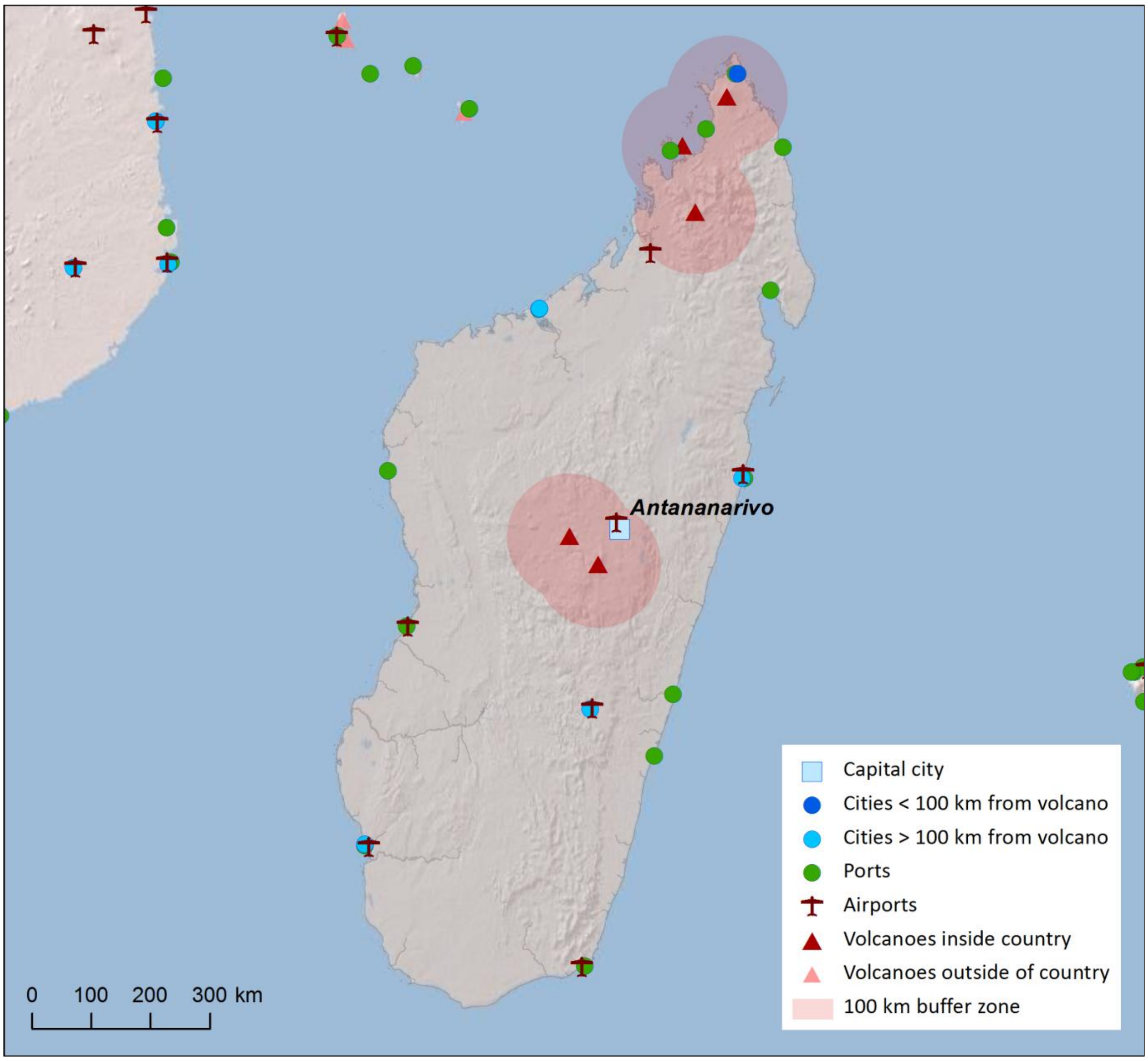


Figure 105: The location of Madagascar's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The volcanoes in Madagascar are distributed in the northern coastal region and in the central highlands. The 100 km radii of the central volcanoes do not reach the coast and therefore do not impact ports, however ports are affected by the northern volcanoes. The capital, Antananarivo, lies within 70 km of both Itasy and Ankaratra Volcanic Fields, therefore considerable critical infrastructure is exposed here, including two airports. One of the other largest cities in Madagascar, Antisiranana, lies within 100 km of Ambre-Bobaomby volcano.

Hazard, Uncertainty and Exposure Assessments

Only Itasy Volcanic Field in Madagascar has a confirmed Holocene eruptive history, with just two eruptions of unknown size. The remaining four volcanoes have no confirmed Holocene activity. The absence of an extensive eruptive history at Madagascar's volcanoes prevents completion of the hazard assessment without significant uncertainties, and as such these volcanoes are unclassified.

Nosy-Be, Ambre-Bobaomby and Ankaizina Field have the smallest local populations and a PEI of 4. Itasy Volcanic Field and Ankaratra Field have larger populations within 100 km, including over 120,000 people living within 10 km at each volcano indicative of increased risk at these volcanoes.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR						Itasy Volcanic Field	
	U- NHHR				Ambre-Bobaomby; Nosy-Be; Ankaizina Field		Ankaratra Field	
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 101: Identity of Madagascar's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Madagascar have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Madagascar.

Pakistan

Description

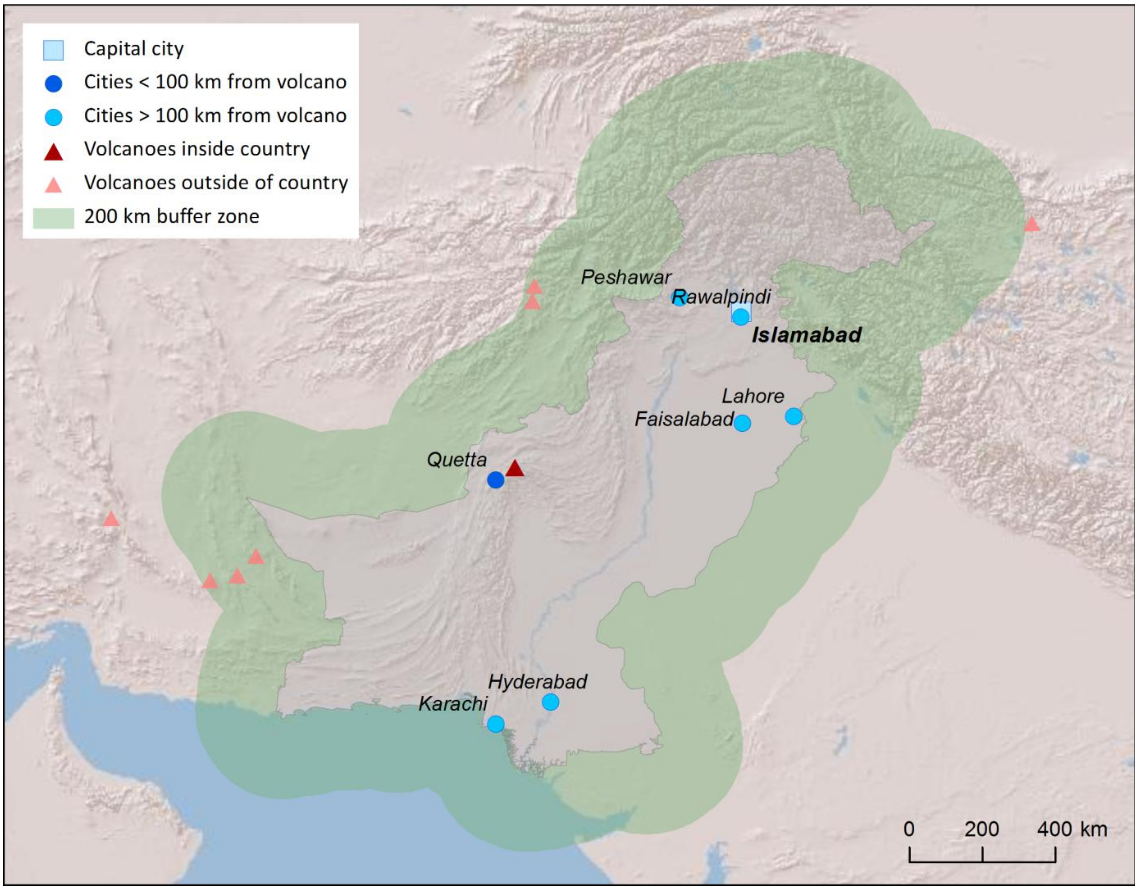


Figure 106: Location of Pakistan's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Pakistan.

Holocene volcanism has been restricted to the Tor Zawar region of west-central Pakistan. The brief Tor Zawar eruption occurred in 2010, producing a scoria/spatter cone and a small lava flow of only 8.2 metres in length. Activity here is theorised as being related to intra-plate processes. However, the origin of the Tor Zawar 'lava' is controversial, with some research indicating that this actually resulted from lightning strikes on steel pylons generating rock fulgurites in Late Cretaceous volcanic rocks (e.g. Kassi et al., 2013).

A small population of less than 10,000 lives within 10 km of Tor Zawar. Past activity indicates effusive events producing very small lava flows, which are likely to only pose a threat to the proximal population. The population within 100 km increases substantially, to just less than 2 million. With only one recorded historical event, the assessment of hazard here is difficult and associated with large uncertainties. Clearly, with controversy surrounding the origin of the Tor Zawar flow, focussed research is required here.

The Asian Disaster Reduction Center (ADRC) produced a report on the hazards in Pakistan in 2009. In this they do not consider volcanic hazards and neither do the National Disaster Management Authority (NDMA). They describe how Pakistan has three levels in their disaster management system: the NDMA, the Provincial Disaster Management Authority (PDMA) and the District Disaster Management Authority (DDMA) which responds first. The National Disaster Management Commission (NDMC) prepares policies and decisions, based on advice from the NDMA. See the full ADRC report for further details of disaster preparedness in Pakistan.

See also:

Kerr, A.C., Khan, M. And McDonald, I. (2010) Eruption of basaltic magma at Tor Zawar, Balochistan, Pakistan on 27 January 2010: geochemical and petrological constraints on petrogenesis, Mineralogical Magazine, 74(6): 1027-1036

Kassi, A.M., Kasi, A. K., Friis, H., and Kakar, D.M. (2013) Occurrences of rock-fulgurites associated with steel pylons of the overhead electric transmission line at Tor Zawar, Ziarat District and Jang Tor Ghar, Muslim Bagh, Pakistan. Turkish Journal of Earth Sciences, 22: 1010-1019.

Asian Disaster Reduction Center: Pakistan: http://www.adrc.asia/nationinformation.php?NationCode=586&Lang=en&NationNum=31

National Disaster Management Authority: http://www.ndma.gov.pk/new/

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The VEI 0 Tor Zawar eruption of 2010 AD.
Number of Holocene eruptions	1 confirmed eruption
Recorded Holocene VEI range	0
Number of historically active volcanoes	1
Number of historic eruptions	1

Number of volcanoes	Primary volcano type	Dominant rock type
1	Small cone(s)	Basaltic (1)

Table 102: The number of volcanoes in Pakistan, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	180,077,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	2,424
Gross National Income (GNI) per capita (2005 PPP $)	2,566
Human Development Index (HDI) (2012)	0.515 (Low)

Population Exposure

Capital city	Islamabad
Distance from capital city to nearest Holocene volcano	483.3 km
Total population (2011)	187,342,721
Number (percentage) of people living within 10 km of a Holocene volcano	9,843 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	111,578 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	1,975,660 (1.1%)

Largest cities, as measured by population, and populations:

Karachi	11,624,219
Lahore	6,310,888
Faisalabad	2,506,595
Rawalpindi	1,743,101
Hyderabad	1,386,330
Peshawar	1,218,773
Quetta	733,675
Islamabad	601,600

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	0

Total length of roads within 100 km of a volcano (km)	615
Total length of railroads within 100 km of a volcano (km)	318

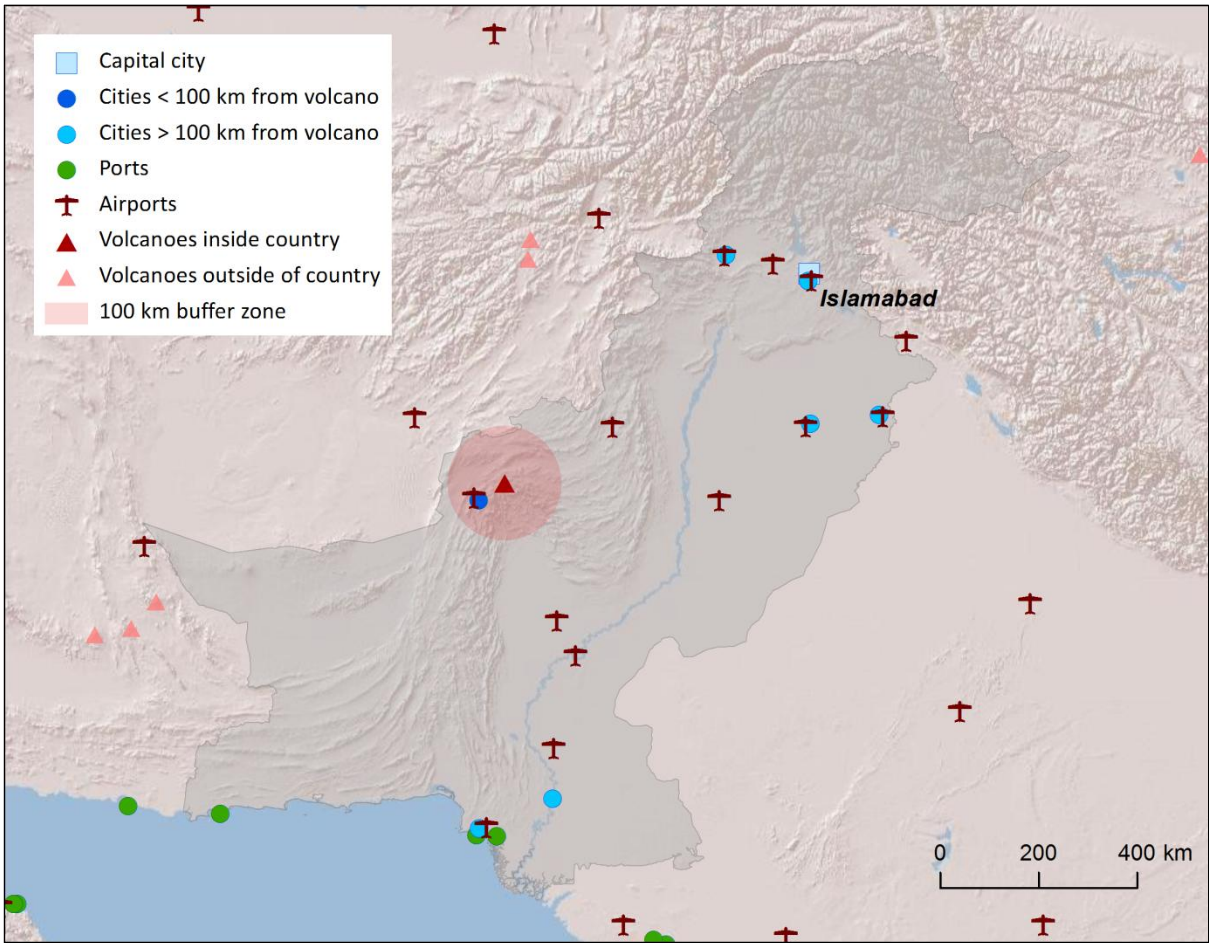


Figure 107: The location of Pakistan's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The Tor Zawar volcano is located in west central Pakistan, within 60 km of one of the largest cities in Pakistan, Quetta and hence exposing significant infrastructure here, including an airport and extensive road and rail network. The capital, Islamabad, is distal to this volcano, located in northern Pakistan. The 100 km radius surrounding Tor Zawar extends for a short distance into neighbouring Afghanistan.

Hazard, Uncertainty and Exposure Assessments

Just one Holocene eruption is recorded at Tor Zawar, making hazard assessment without significant uncertainties impossible. This volcano is therefore unclassified.

There is only a small local population to Tor Zawar, suggestive of a low risk level.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR	Tor Zawar						
	U- HR							
	U- NHHR							
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 103: Identity of Pakistan's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Tor Zawar has been historically active, however no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at here.

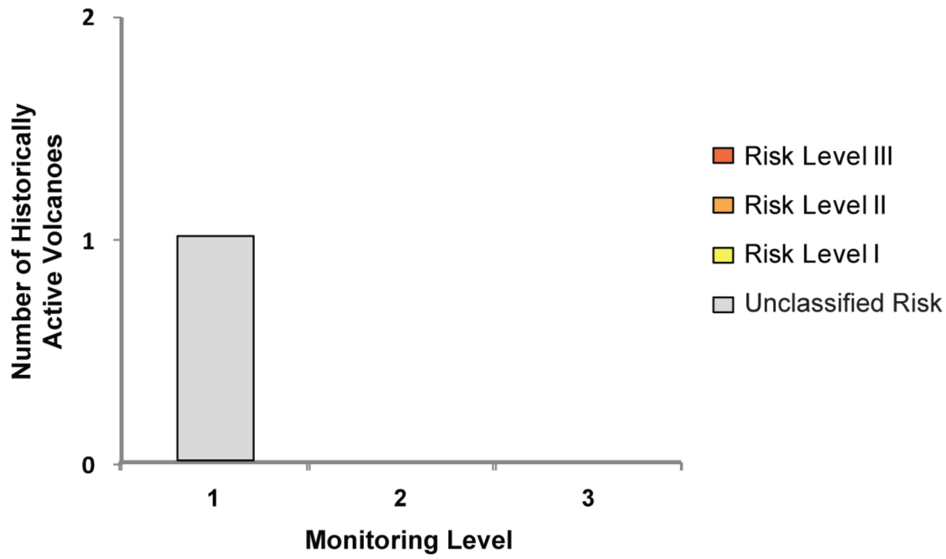


Figure 108: The monitoring and risk levels of the historically active volcanoes in Pakistan. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Saudi Arabia

Description

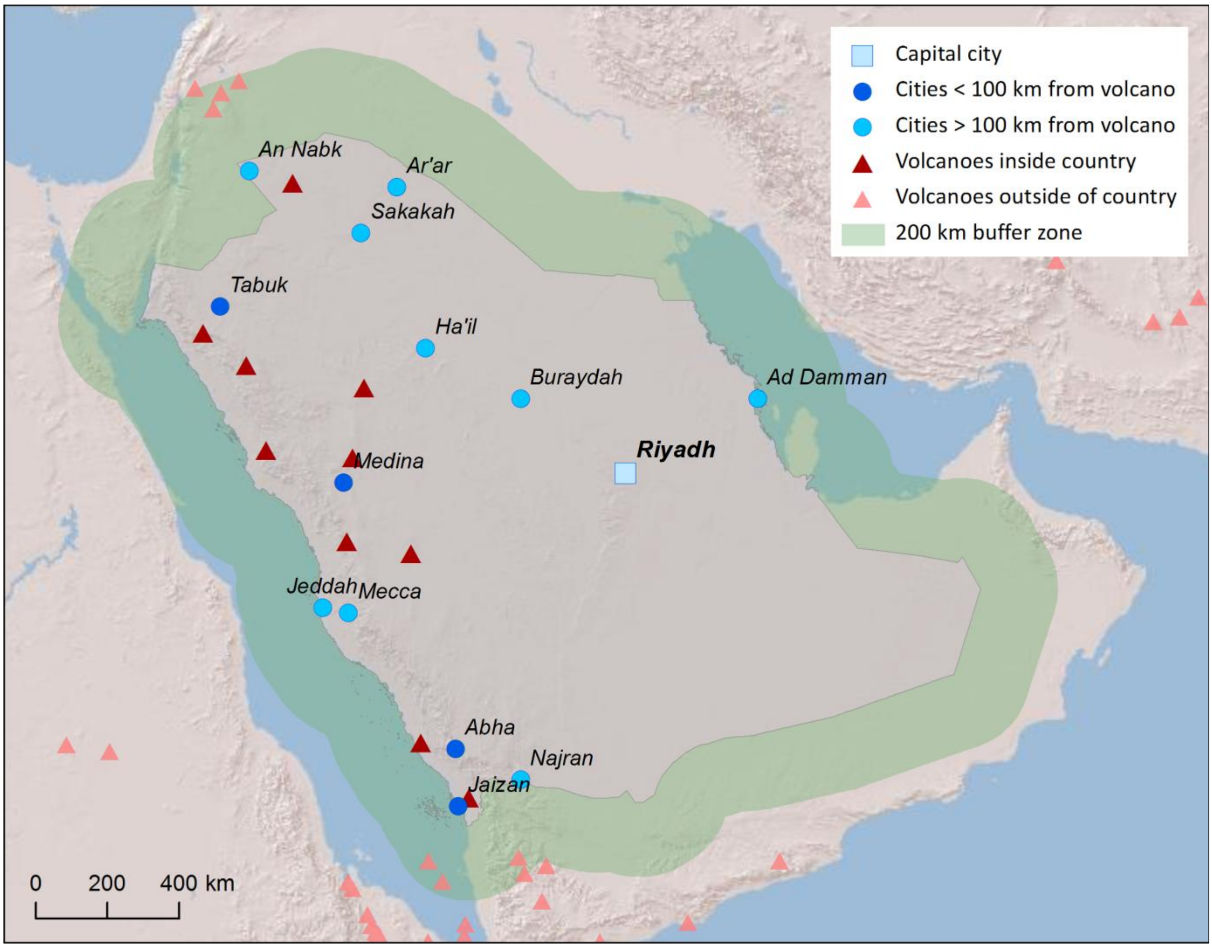


Figure 109: Location of Saudi Arabia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Saudi Arabia.

Ten Holocene volcanic fields are located in Saudi Arabia. These volcanic fields are distributed primarily through the west of the country, from Al Harrah in north-western Saudi Arabia, near the border with Jordan, to the southernmost Jabal Yar, near the border with Yemen. Volcanism here is due to intra-plate processes. The Saudi Arabian basaltic volcanic fields comprise multiple cones, vents and lava fields.

Five volcanic fields have confirmed Holocene records of eruptions, producing six eruptions. The remaining five Holocene volcanic fields have activity of suspected Holocene age. Only a small range of eruption sizes are recorded here, of VEI 2 and 3, indicating mild to moderate size events. Three of these eruptions have records of associated lava flows. The largest eruption was the VEI 3 eruption of Harrat Rahat in 1256 AD, in which a 23 km long lava flow was produced from an alignment of scoria cones, which reached within 4 km of Medina, now one of the most populous cities in Saudi Arabia. Although no pyroclastic flows are recorded here during dated eruptions, pyroclastic flow and surge deposits are found at this volcano and more silicic rocks have been produced in the past.

The only historically active volcanic field in Saudi Arabia is Jabal Yar. The last eruption recorded was a VEI 2 event in 1810. Unrest has been recorded since 1900, with active hot springs identified. Activity at volcanoes in the Red Sea can affect Saudi Arabia, and eruptions of Jebel at Tair (2007) and a new island in 2012 produced vesicular products that washed up on the south-western shores of Saudi Arabia.

The assessment of hazard at all of Saudi Arabia's volcanic fields is complicated by sparse eruption histories, and hence large uncertainties.

Several of Saudi Arabia's most populous cities are within 100 km of one or more Holocene volcanic fields. This exposes a large population, with about 4.6 million (~18% of the country's population) living within this radius. Several volcanic fields have very high populations located within just 10 km, in part due to the expansive nature of volcanic fields and widespread nature of the vents. Were activity to occur of a similar size to that of the Holocene record, lava flows and localised minor explosive activity could be a feature, and these hazards would particularly affect people living within this 10 km distance.

The Saudi Geological Survey (SGS) maintain a seismograph network on the Medina side of Harrat Rahat to monitor for signs of volcanic activity, and also monitors the temperatures of hot springs at volcanic fields across the country. The SGS is responsible for the monitoring of the volcanic fields and provides publically accessible information about the activity in the country. They work to mitigate risks and negate the negative effects of geological hazards. They operate a public hazard education program. In the event of unrest or eruption, the SGS report on activity and damage incurred and provide advice and recommendations to the relevant civil authorities, including the Civil Defence, Ministry of Water and Electricity, Ministry of Municipal and Rural Affairs, Ministry of Transportation, and Ministry of Culture and Information.

Note that all 'volcanoes' discussed here are volcanic fields normally comprising multiple, monogenetic (single eruption) vents.

See also:

Saudi Geological Survey: Volcanoes
http://www.sgs.org.sa/English/NaturalHazards/Pages/Volcanoes.aspx

Volcano Facts

Number of Holocene volcanoes	10
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	3

Number of fatalities caused by volcanic eruptions	?15
Tectonic setting:	Intra-plate
Largest recorded Pleistocene eruption: -	-
Largest recorded Holocene eruption:	The VEI 3 eruption of Harrat Rahat in 1256 AD.
Number of Holocene eruptions:	6 confirmed eruptions. 1 uncertain eruption
Recorded Holocene VEI range:	2 – 3 and unknown.
Number of historically active volcanoes	1
Number of historic eruptions	1

Number of volcanoes	Primary volcano type	Dominant rock type
10	Small cone(s)	Basaltic (10)

Table 104: The number of volcanoes in Saudi Arabia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	28,396,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	21,430
Gross National Income (GNI) per capita (2005 PPP $)	22,616
Human Development Index (HDI) (2012)	0.782 (High)

Population Exposure

Capital city	Riyadh
Distance from capital city to nearest Holocene volcano	585.5 km
Total population (2011)	26,131,703
Number (percentage) of people living within 10 km of a Holocene volcano	211,757 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	637,123 (2.4%)
Number (percentage) of people living within 100 km of a	4,623,079 (17.7%)

Holocene volcano

Ten largest cities, as measured by population, and populations:

Riyadh	4,205,961
Jeddah	2,867,446
Mecca	1,323,624
Medina	1,300,000
Tabuk	455,450
Buraydah	391,336
Najran	258,573
Abha	210,886
Sakakah	128,332
An Nabk	49,372

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	5
Total length of roads within 100 km of a volcano (km)	5,355
Total length of railroads within 100 km of a volcano (km)	0

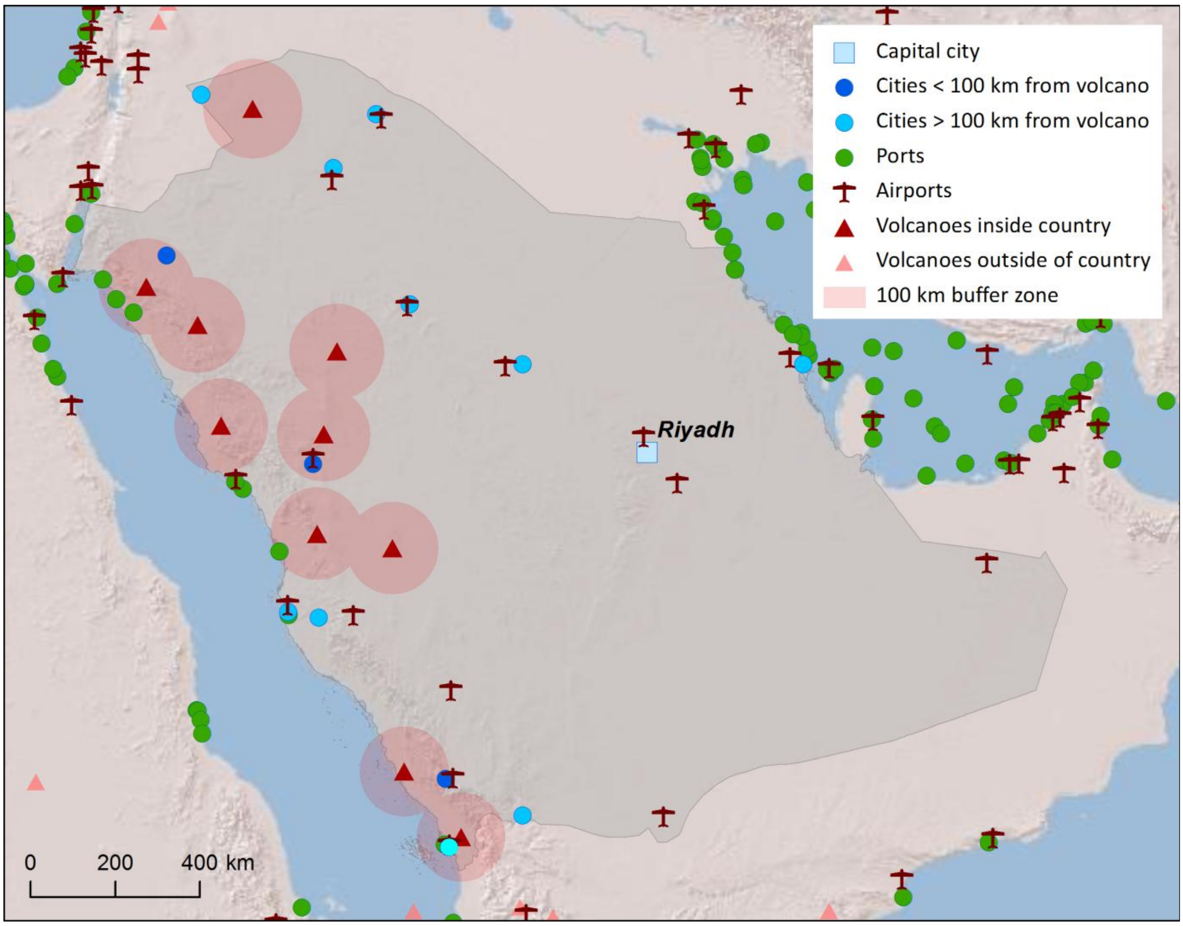


Figure 110: The location of Saudi Arabia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The volcanoes in Saudi Arabia are distributed along the western stretch of the country, bordering the Red Sea. The southernmost volcano, Jabal Yar, is located near the border with Yemen and the 100 km radius for this volcano extends into Yemen, exposing infrastructure here. In the north, the 100 km radius around the Al Harrah volcano extends into neighbouring Jordan. The capital of Saudi Arabia, Riyadh, is located to the east of the volcanic belt, distal to the volcanoes. However, several major cities are situated within the 100 km radii of Saudi Arabia's volcanoes, including Tabuk, Medina, Abha and Jazan, exposing considerable critical infrastructure, including ports, airports and an extensive road network.

Hazard, Uncertainty and Exposure Assessments

The eruptive history of Saudi Arabia's volcanoes is sparse. There are no confirmed Holocene eruptions at 5 out of the 10 volcanoes here. Harrat Khaybar, Harrat 'Uwayrid and Harrat Lunayyir have a Holocene record of just one eruption each, whilst Harrat Rahat has two confirmed events. Jabal Yar is the only volcano in Saudi Arabia with a confirmed historical eruption, which occurred in 1810. The absence of an extensive record for the volcanoes here prevents hazard assessment without large uncertainties, and as such these volcanoes are unclassified.

The PEI ranges from low to very high at the Saudi Arabian volcanoes, with four volcanoes with high PEI's of 5 – 7. Harrat Rahat, Jabal Yar and Al Harrah all have very high populations living within 10 km, at over 1 million, over 290,000 and over 276,000 respectively.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR						Jabal Yar	
	U- HR		Harrat 'Uwayrid,; **Harrat Lunayyir**		Harrat Khaybar			Harrat Rahat
	U- NHHR		Harrat ar Rahah	Harrat Ithnayn; Harrat Kishb		Harrat al Birk	Al Harrah	
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 105: Identity of Saudi Arabia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Only one volcano, Jabal Yar, has a record of historical activity. At the time of the writing of this report, there was no information available to indicate the presence of a dedicated monitoring system at Jabal Yar. A national seismic network is located in Saudi Arabia and the Saudi Geological Survey monitor some Holocene volcanoes in the country.

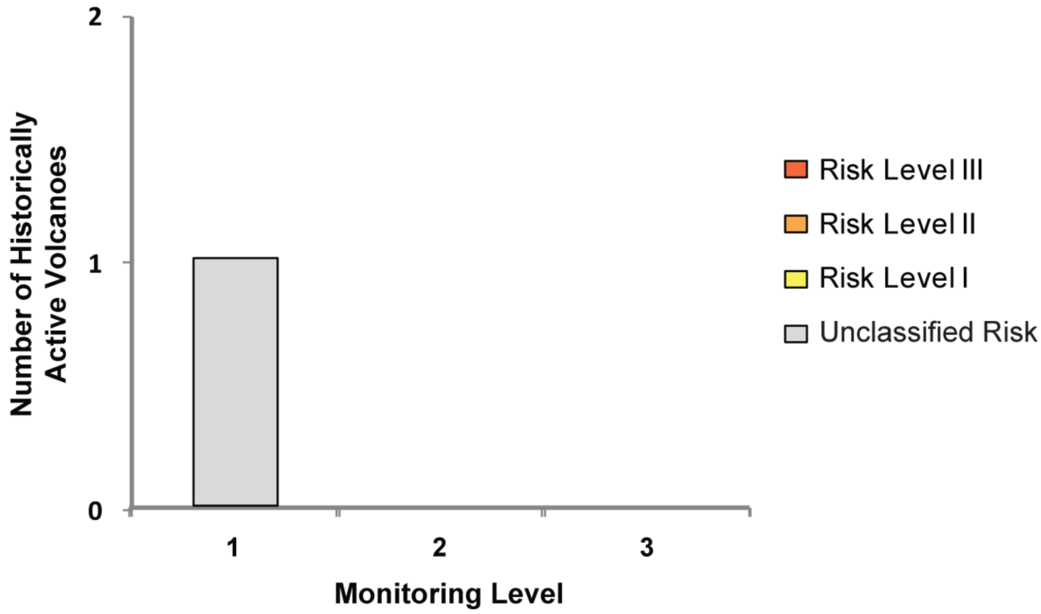


Figure 111: The monitoring and risk levels of the historically active volcanoes in Saudi Arabia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

South Africa

Description

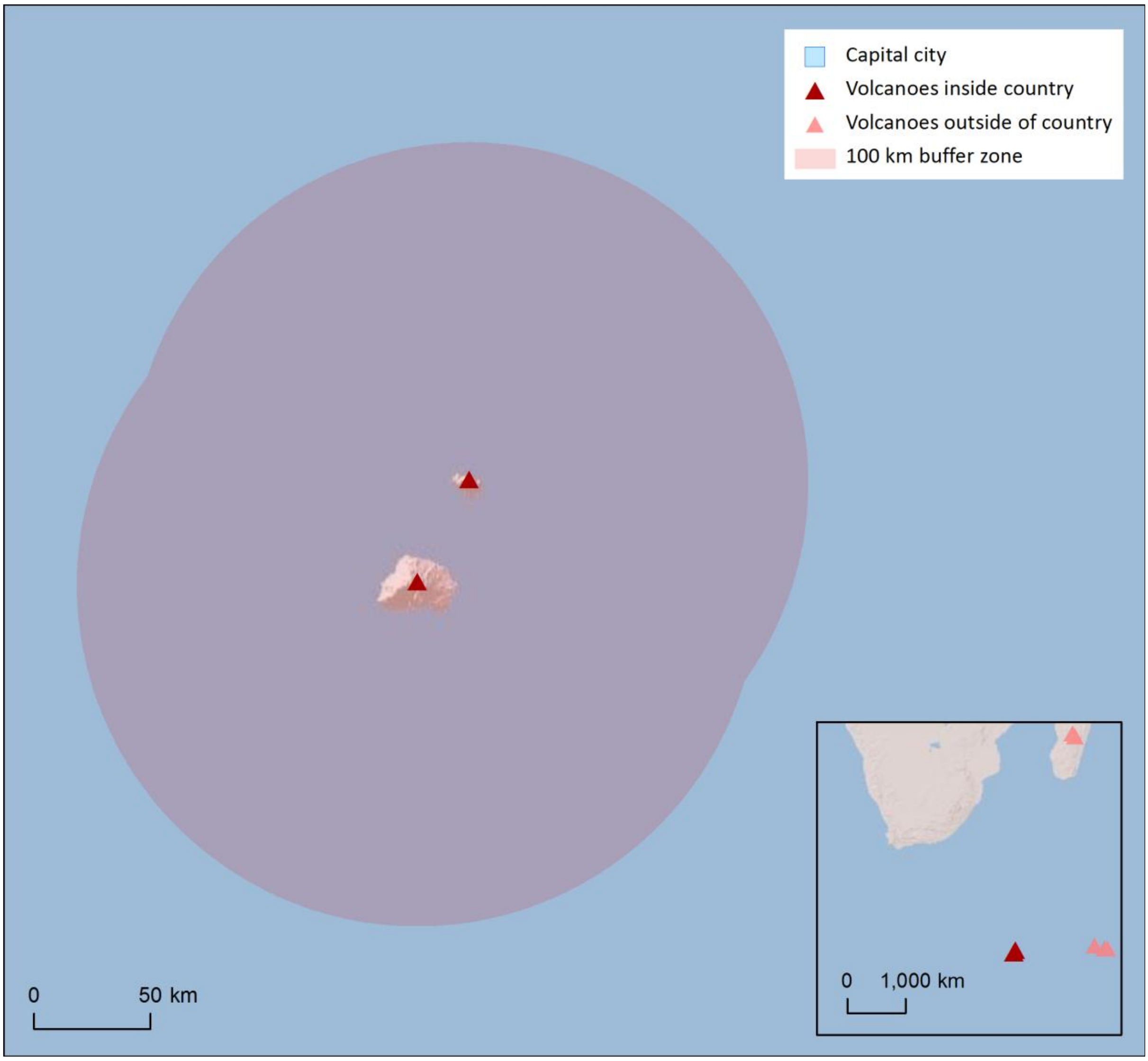


Figure 112: Location of South Africa's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect South Africa.

Two island volcanoes, Marion Island and Prince Edward Island, are located about 2000 km off the south-east coast of South Africa. These basaltic shield volcanoes are related to rifting between the Antarctic and African Plates.

Only Marion Island has recorded historical eruptions, with Prince Edward Island having suspected but unconfirmed Holocene activity, making Marion Island the most frequently active volcano in South Africa. Marion Island was most recently active with a VEI 1 eruption in 2004. No eruptions greater than VEI 1 are recorded. Small cinder and tuff cones are distributed across both islands, indicating that localised mild explosive activity occurs along with effusive production of lavas.

These remote islands have no permanent population, however a research base, with 6 people conducting environmental and biological research, is maintained at the South African National Antarctic Programme on Marion Island. The base is the only infrastructure exposed here, with no other population or infrastructure lying within 100 km of the volcanoes. Given the population size and the history of small eruptions the risk is low. However, as Marion Island is small and remote, timely evacuation of the research base has to be considered.

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Two eruptions of VEI 1 are recorded at Marion Island in 1980 and 2004.
Number of Holocene eruptions	2 confirmed eruptions.
Recorded Holocene VEI range	1
Number of historically active volcanoes	1
Number of historical eruptions	2

Number of volcanoes	Primary volcano type	Dominant rock type
2	Shield(s)	Basaltic (2)

Table 106: The number of volcanoes in South Africa, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts (South Africa)

Total population (2012)	52,464,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	9,678
Gross National Income (GNI) per capita (2005 PPP $)	9,594

Human Development Index (HDI) (2012)	0.629 (Medium)

Population Exposure

Capital city	Pretoria
Distance from capital city to nearest Holocene volcano	1929 km
Total population (2011)	49,004,031
Number (percentage) of people living within 10 km of a Holocene volcano	0 (0%)
Number (percentage) of people living within 30 km of a Holocene volcano	0 (0%)
Number (percentage) of people living within 100 km of a Holocene volcano	0 (0%)

Ten largest cities (South Africa), as measured by population, and populations:

Cape Town	3,433,441
Durban	3,120,282
Johannesburg	2,026,469
Pretoria	1,619,438
Port Elizabeth	9,676,77
Pietermaritzburg (Ulundi)	750,845
Bloemfontein	463,064
Richards Bay	252,968
Kimberley	142,089
Bisho	137,287

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The remote Marion Island and Prince Edward Island are uninhabited and therefore lack any critical infrastructure that would lie within 100 km of these volcanoes.

Hazard, Uncertainty and Exposure Assessments

Only Marion Island has a record of confirmed Holocene eruptions, in 1980 and 2004. Prince Edward Island has suspected Holocene age activity. The absence of an extensive record for South Africa's volcanoes prevents a hazard assessment without considerable uncertainties. These volcanoes are therefore unclassified.

With no permanent population living within 100 km of either South African volcanoes, the PEI is classed at 1.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**	**Marion Island**						
	U- HR							
	U- NHHR	Prince Edward Island						
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 107: Identity of South Africa's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Marion Island has been historically active, however no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at the unclassified Marion Island or Prince Edward Island.

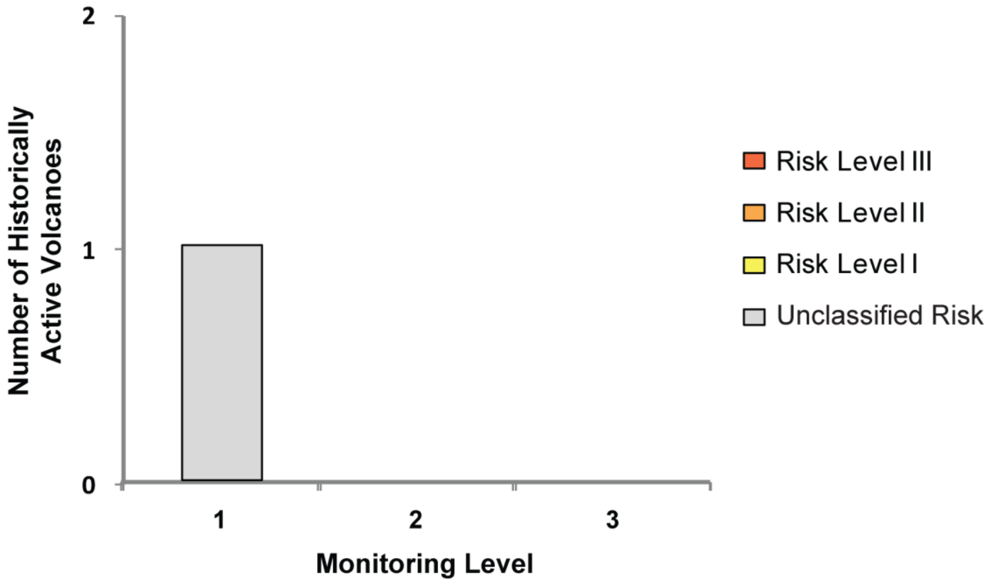


Figure 113: The monitoring and risk levels of the historically active volcanoes in South Africa. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Syria

Description

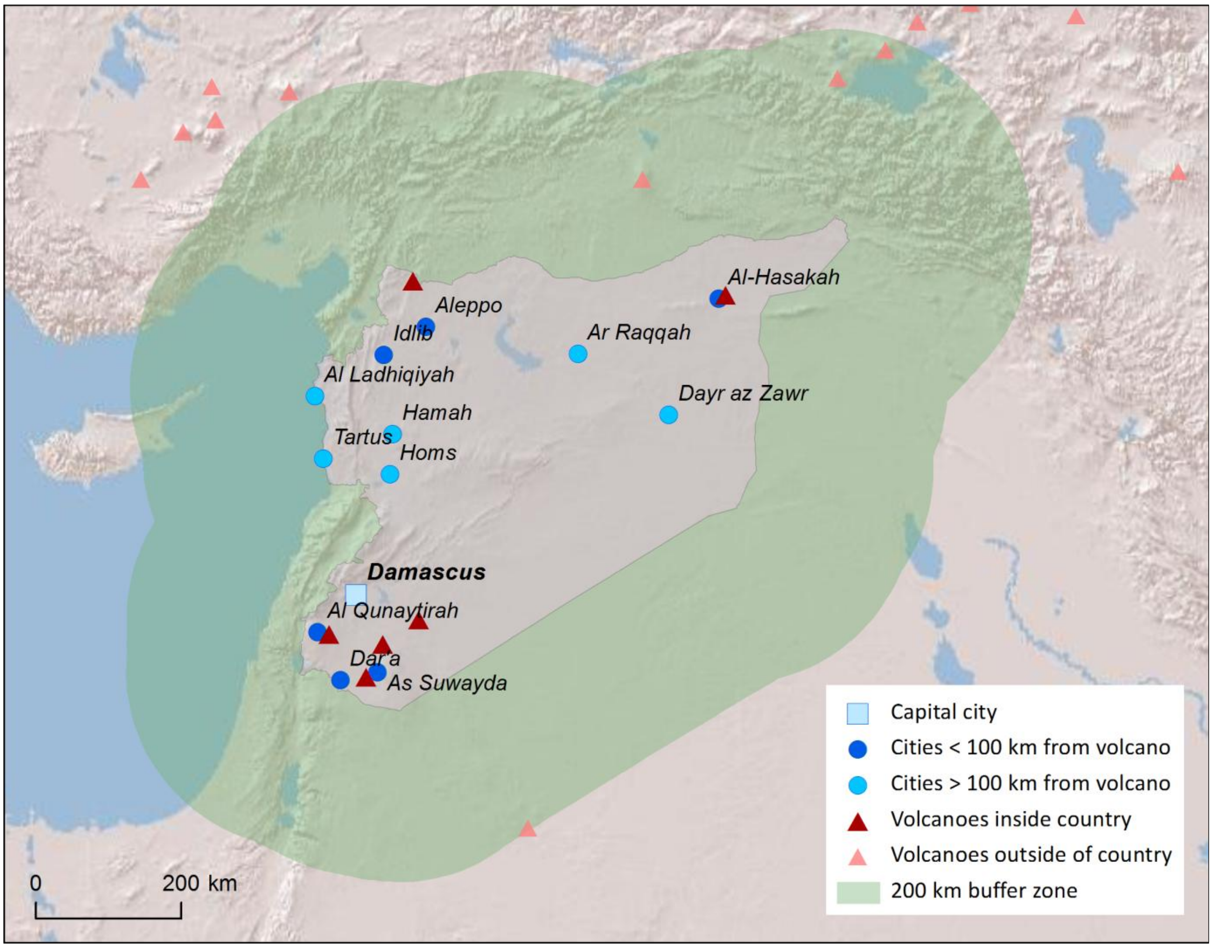


Figure 114: Location of Syria's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Syria.

Six Holocene volcanoes are located in Syria, with four grouped in the south-west of the country, one in the north-east and one in the north-west. Lying near the borders of the Arabian, African and Eurasian Plates volcanism here is due to rifting, with Syria being the northern end of the Great Rift Valley. All volcanoes here are volcanic fields of multiple basaltic cones.

With a dominantly basaltic composition and resulting from rifting, it is unsurprising that activity here has comprised only small eruptions and effusions of lava. Only three Holocene eruptions are confirmed, all of VEI 0 at two unnamed volcanoes in the south-west and north-west of the country and at Es Safa. Es Safa, situated about 50 km south-east of Syria's capital, Damascus, is the only volcano in Syria to have a record of historical activity.

The absence of a comprehensive eruptive history for all of Syria's volcanoes makes the assessment of hazard difficult and associated with significant uncertainties. With several of Syria's most populous cities being situated close to the Holocene volcanoes, and a large population living within

10 km of a Holocene volcano, the risk from volcanism is high. However, further research would be beneficial to more fully understand volcanism in this country and the hazards posed.

Volcano Facts

Number of Holocene volcanoes	6
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	2
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption:	-
Largest recorded Holocene eruption	All eruptions are recorded at VEI 0.
Number of Holocene eruptions	3 confirmed eruptions.
Recorded Holocene VEI range	0 and unknown
Number of historically active volcanoes	1
Number of historic eruptions	1

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
6	Small cone(s)	Basaltic (6)

Table 108: The number of volcanoes in Syria, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	21,923,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,741
Gross National Income (GNI) per capita (2005 PPP $)	4,674
Human Development Index (HDI) (2012)	0.648 (Medium)

Population Exposure

Capital city	Damascus
Distance from capital city to nearest Holocene volcano	54.6 km
Total population (2011)	22,517,750
Number (percentage) of people living within 10 km of a Holocene volcano	248,262 (1.1%)
Number (percentage) of people living within 30 km of a Holocene volcano	1,898,815 (8.4%)
Number (percentage) of people living within 100 km of a Holocene volcano	12,409,379 (55.1%)

Ten largest cities, as measured by population, and populations:

Aleppo	1,602,264
Damascus	1,569,394
Homs	775,404
Hamah	460,602
Dayr az Zawr	242,565
Ar Raqqah	177,636
Idlib	128,840
Tartus	89,457
As Suwayda	59,052
Al Qunaytirah	36,143

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	2,921
Total length of railroads within 100 km of a volcano (km)	763

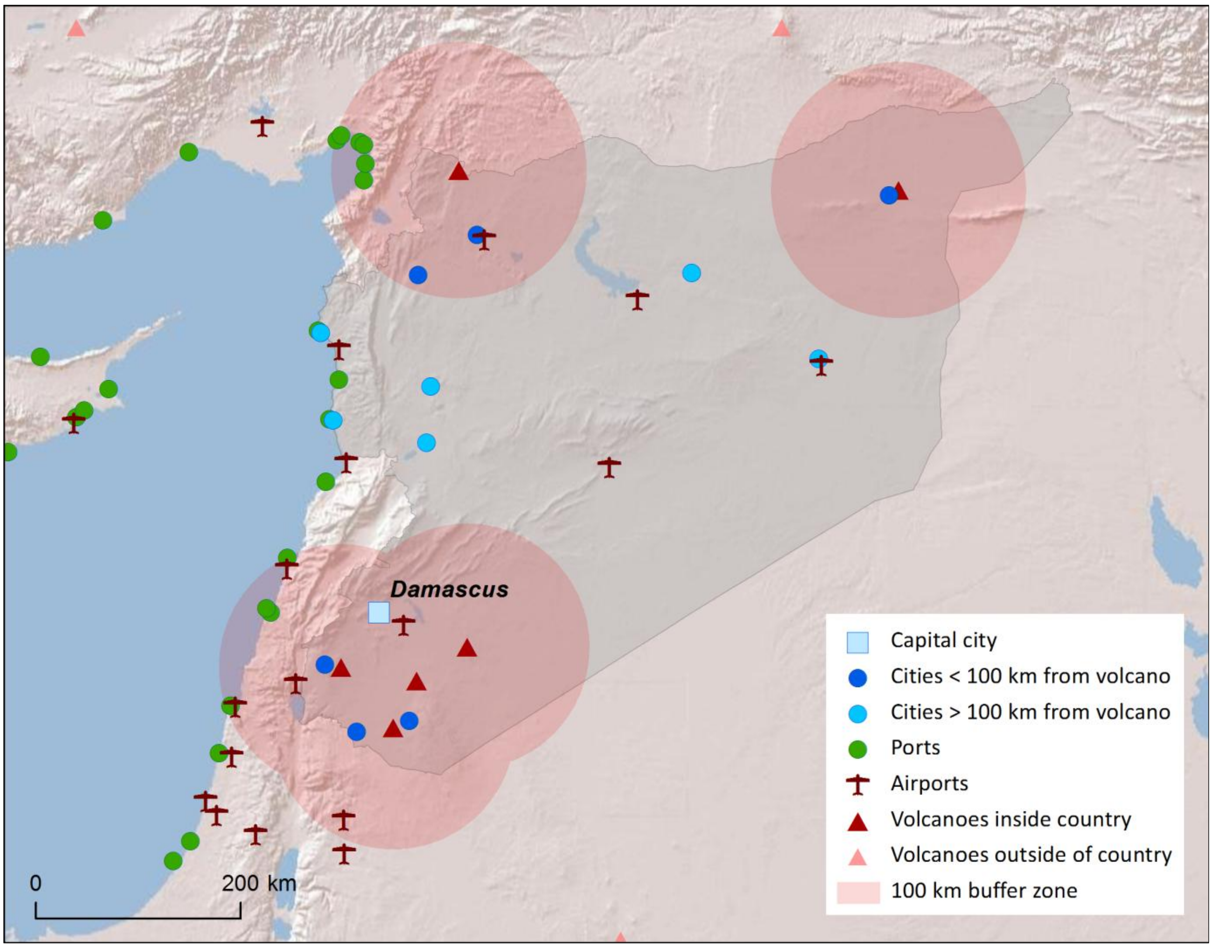


Figure 115: The location of Syria's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The Syrian volcanoes are located in three groups, to the south, the north-west and north-east. The Unnamed volcano in the north-west is close to the border with Turkey and the 100 km radius of this volcano extends into Turkey affecting infrastructure, including a number of ports there. Sharat Kovakab volcano in the north-east is located within 100 km of both Turkey and Iraq, therefore exposing infrastructure in these countries. The southern volcanoes of Jabal ad Druze, Golan Heights, Es Safa and an unnamed volcano have 100 km radii extending into Jordan, Israel and the West Bank and Lebanon exposing considerable infrastructure in these countries, including multiple ports and airports. The 100 km radius of the Karaca Dag volcano in Turkey extends into northern Syria. At least seven major cities lie within 100 km of the Syrian volcanoes, including the capital, Damascus, exposing much of the country's critical infrastructure, including multiple airports and an extensive road and rail network.

Hazard, Uncertainty and Exposure Assessments

The eruptive histories for Syria's volcanoes are sparse, with just three confirmed Holocene age eruptions in Syria from the two Unnamed volcanoes and Es Safa. Only Es Safa's eruption was historical in age, occurring in 1850. The absence of extensive eruption records prevents hazard assessment and as such these volcanoes are unclassified.

The PEI at all Syrian volcanoes is very high at PEI 6 and 7, indicating that these volcanoes would classify at Risk Levels II and III were the hazard known.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**						Es Safa	
	U- HR						Unnamed; Unnamed	
	U- NHHR						Sharat Kovakab	Golan Heights; Jabal ad Druze
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 1093: Identity of Syria's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Es Safa has been historically active, however no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at this Risk Level II volcano.

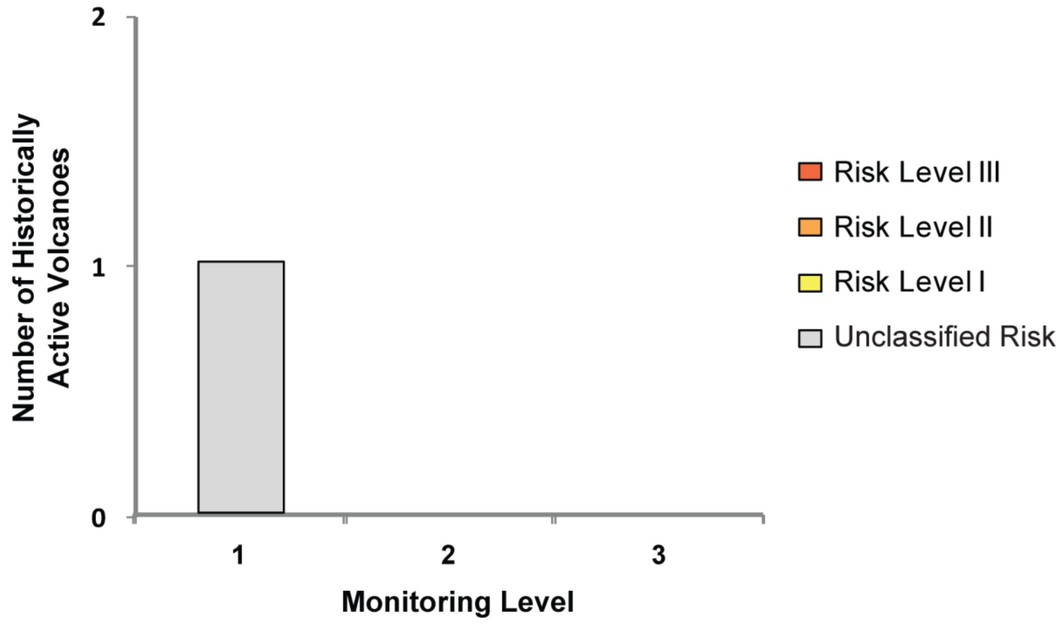


Figure 116: The monitoring and risk levels of the historically active volcanoes in Syria. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Yemen

Note that we include here the four Yemeni volcanoes located in the Red Sea, which are included in the Region 2 "Africa and Red Sea" description as defined in this region by the Global Volcanism Program.

Description

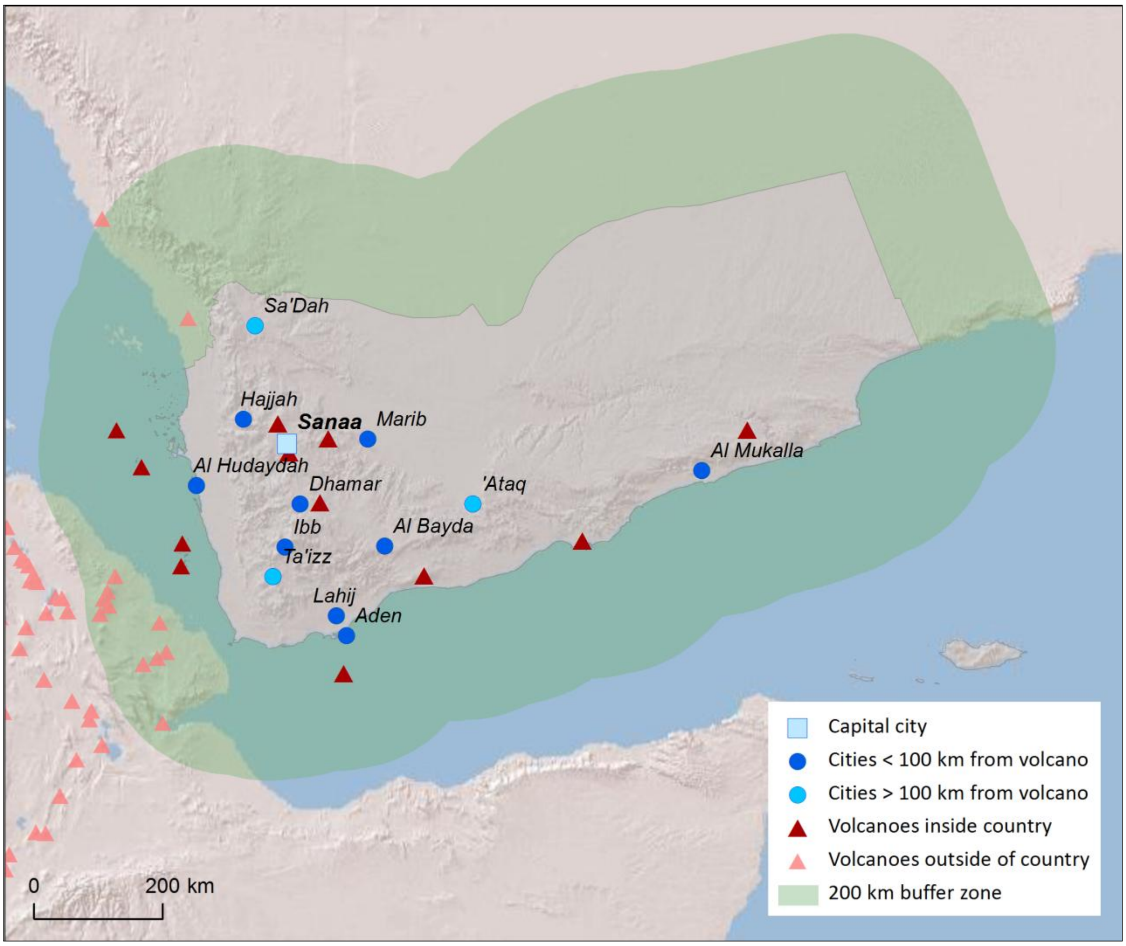


Figure 117: Location of Yemen's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Yemen.

Twelve Holocene volcanoes are located in Yemen, four of which are situated in the Red Sea between Yemen and Eritrea, one off the southern coast in the Gulf of Aden and the remaining on mainland Yemen. These volcanoes are formed along the East African and Red Sea Rift systems, due to the divergence of the African and Arabian plates.

The volcanoes are dominantly basaltic, and form a variety of shields and small cones. Jebel at Tair is the only Yemeni stratovolcano, and is the most northerly of the Red Sea volcanoes. The eruptions at these volcanoes have been effusive to moderately explosive, with a Holocene record of lava flows at four volcanoes and a range of eruption sizes from VEI 0 to VEI 3. The most recent VEI 3 eruption occurred at Jebel at Tair in 2007. This eruption involved the evacuation of about 50 people and resulted in at least four fatalities, with further unconfirmed fatalities.

The volcanoes are fairly widespread across Yemen and as such many of the country's largest cities, including the capital, Sana'a, are situated within 100 km of the volcanoes. About 74% of the total population live within these radii. With dominantly effusive, lava flow producing eruptions, the most distal populations within these radii would likely avoid impact. However, Sana'a lies about 11 km from Jabal el-Marha, a volcano with a recent 1.8 km lava flow. Should a similarly small eruption occur here there could be significant consequences for the approximately 8,000 people living within 5 km of this vent, particularly damage to property and infrastructure.

There is no evidence of a ground-based monitoring network dedicated to volcano surveillance here, however the Seismological and Volcanological Observatory Center (SVOC) at the Yemen National Seismological Observatory Center operate a national seismic network across the country and are responsible for the monitoring of volcanic activity in Yemen.

The Asian Disaster Reduction Center (ADRC) produced a report on the hazards in Yemen in 2012. In this they consider volcanic hazards, describing these in the central and western plateau of the country. They indicate that six fatalities resulted from the 2007 eruption of Jebel at Tair. Following the Hyogo Framework for Action, Yemen is working to address disaster risk reduction. The ADRC describe how the National Disaster Management Unit (NDMU) and the Directorate of Environmental Emergencies and Disasters have been established to address disaster management and response and resources have been allocated for the development of an early warning system. See the ADRC report (listed below) for full details.

See also:

Hughes, R., and Collings, A. (2000) Seismic and volcanic hazards affecting the vulnerability of the Sana'a area of Yemen, in McGuire, W.G., Griffiths, D.R., Hancock, P.L., & Stewart, I.S. (eds) The Archaeology of Geological Catastrophes, Geological Society, London, Special Publications, v. 171, p355-372

Seismological and Volcanological Observatory Center of Yemen, http://www.nsoc.org.ye/

Asian Disaster Reduction Center: Yemen:
http://www.adrc.asia/nationinformation.php?NationCode=887&Lang=en&NationNum=02

Volcano Facts

Number of Holocene volcanoes	12
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	4
Number of fatalities caused by volcanic eruptions	4?

Tectonic setting:	Those volcanoes found in the Red Sea are in a rift zone setting. The mainland-Yemen volcanoes are in an intra-plate setting.
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Two VEI 3 eruptions are recorded at Jebel at Tair and Harra es-Sawâd in 2007 and 1253 AD respectively.
Number of Holocene eruptions	12 confirmed eruptions. 2 uncertain eruptions.
Recorded Holocene VEI range	0 to 3 and unknown.
Number of historically active volcanoes	3
Number of historical eruptions	8

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Basaltic (1)
3	Shield(s)	Basaltic (3)
7	Small cone(s)	Basaltic (7)
1	Submarine	Unknown (1)

Table 110: The number of volcanoes in Yemen, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	24,017,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	2,060
Gross National Income (GNI) per capita (2005 PPP $)	1,820
Human Development Index (HDI) (2012)	0.458 (Low)

Population Exposure

Capital city	Sana'a
Distance from capital city to nearest Holocene volcano	15.3 km
Total population (2011)	24,133,492

Number (percentage) of people living within 10 km of a Holocene volcano	698,094 (2.9%)
Number (percentage) of people living within 30 km of a Holocene volcano	3,872,840 (16.1%)
Number (percentage) of people living within 100 km of a Holocene volcano	17,909,473 (74.2%)

Ten largest cities, as measured by population, and populations:

Sanaa	1,937,451
Al Hudaydah	617,871
Ta'izz	615,222
Aden	550,602
Al Mukalla	258,132
Ibb	234,837
Hajjah	43,549
Al Bayda	37,821
Sa'Dah	31,859
Lahij	23,375

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	4
Total length of roads within 100 km of a volcano (km)	1,777
Total length of railroads within 100 km of a volcano (km)	0

The Yemeni volcanoes are located through mainland Yemen, in the Red Sea and Gulf of Aden to the south. Those volcanoes located in the Red Sea have 100 km radii which extend into Eritrea, exposing infrastructure here. Many of the largest cities in Yemen, including the capital, Sana'a, are situated within 100 km of the mainland volcanoes, exposing considerable infrastructure here, including airports and an extensive road network. Several ports along the coast are affected.

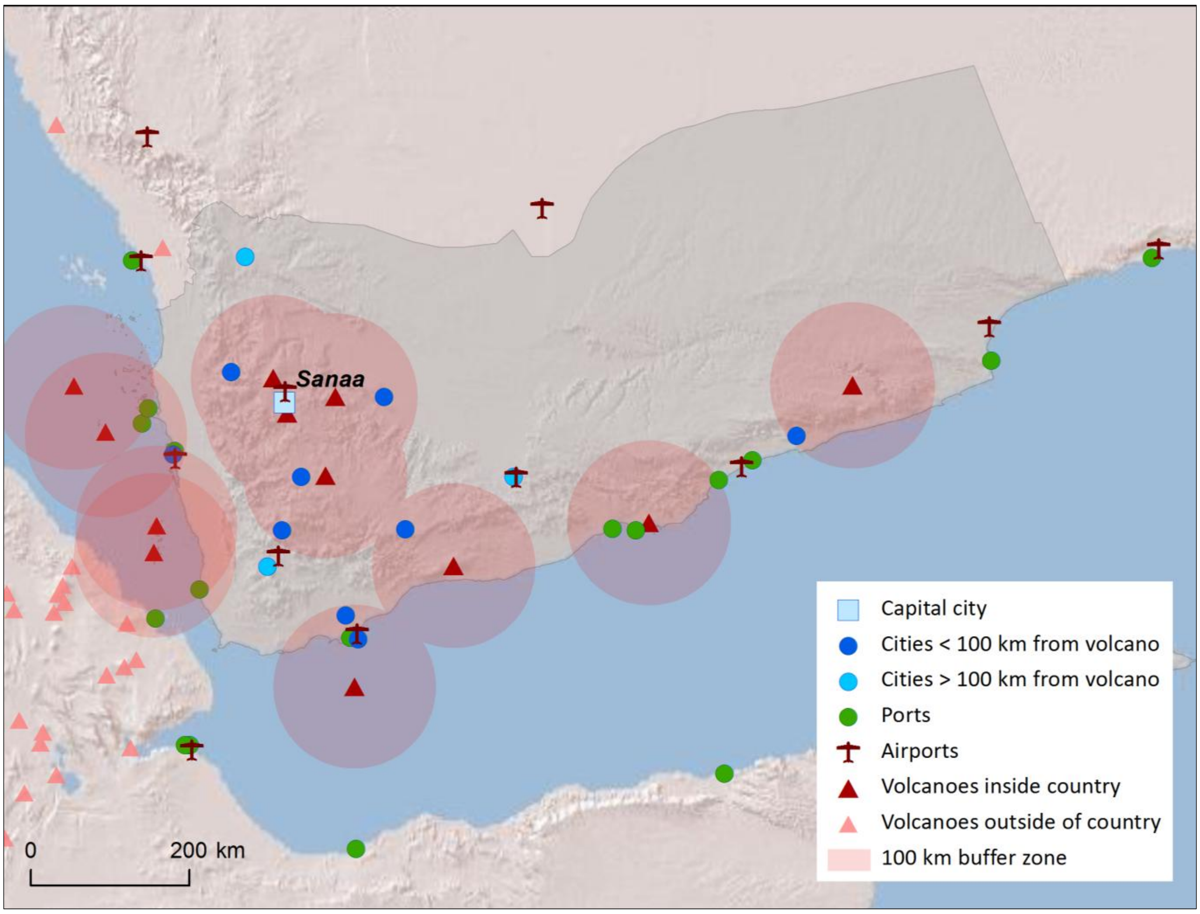


Figure 118: The location of Yemen's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Of the volcanoes in Yemen, only Jebel at Tair has a sufficiently extensive eruptive history for hazard assessment. This volcano is classed at Hazard Level I due to its record of VEI 2 eruptions and lava effusions. All other Yemeni volcanoes are unclassified. Of these, six have no confirmed Holocene age eruptions, three have Holocene eruptions and two, the Zubair Group and Harras of Dhamar have historical activity, most recently in 2011 and 1937 respectively.

PEI ranges from low to very high in Yemen with five volcanoes classified with PEI levels of 5 to 7 indicative of high populations within 100 km. Jebel at Tair has a small local population, with no-one living within 30 km.

		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7
CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I		Jebel at Tair					
UNCLASSIFIED	U – HHR		**Zubair Group**					**Harras of Dhamar**
	U- HR					Harra es-Sawâd	Jabal Haylan	Harra of Arhab
	U- NHHR		Hanish; Unnamed; Bir Borhut	Zukur; Harra of Bal Haf			Jabal el-Marha	

*Table 111: Identity of Yemen's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Jebel at Tair	2	I

Table 112: Classified volcanoes of Yemen ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

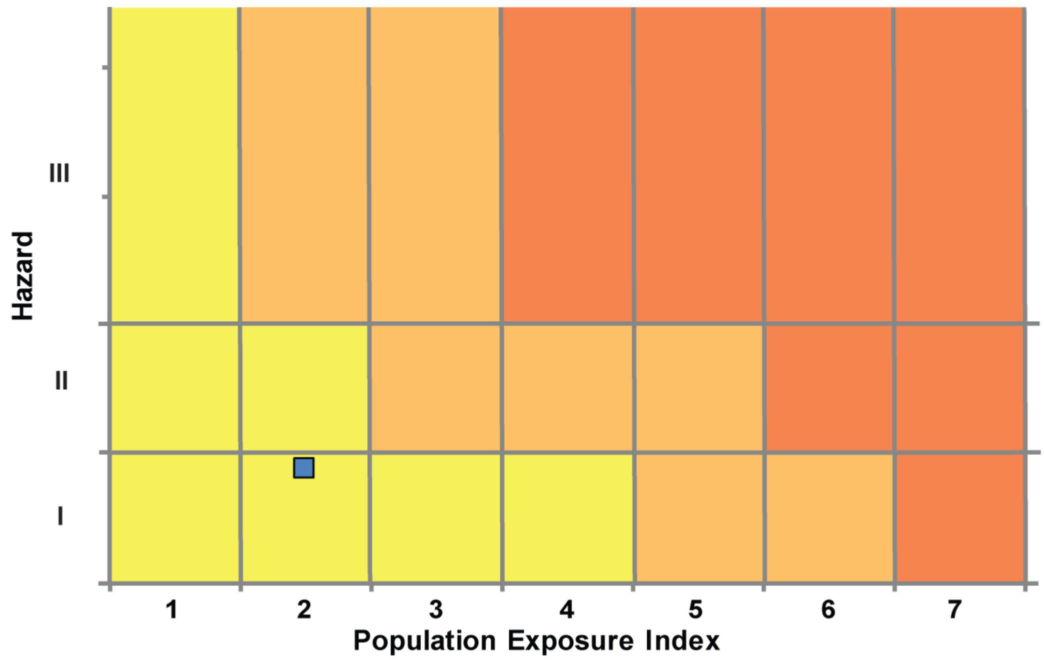


Figure 119: Distribution of Yemen's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The Seismological and Volcanological Observatory Center (SVOC), part of the Geological Survey and Mineral Resources Board, has installed, maintains and monitors The Yemen National Seismic Network of 18 seismic stations across the country, plus another 17 at sites of strategic importance (e.g. cities, dams). It is unclear if any stations are dedicated to volcanic monitoring, however an extensive network would likely detect some of the precursory seismic signals associated with volcanic activity.

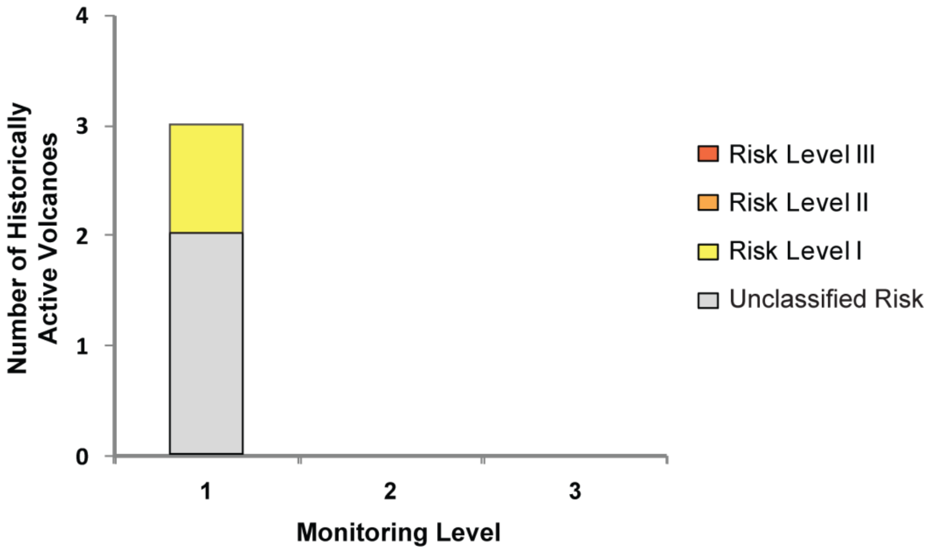


Figure 120: The monitoring and risk levels of the historically active volcanoes in Yemen. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 4: New Zealand to Fiji

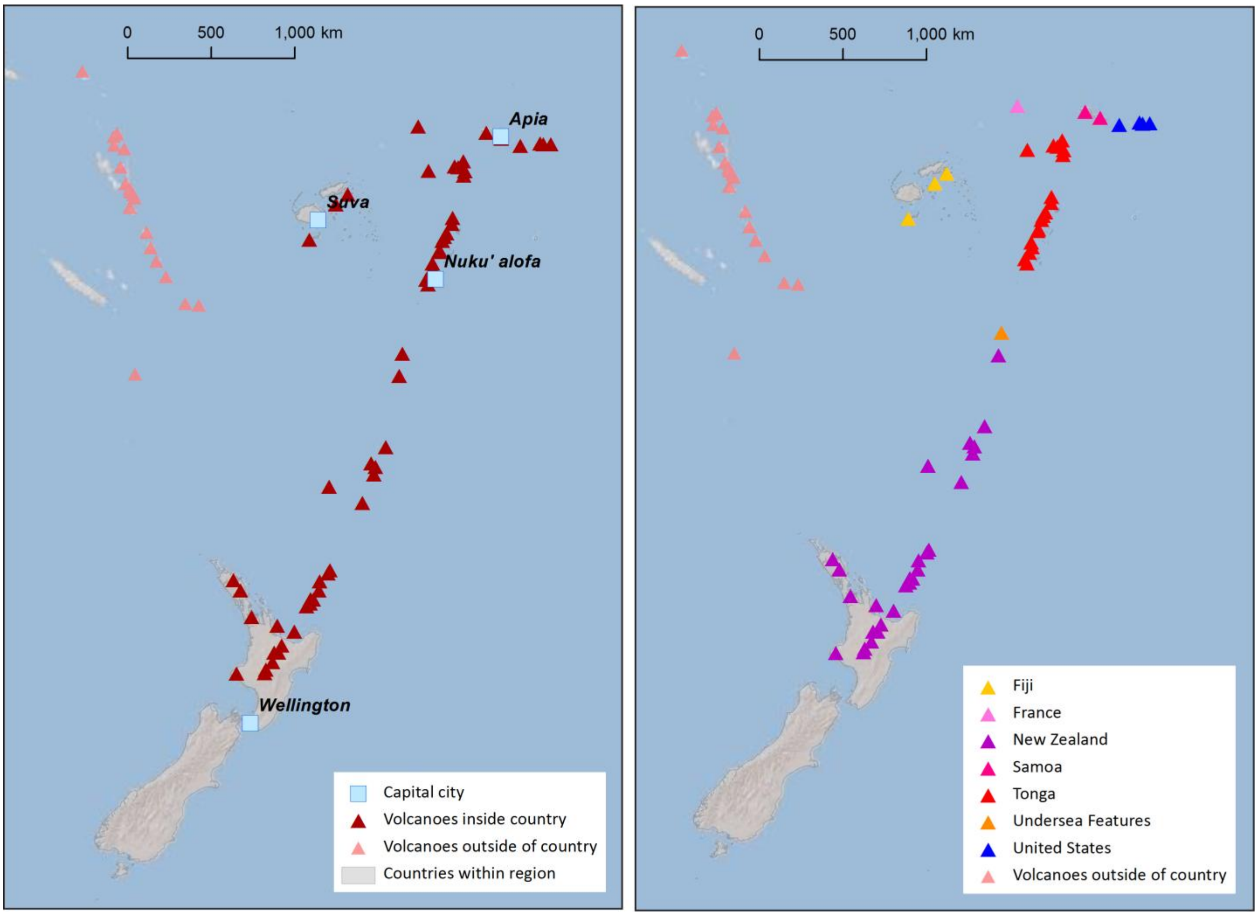


Figure 121: The distribution of Holocene volcanoes through the New Zealand to Fiji region. The capital cities of the constituent countries are shown.

Description

Region 4: New Zealand to Fiji comprises volcanoes throughout the New Zealand –Kermadec-Tonga trench to Samoa in the north and Fiji east of this trench. Six countries are represented here. All are included in this regional discussion, and individual country profiles are provided, however the French Wallis Islands are included in the country profile for France in Region 13.

Country	Number of volcanoes
Fiji	3
France (See Region 13)	1
New Zealand	27 + 1 from Region 13
Samoa	2
Tonga	18
USA - American Samoa	4

Table 113: The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

Fifty-six Holocene volcanoes are located in this region. Most of these volcanoes (27) are in New Zealand and Tonga (18). Volcanism here is largely related to the subduction of the Pacific Plate beneath the Indo-Australian Plate. The Samoan hotspot to the north of the Tonga trench controls volcanism in Samoa.

Twenty-four volcanoes in this region are submarine. Subaerial volcanoes vary in form throughout the region, though most are stratovolcanoes and calderas (15). The rock type through this region is dominantly andesitic, though ranges from basaltic to rhyolitic.

Along with volcano morphology and composition, a range of activity styles and eruption magnitudes are recorded through the Holocene, with eruptions of VEI 0 to 6. About 80% of eruptions here have been small, at VEI 0 – 2, however about 41 (11%) eruptions have been large explosive VEI ≥4 events. These VEI ≥4 eruptions have largely been restricted to New Zealand, with just two in Tonga, although pyroclastic flows are reported in New Zealand, Tonga and Fiji. The largest Holocene eruption in this region was the VEI 6 eruption of the Taupo Ignimbrite at Taupo, New Zealand about 1,800 years ago.

Twenty-eight volcanoes have historical records of 296 eruptions, 85% of which were recorded through direct observations. 6% of historical events have involved the production of pyroclastic flows and lahars, with 10 % producing lava flows.

Just 2% of historical eruptions have resulted in loss of life, largely due to the low population in this region and the number of submarine volcanoes. Most volcanoes (80%) have low proximal populations, and as such are considered relatively low risk. However the hazard is poorly constrained at many volcanoes due to sparse eruption records. Just one Risk Level III volcano is located in this region: Taupo in New Zealand, with a history of large explosive events and a moderate local population.

Outside of New Zealand dedicated ground-based monitoring is largely absent. Within New Zealand GNS Science and GeoNet monitor the volcanoes and provide hazard and risk data and advice.

Volcano facts

Number of Holocene volcanoes	56
Number of Pleistocene volcanoes with M≥4 eruptions	11
Number of volcanoes generating pyroclastic flows	11 (42 eruptions)
Number of volcanoes generating lahars	5 (21 eruptions)
Number of volcanoes generating lava flows	18 (75 eruptions)
Number of eruptions with fatalities	8
Number of fatalities attributed to eruptions	422
Largest recorded Pleistocene eruption	The eruption of the Whakamaru Group at Maroa at 335 ka at a magnitude of 8.2 is the largest recorded eruption in this region

	in the Quaternary.
Largest recorded Holocene eruption	The largest Holocene eruption in this region is recorded as the 1.8 ka Taupo Ignimbrite eruption from Taupo, at M6.9.
Number of Holocene eruptions	437 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 6 and unknown.
Number of historically active volcanoes	28
Number of historical eruptions	296

Number of volcanoes	Primary volcano type	Dominant rock type
6	Caldera(s)	Andesitic (1), Basaltic (1), Rhyolitic (3), Unknown (1)
9	Large cone(s)	Andesitic (8), Dacitic (1)
2	Lava dome(s)	Andesitic (1), Rhyolitic (1)
5	Shield(s)	Basaltic (4), Rhyolitic (1)
5	Small cone(s)	Basaltic (5)
24	Submarine	Andesitic (9), Basaltic (2), Dacitic (6), Unknown (3)

*Table **114:** The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.*

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	80

*Table **115**: Average recurrence interval (years between eruptions) for small and large eruptions in New Zealand to Fiji.*

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 80 years.

Eruption Size

Eruptions of VEI 0 to 6 are recorded through the New Zealand to Fiji region, representing a range of eruption styles from gentle effusive events to very large explosive eruptions. VEI 2 events dominate the record, with nearly 50% of all Holocene eruptions classed as such. Despite this, over 11% of eruptions here are explosive at VEI≥4.

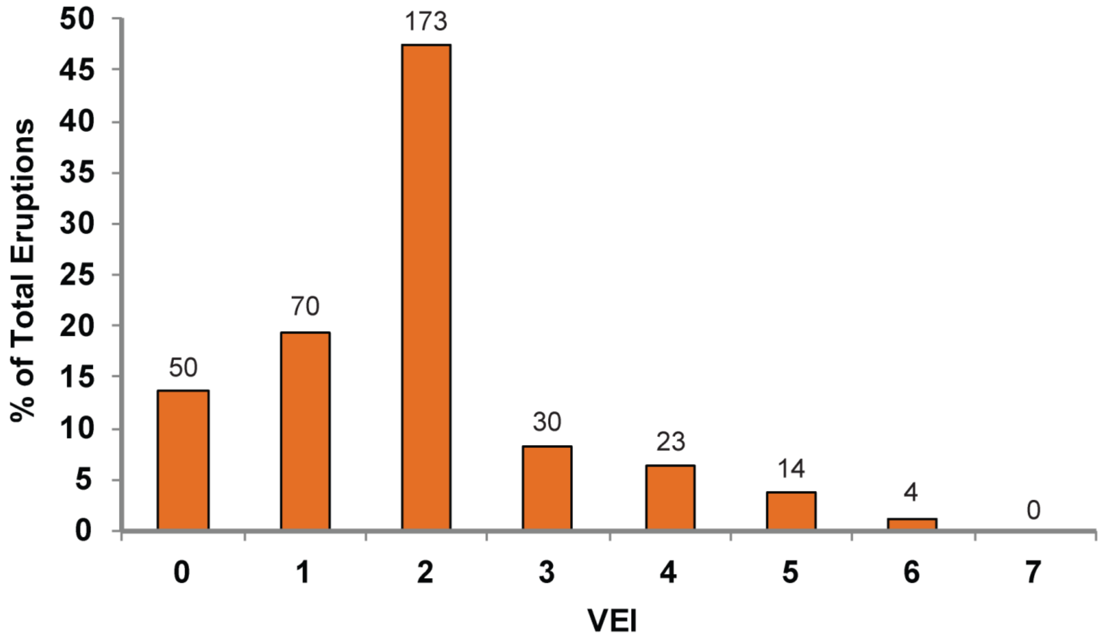


Figure 122: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 73 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	5,539,791
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,008 – 24,818 (Mean 9,279)
Gross National Income (GNI) per capita (2005 PPP $)	3,928 – 24,358 (Mean 9,132)
Human Development Index (HDI) (2012)	0.702 – 0.919 (Medium to Very High, Mean 0.758 High)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	607,041 (10.96 %)
Number (percentage) of people living within 30 km of a Holocene volcano	1,834,645 (33.12 %)
Number (percentage) of people living within 100 km of a Holocene volcano	2,896,592 (52.29 %)

CLASSIFIED	**Hazard III**	Raoul Island			Taupo			
	Hazard II		Tongariro; Ruapehu; Hunga Tonga-Hunga Ha'apai; Fonualei; Niuafo'ou					
	Hazard I	Rumble III; Monowai Seamount	White Island; Falcon Island; Tofua; Metis Shoal	Okataina; Taveuni				
UNCLASSIFIED	**U – HHR**	**Havre Seamount**	Taranaki [Egmont]; **Unnamed; Unnamed**; **Home Reef**; Late; **Unnamed**; **Curacoa**; **Tafu-Maka**; **West Mata**; **Vailulu'u**; Ofu-Olosega; **Savai'i**; Nabukelevu					
	U- HR	Healy; Macauley Island	Mayor Island; **Maroa**	Reporoa	Kaikohe-Bay of Islands			Auckland Field
	U- NHHR	Clark; Tangaroa; **Rumble V; Rumble IV;** Rumble II West; Brothers; Volcano W; **Curtis Island;** Giggenbach; Unnamed; Niua Tahi	Unnamed; Kao; Tafahi; Ta'u; Koro		Upolu; Wallis Islands	Whangarei; Tutuila		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table **116**: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
1	7
0	6
2	5
4	4
3	3
29	2
17	1

*Table **117**: The number of volcanoes in New Zealand to Fiji classed in each PEI category.*

Risk Levels

Number of Volcanoes	Risk Level
1	III
0	II
14	I
41	Unclassified

*Table **118**: The number of volcanoes in the New Zealand to Fiji region classified at each Risk Level.*

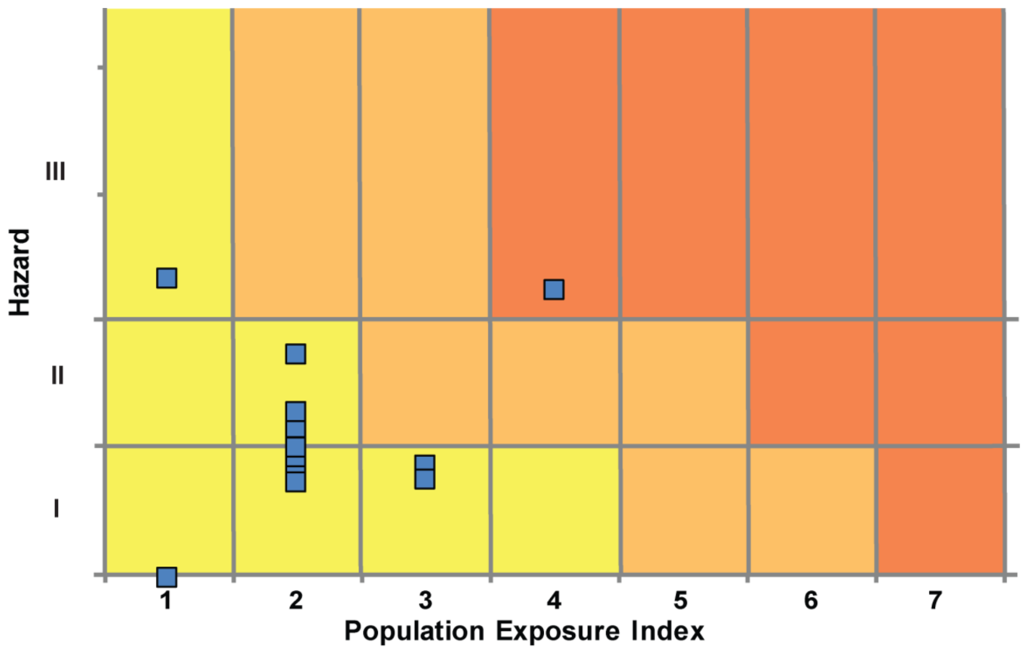


Figure 123: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

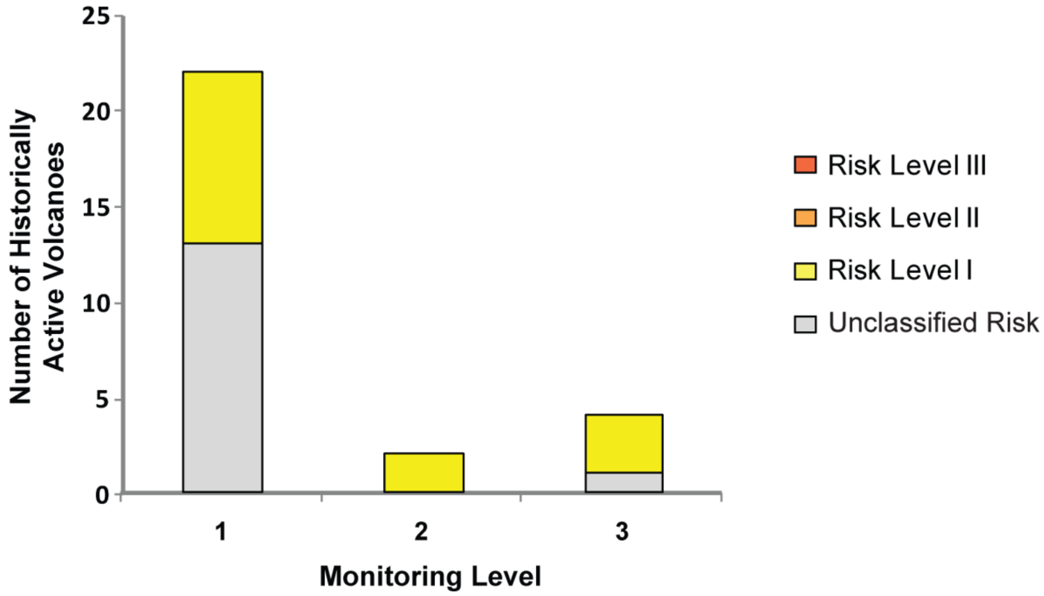


Figure 124: The monitoring and risk levels of the historically active volcanoes in New Zealand to Fiji. Monitoring Level 1indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Fiji

Description

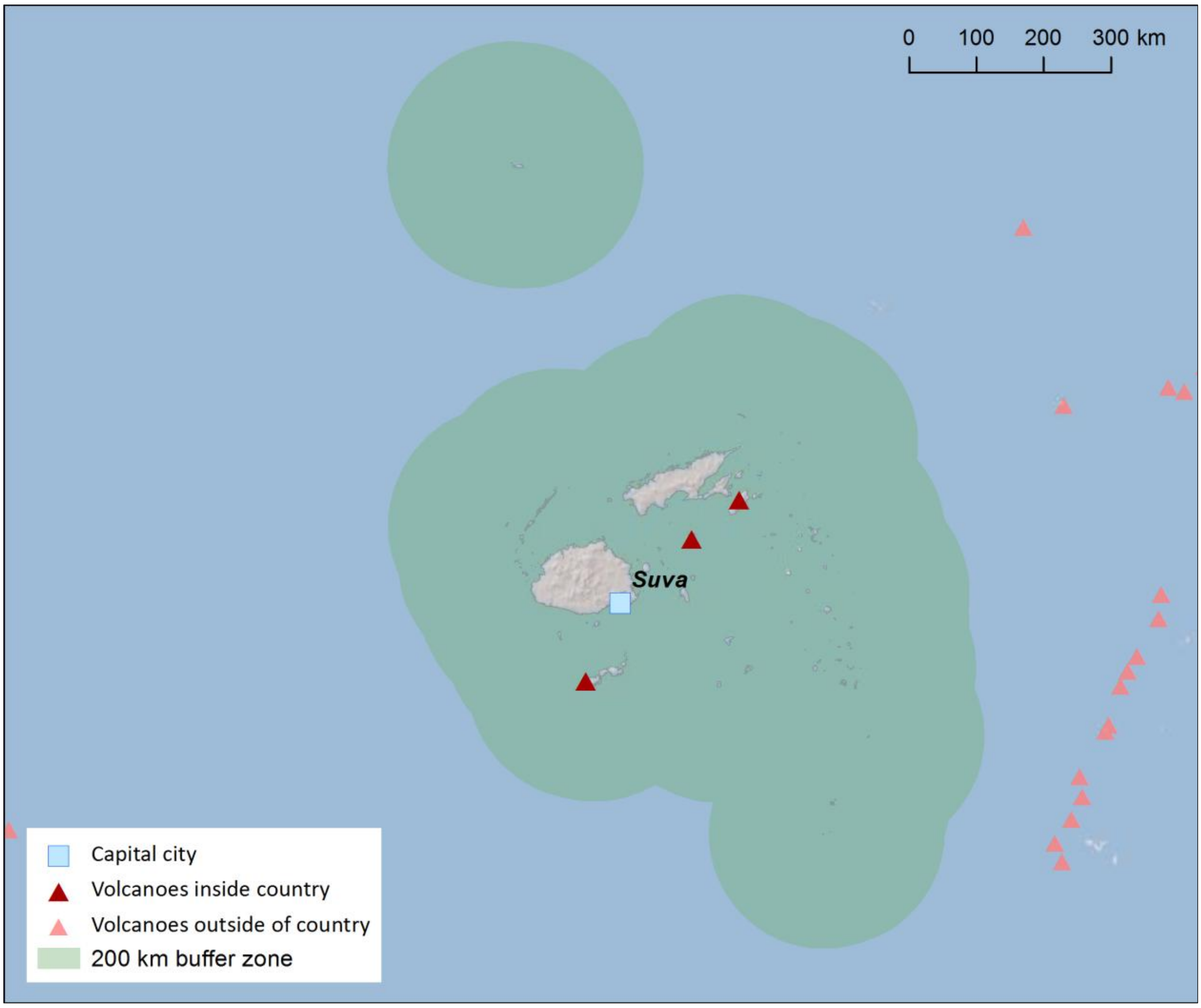


Figure 125: Location of Fiji's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Fiji.

Three Holocene volcanoes are located in Fiji, two on islands located north-east, and one located south, off the coast of the main Fijian islands. These volcanoes are the basaltic cinder cones of Koro, the basaltic shield Taveuni and the andesitic lava dome complex of Nabukelevu. The cause of recent volcanism here is unclear with the islands of Fiji located on a subduction zone that is no longer active.

Only Taveuni and Nabukelevu volcanoes have records of confirmed eruptions during the Holocene, with 37 eruptions. Koro has activity of suspected Holocene age. All eruptions have been small to moderate size VEI 0 to 2, with only two eruptions producing pyroclastic flows. 23 Holocene eruptions have produced lava flows. Both Tavenui and Nabukelevu have been historically active, with an eruption in 1550 and 1660 AD respectively. No activity or unrest has been recorded since the 1600s.

About 6,000 people live within 10 km of the Fijian volcanoes, and about a quarter of the population live within 100 km of one or more Holocene volcano.

Volcano Facts

Number of Holocene volcanoes	3
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	30 eruptions are recorded at VEI 2.
Number of Holocene eruptions	37 confirmed eruptions.
Recorded Holocene VEI range	0 – 2
Number of historically active volcanoes	2
Number of historic eruptions	2

Number of volcanoes	Primary volcano type	Dominant rock type
1	Lava dome(s)	Andesitic (1)
1	Shield(s)	Basaltic (1)
1	Small cone(s)	Basaltic (1)

*Table **119**: The number of volcanoes in Fiji, their volcano type classification and dominant rock type according to VOTW4.0.*

Socio-Economic Facts

Total population (2012)	876,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,199
Gross National Income (GNI) per capita (2005 PPP $)	4,087
Human Development Index (HDI) (2012)	0.702 (Medium)

Population Exposure

Capital city	Suva
Distance from capital city to nearest Holocene volcano	121.3 km
Total population (2011)	883,125
Number (percentage) of people living within 10 km of a Holocene volcano	6,219 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	19,403 (2.2%)
Number (percentage) of people living within 100 km of a Holocene volcano	203,344 (23%)

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The three Fijian volcanoes are situated on islands to the south of the main islands. Koro and Tavenui volcanoes in the north are located within about 70 km of the main island of Vanua Levu and thus much of this island falls within the 100 km radii of these volcanoes, exposing much of principal infrastructure here. The 100 km radius of Nabukelevu volcano in the south only just reaches the southern tip of the island of Vitu Levu. The capital, Suva, is located on Vitu Levu, but lies at over 120 km distance from Nabukelevu. Multiple small islands and small settlements are located within the 100 km radii of the Fijian volcanoes, exposing much of the infrastructure here.

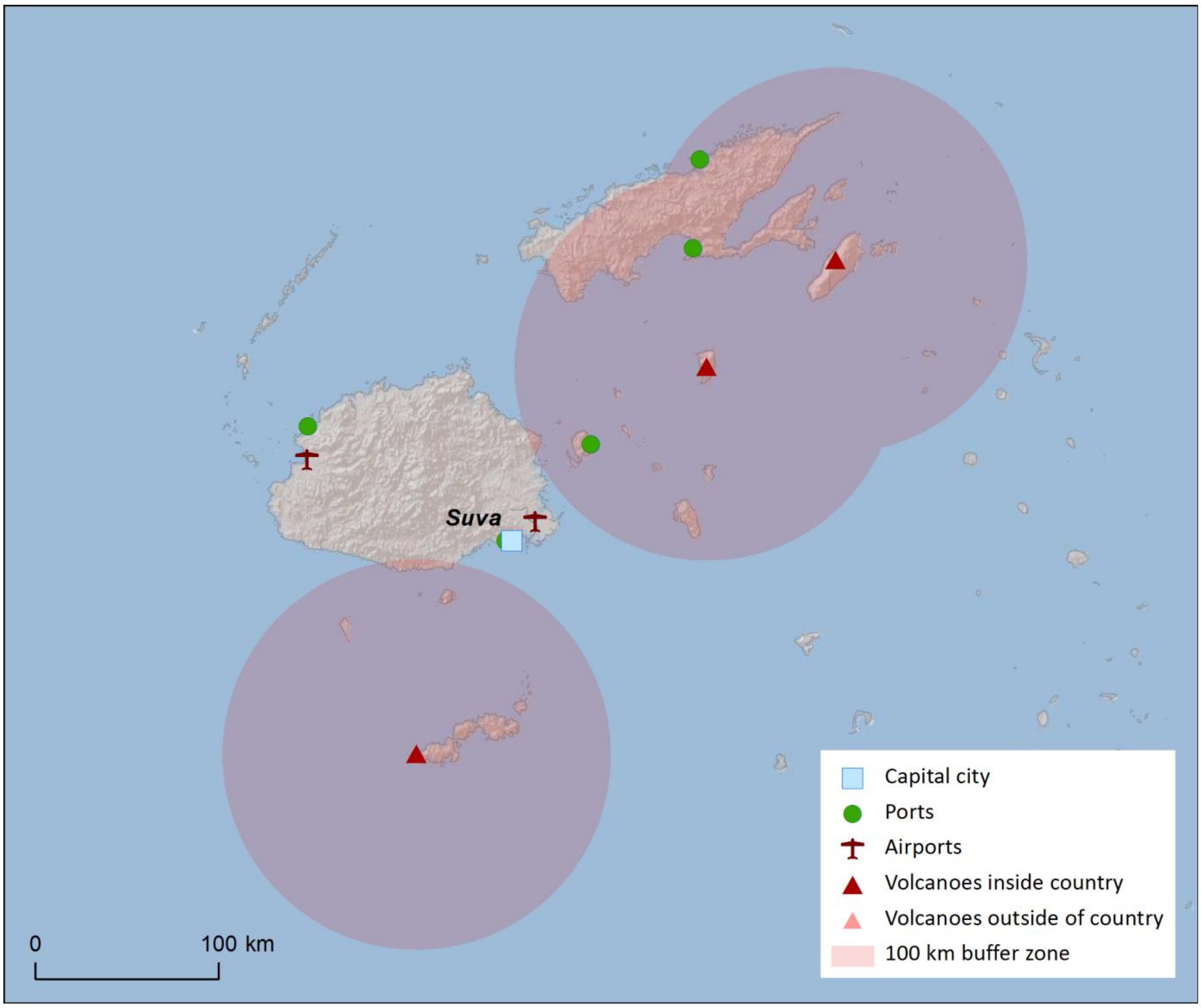


Figure 126: The location of Fiji's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of data available in the eruption record for the volcanoes of Fiji. Only Taveuni has a classified hazard score, which, based on a record of eruptions not exceeded VEI 2 is classed at Hazard Level I. The remaining volcanoes have insufficient data to determine hazard without large uncertainties. Indeed, Koro has no confirmed Holocene eruptions.

The PEI in Fiji is low to moderate, with the highest PEI at Taveuni. The relatively low PEI in combination with the Hazard Level categorises Fiji's classified volcano as Risk Level I.

		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7
CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I			Taveuni				
UNCLASSIFIED	U – HHR		Nabukelevu					
	U- HR							
	U- NHHR		Koro					

*Table **120**: Identity of Fiji's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Taveuni	3	I

Table 121: Classified volcanoes of Fiji ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

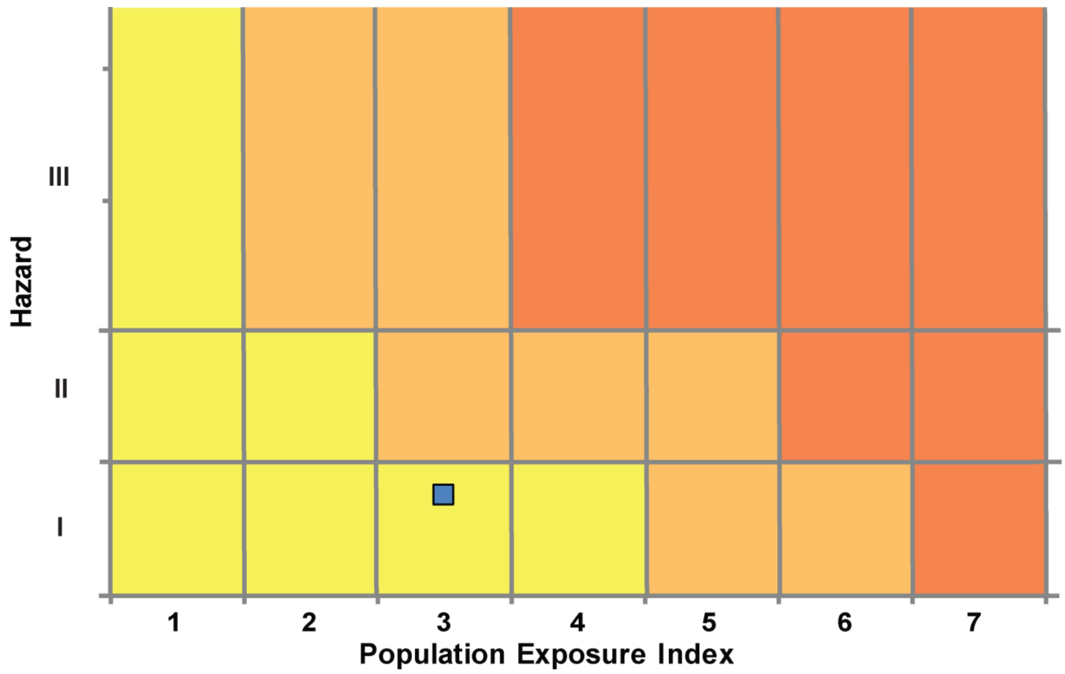


Figure 127: Distribution of Fiji's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Two volcanoes have historical eruption records in Fiji: the risk level 1 Taveuni and the unclassified Nabukele volcano. No information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any of the volcanoes in Fiji.

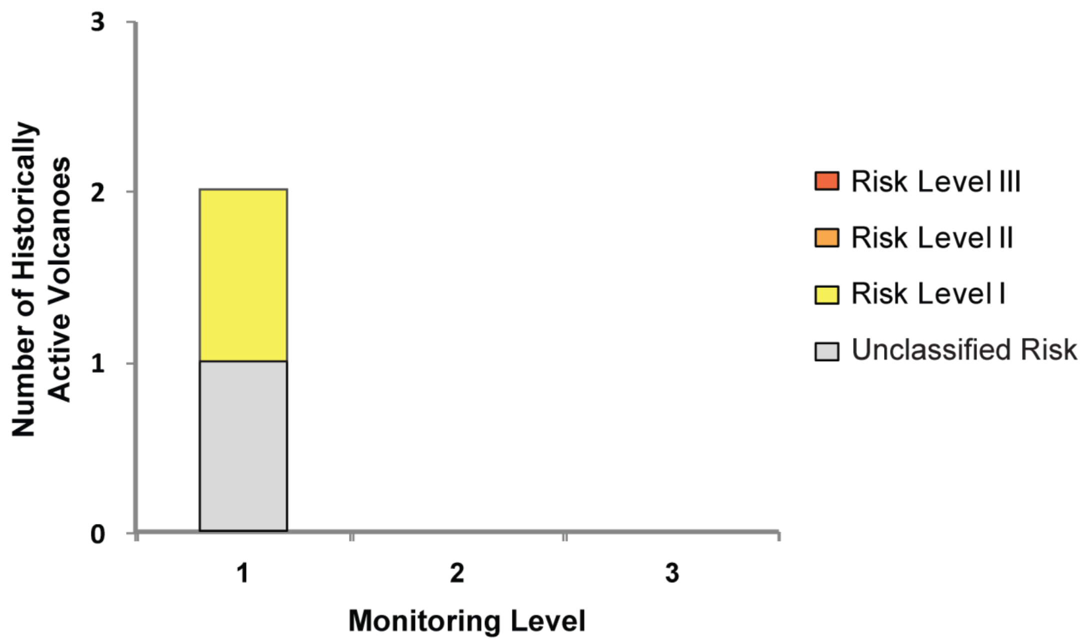


Figure 128: The monitoring and risk levels of the historically active volcanoes in Fiji. Monitoring Level 1indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

New Zealand

Note that we include Antipodes Island in this discussion, from Region 13.

Description

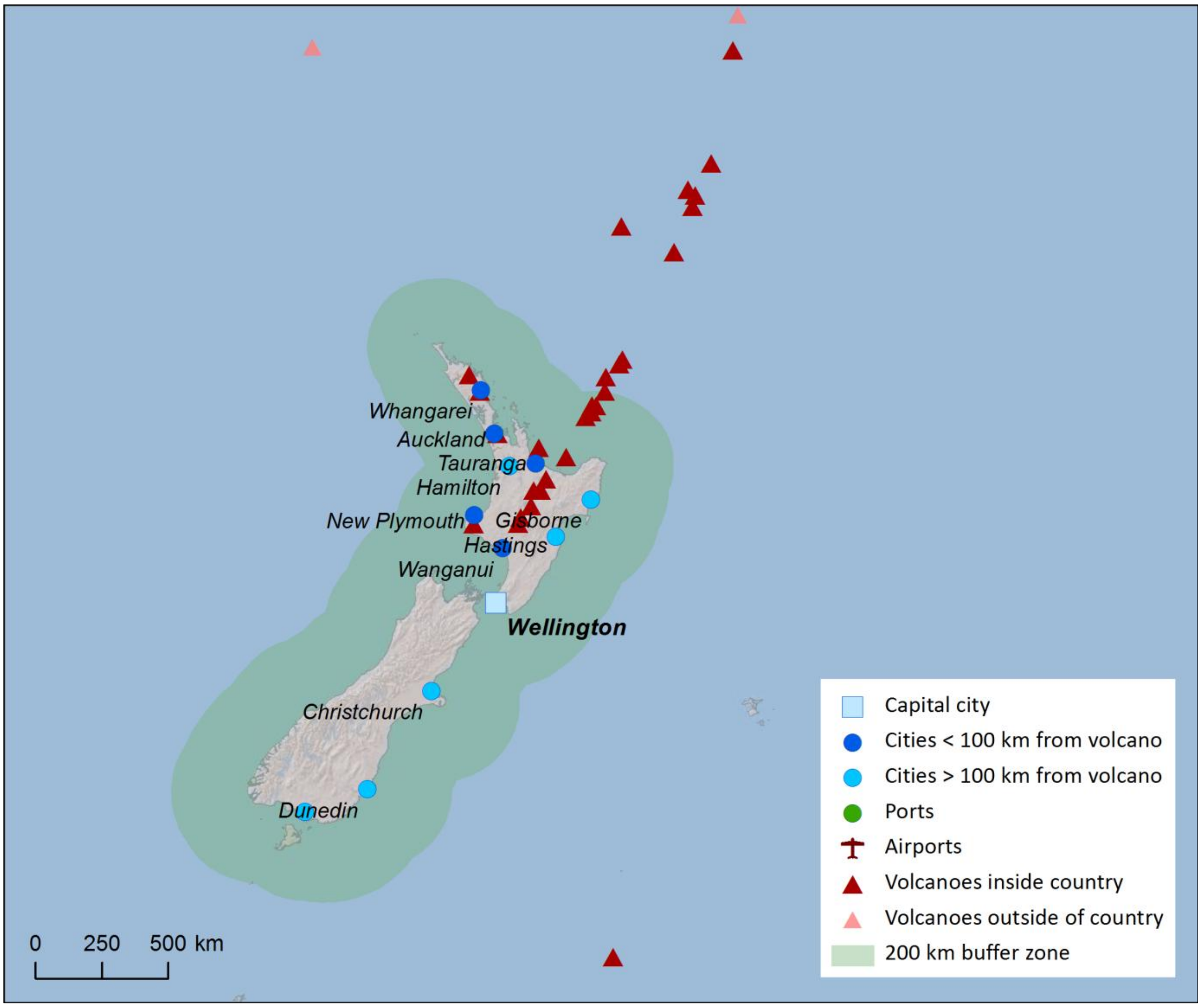


Figure 129: Location of New Zealand's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect New Zealand.

Twenty-eight Holocene volcanoes are recorded in New Zealand. These are located throughout the North Island and in the Kermadec Islands. Volcanism here is mostly due to the subduction of the Pacific Plate beneath the Indo-Australian Plate. The Antipodes Island volcano, located to the south-east of the South Island is related to intra-plate activity. The volcanoes of the Kermadecs are largely submarine features, whilst on the North Island stratovolcanoes and calderas dominate.

Large explosive eruptions are documented back into the Pleistocene in New Zealand, with eleven volcanoes having Pleistocene records of eruptions of VEI ≥4. Just fourteen of the volcanoes considered as active in the Holocene have confirmed eruptions in this time. The remaining volcanoes have activity of suspected Holocene age. 326 Holocene eruptions are documented in New Zealand of VEI 0 to 6. This range in size indicates a variety of activity styles from minor events to very large explosive eruptions. About 12% of Holocene eruptions here were of VEI ≥4. 39 eruptions are recorded as having produced pyroclastic flows, and 20 resulted in lahars. The largest Holocene eruption was the VEI 6 eruption of the Taupo about 1,800 years ago. This produced the Taupo Ignimbrite which covered about 20,000 square kilometres of the North Island. Taupo also produced the World's most recent VEI 8 eruption, about 23,000 years ago.

Nine volcanoes have a record of historical activity, and indeed 228 of the 326 Holocene eruptions were recorded post-1500 AD with most of these recorded through direct observations.

Much of the North Island of New Zealand lies within 100 km of one or more Holocene volcano, exposing a considerable amount of infrastructure and a large population, with several of New Zealand's most populous cities located here. About 530,000 people live within 10 km of one or more volcano. This distance is typically the area where hazard is highest, although this is dependent on the morphology of the volcano amongst other factors. Over half of New Zealand's total population live within 100 km of one or more Holocene volcanoes. Despite these large totals, the proximal population of most of New Zealand's volcanoes is relatively small. A particular exception to this is Auckland Volcanic Field beneath the city of Auckland. This volcanic field comprises multiple vents over a large, heavily populated area, where even a small eruption could have a large impact.

Populations have evacuated during eruptions of Tongariro, White Island, Ruapehu and Raoul Island between 1885 and 2012. Lives were lost in seven eruptions.

GNS Science undertakes research and analysis to provide the information needed to help minimise the impact of future volcanic activity. In collaboration with the Earthquake Commission to form GeoNet, GNS Science monitors New Zealand's volcanoes and provides hazard information. Dedicated ground-based monitoring is undertaken at historically active volcanoes. GNS Science release volcanic alert bulletins which are publically available, using an alert level system of 0 to 5 with increasing activity. Separate aviation colour codes are also provided.

GNS Science provides monitoring information prior to events and is also responsible for the provision of data and advice on local and regional hazards and impacts during eruptions. They produce hazard maps indicating the vulnerability of areas to lava flows, pyroclastic flows and ash fall and analyse the vulnerability of infrastructure. Eruption scenarios are developed for emergency management and risk assessment purposes and advice is provided for mitigation of damage.

Alert Levels are declared by GNS Science, and if a life-threatening eruption is likely to occur, a civil defence emergency will be declared and evacuations of the areas at risk will be ordered. Advice is provided to the public on what to do before, during and after unrest and eruptions.

See also:

GNS Science: http://www.gns.cri.nz/Home/Our-Science/Natural-Hazards/Volcanoes

GeoNet: http://info.geonet.org.nz/display/volc/Volcano

Get Ready Get Thru: http://www.getthru.govt.nz/disasters/volcano/

Volcano Facts

Number of Holocene volcanoes	28
Number of Pleistocene volcanoes with M≥4 eruptions	11
Number of volcanoes generating pyroclastic flows	9
Number of volcanoes generating lahars	4
Number of volcanoes generating lava flows	9
Number of fatalities caused by volcanic eruptions	386
Tectonic setting	27 Subduction Zone, 1 Intra-plate
Largest recorded Pleistocene eruption	The M8.2 eruption of the Whakamaru Group at 335 ka from Maroa.
Largest recorded Holocene eruption	1.8 ka Taupo Ignimbrite eruption at M6.9
Number of Holocene eruptions	326 confirmed eruptions. 15 uncertain eruptions and 5 discredited eruptions.
Recorded Holocene VEI range:	0 – 6 and unknown.
Number of historically active volcanoes	9
Number of historic eruptions	228

Number of volcanoes	Primary volcano type	Dominant rock type
4	Caldera(s)	Basaltic (1), Rhyolitic (3)
5	Large cone(s)	Andesitic (5)
1	Lava dome(s)	Rhyolitic (1)
1	Shield(s)	Rhyolitic (1)
4	Small cone(s)	Basaltic (4)
13	Submarine	Andesitic (5), Basaltic (1), Dacitic (2), Unknown (1)

Table 122: The number of volcanoes in New Zealand, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	4,464,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	24,818

Gross National Income (GNI) per capita (2005 PPP $)	24,358
Human Development Index (HDI) (2012)	0.919 (Very High)

Population Exposure

Capital city	Wellington
Distance from capital city to nearest Holocene volcano	228 km
Total population (2011)	4,290,347
Number (percentage) of people living within 10 km of a Holocene volcano	532,485 (12.4%)
Number (percentage) of people living within 30 km of a Holocene volcano	1,607,106 (37.5%)
Number (percentage) of people living within 100 km of a Holocene volcano	2,346,034 (54.7%)

Ten largest cities, as measured by population, and populations:

Auckland	417,910
Wellington	381,900
Christchurch	363,926
Hamilton	152,641
Dunedin	114,347
Tauranga	110,338
Hastings	61,696
Whangarei	50,900
New Plymouth	49,168
Invercargill	47,287

Infrastructure Exposure

Number of airports within 100 km of a volcano	7
Number of ports within 100 km of a volcano	8
Total length of roads within 100 km of a volcano (km)	5,617
Total length of railroads within 100 km of a volcano (km)	770

The numerous volcanoes of New Zealand are distributed in a north-east trending chain through the North Island and the Kermadec Islands. Much of the North Island lies within the 100 km radii of the volcanoes here, exposing most of the critical infrastructure of this area. The capital, Wellington, lies over 200 km to the south, however several of New Zealand’s largest cities are fully encompassed and exposed within these radii, exposing an extensive road and rail network and multiple ports and airports. Many submarine volcanoes lie between New Zealand and the Kermadec Islands, thus having no infrastructure exposed here. Raoul Island and Macauley Island in the Kermadec Islands are uninhabited with the exception of the Raoul Island Station, with this being the only infrastructure exposed here.

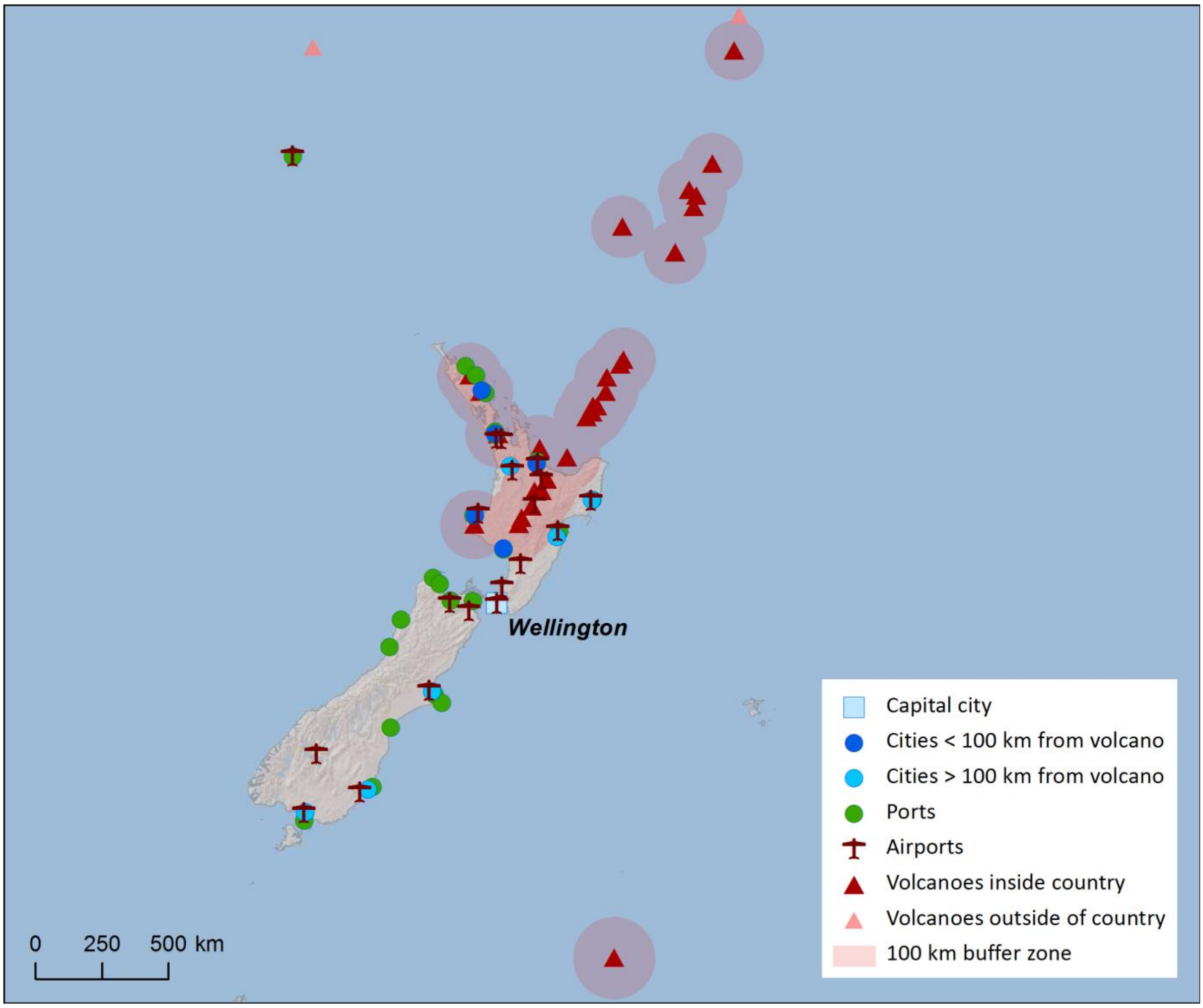


Figure 130: The location of New Zealand's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The volcanoes of New Zealand have varying levels of data available in their eruption records. About 30% of volcanoes have appropriate eruptive histories to define the hazard. These classified volcanoes span all three hazard levels: four at Level I, two at Level II and two at Level III. Taupo and Raoul Island are categorised at Hazard Level III having records of explosive eruptions including VEI 6 eruptions during the Holocene. With the exception of Taupo, all classified volcanoes have had eruptions since 1900.

Of the unclassified volcanoes, just one has had eruptions since 1900 AD: Havre Seamount. Taranaki [Egmont] has historical activity recorded, and seven further volcanoes have Holocene eruption records. Eleven volcanoes have no confirmed Holocene age eruptions. Four unclassified volcanoes have records of unrest above background levels since 1900 (Maroa, Rumble V and IV and Curtis Island).

On the whole the populations local to the New Zealand volcanoes are relatively small, generating low to moderate PEIs. Just two volcanoes have a high PEI: Whangarei at PEI 5 and Auckland Field at PEI 7. Despite an unclassified hazard level, the large local population would make Auckland Field a Risk Level III volcano. Taupo is designated at Hazard Level III, which in combination with a moderate PEI makes this Risk Level III. Most classified New Zealand volcanoes are considered at Risk Level I, with a low PEI and Hazard Levels of I-II.

CLASSIFIED	**Hazard III**	Raoul Island			Taupo			
	Hazard II		Tongariro; Ruapehu					
	Hazard I	Rumble III; Monowai Seamount	White Island	Okataina				
UNCLASSIFIED	**U – HHR**	**Havre Seamount**	Taranaki [Egmont]					
	U- HR	Healy; Macauley Island	Mayor Island; **Maroa**	Reporoa	Kaikohe-Bay of Islands			Auckland Field
	U-NHHR	Clark; Tangaroa; **Rumble V; Rumble IV;** Rumble II West; Brothers; Volcano W; **Curtis Island;** Giggenbach; Antipodes Island				Whangarei		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 123: Identity of New Zealand's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Taupo	4	III
Okataina	3	I
White Island	2	I
Tongariro	2	I
Ruapehu	2	I
Rumble III	1	I
Raoul Island	1	I
Monowai Seamount	1	I

Table 124: Classified volcanoes of New Zealand ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 7 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 1 volcano.

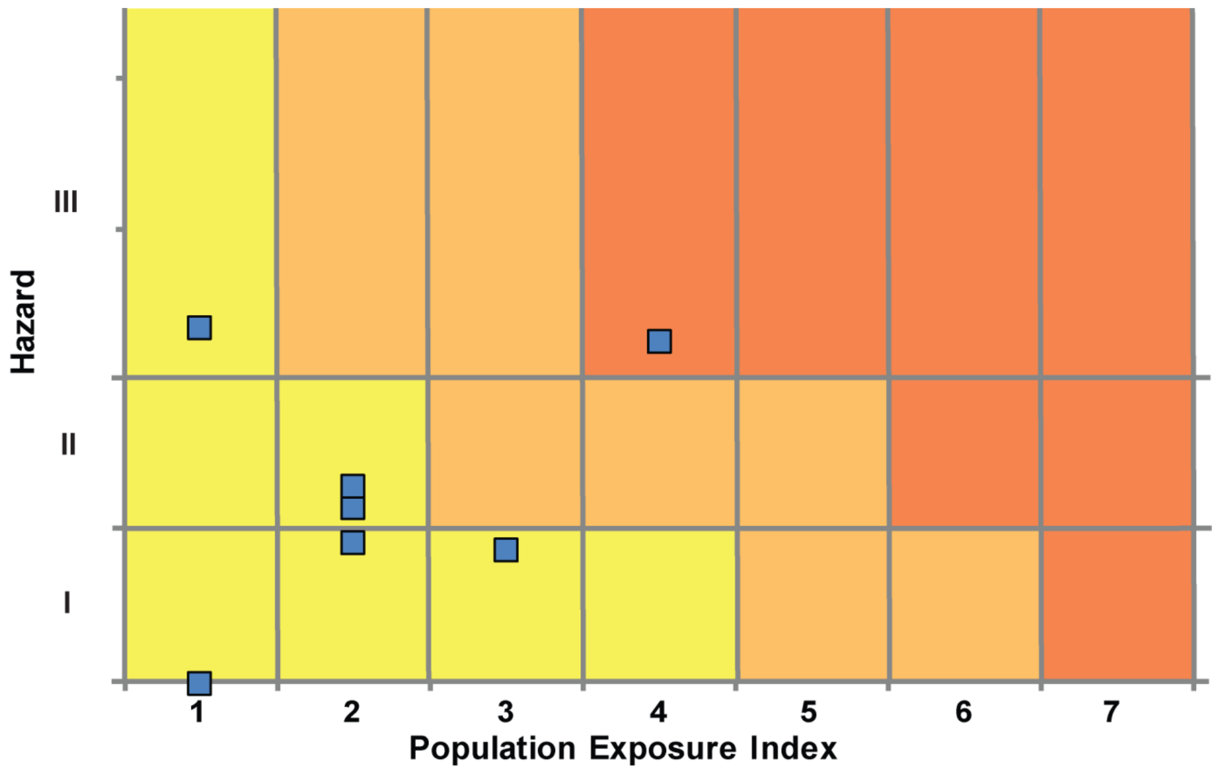


Figure 131: Distribution of New Zealand's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Nine volcanoes have records of historical activity in New Zealand. Of these, all but two unclassified volcanoes are Risk Level I. GeoNet, a collaboration between the Earthquake Commission and GNS Science, is responsible for the monitoring of New Zealand's volcanoes and provision of hazard information. Four historically active volcanoes are monitored using seismic networks of four or more seismometers, three of which have additional deformation monitoring. Two volcanoes have three or fewer seismometers and deformation monitoring. The submarine volcanoes do not currently have dedicated ground-based monitoring. Monitoring is also undertaken at volcanoes which have not been historically active, including the Auckland Volcanic Field.

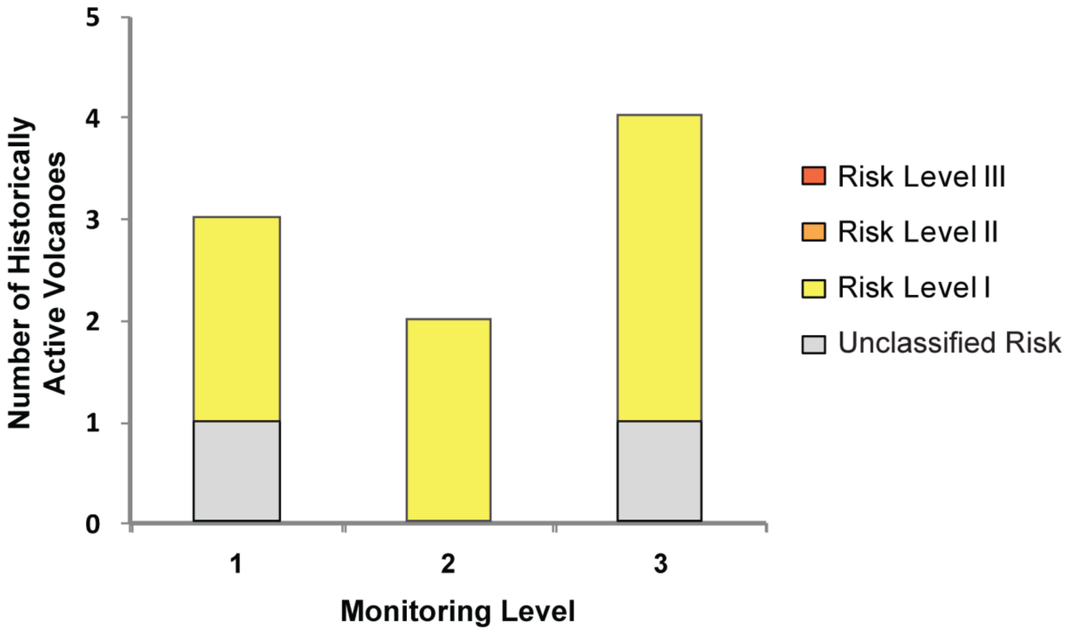


Figure 132: The monitoring and risk levels of the historically active volcanoes in New Zealand. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Samoa

Samoa is a country that forms the western part of the Samoan Island Chain, whilst the eastern half of the chain is American Samoa. Samoa and American Samoa have individual profiles.

Description

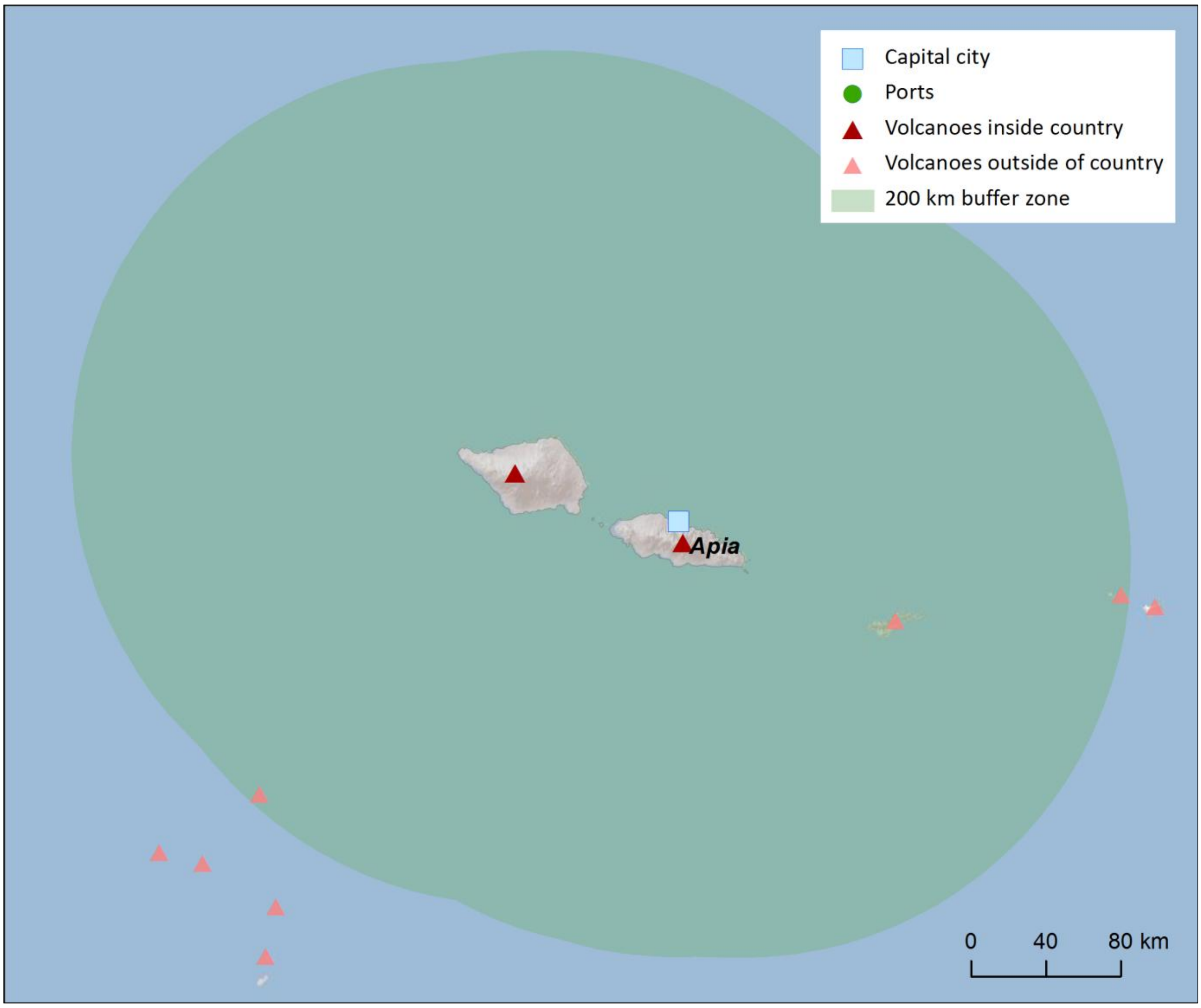


Figure 133: Location of Samoa's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Samoa.

Two Holocene volcanoes are located on the largest islands of Samoa, Upola (Upolu volcano) and Savai'i (Savai'i volcano). These are both basaltic shield volcanoes that have developed as a result of intraplate processes (the Samoan plate) and subduction in the Tonga-Kermadec-New Zealand subduction zone.

Twelve eruptions are recorded at Savai'i between 1990 BC and 1905 AD. No confirmed eruptions are recorded at Upolu, however Holocene activity is suspected here.

Most of Savai'i's eruptions are of an unknown magnitude, with only the three most recent events attributed a size of VEI 1 and 2. Typically, eruptions of unknown size are expected to have been small events, and as most produced lava flows at this basaltic shield, it is likely that these eruptions were of a similar size to the recent eruptions.

The entirety of the Samoan islands lie in close proximity to the volcanoes, and about 10% of the population live within 10 km of these volcanoes. Evacuations and property damage are recorded in the 1760, 1902 and 1905 eruptions of Savai'i.

Comprehensive eruptive histories are absent for Samoa, and hazard assessments are thus complicated by uncertainties, particularly at Upolu. Cronin et al., (2006) suggest five possible future eruption types – long-term lava field, short-term spatter cones, explosive-phreatomagmatic, explosive scoria-cone and submarine flank collapse. They suggest that predicting the location of future vents is impossible, given the distribution of hundreds of monogenetic vents across the islands, however they produce maps to indicate the relative potential for new vents. They go on to recommend further research to better understand volcanism in Samoa, the installation of a monitoring network, early warning systems, disaster preparedness and crises response planning.

See also:

Cronin, S., Bonte-Graentin, M., and Nemeth, K. (2006). Samoa technical report: Review of volcanic hazard maps for Savai'i and Upolu, EU EDF 8 – SOPAC Project Report 59, July 2006.
http://mro.massey.ac.nz/bitstream/handle/10179/556/strcn.pdf?sequence=3

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Two VEI 2 eruptions at Savai'i in 1760 and 1905.
Number of Holocene eruptions	12 confirmed eruptions.
Recorded Holocene VEI range	1 – 2 and Unknown.
Number of historically active volcanoes	1
Number of historic eruptions	4

Number of volcanoes	Primary volcano type	Dominant rock type
2	Shield(s)	Basaltic (2)

Table 125: The number of volcanoes in Samoa, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	189,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,008
Gross National Income (GNI) per capita (2005 PPP $)	3,928
Human Development Index (HDI) (2012)	0.702 (Medium)

Population Exposure

Capital city	Apia
Distance from capital city to nearest Holocene volcano	12.4 km
Total population (2011)	193,161
Number (percentage) of people living within 10 km of a Holocene volcano	18,515 (9.6%)
Number (percentage) of people living within 30 km of a Holocene volcano	150,605 (78%)
Number (percentage) of people living within 100 km of a Holocene volcano	187,163 (96.9%)

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

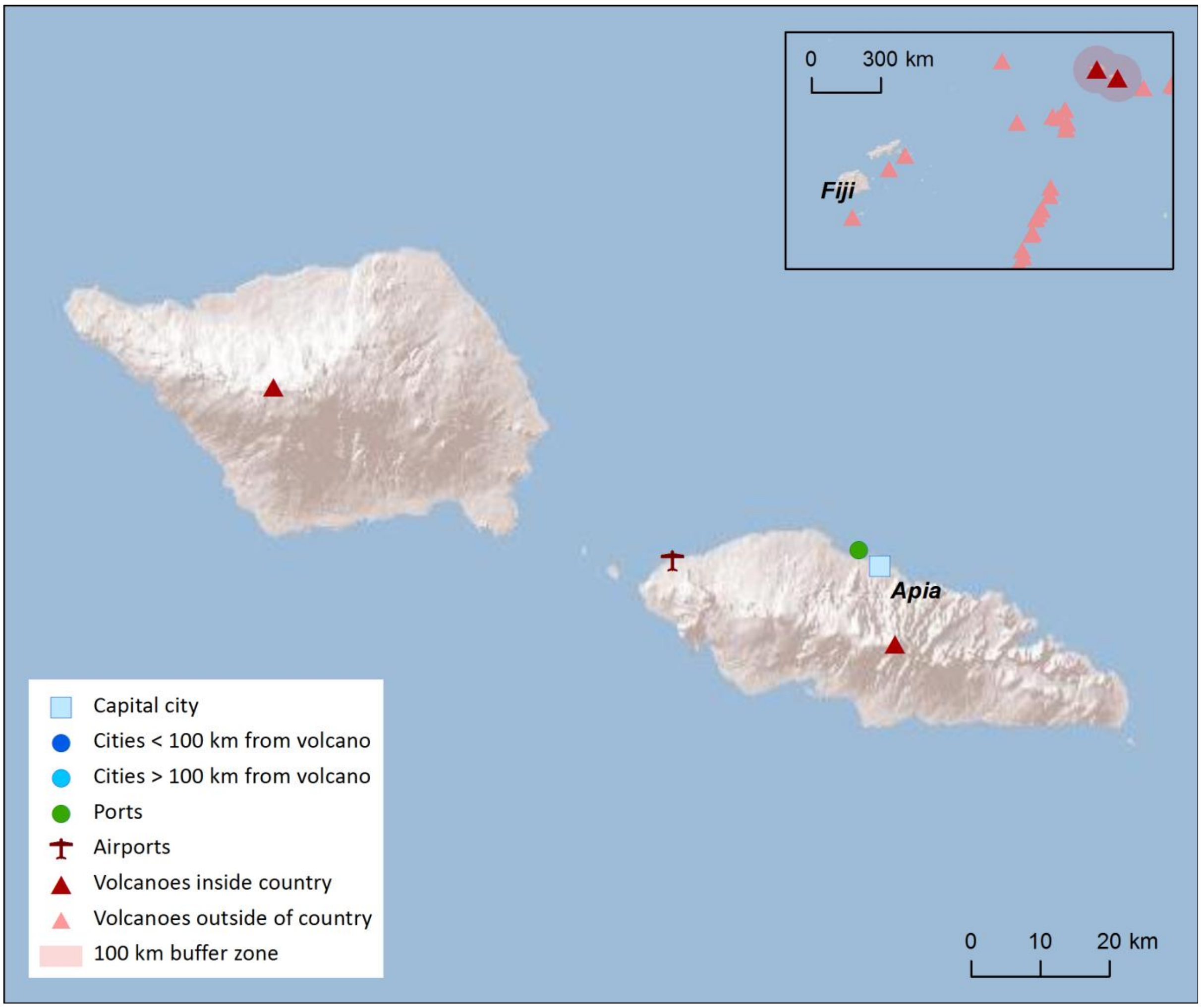


Figure 134: The location of Samoa's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The Samoan volcanoes are located on the largest islands in the country, Upola and Savai'i. As these islands measure no more than 75 km across, they in their entirety lie within the 100 km radii of the volcanoes. This places all critical infrastructure within these radii, including the capital, Apia, which lies at just 12 km from Upolu volcano.

Hazard, Uncertainty and Exposure Assessments

Both of Samoa's volcanoes lack extensive eruption records, which prevents the assessment of hazard without large uncertainties. These volcanoes are therefore unclassified. Savai'i has 12 confirmed eruptions recorded during the Holocene, including events since 1900 AD, however the size of the eruptions is only known in three of these. There are no confirmed eruptions from Upolu during the Holocene.

Both Samoan volcanoes have a low to moderate PEI.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		**Savai'i**					
	U- HR							
	U- NHHR				Upolu			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 126: Identity of Samoa's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

One unclassified volcano, Savai'i, has historical eruption records in Samoa. No information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any of the volcanoes in Samoa.

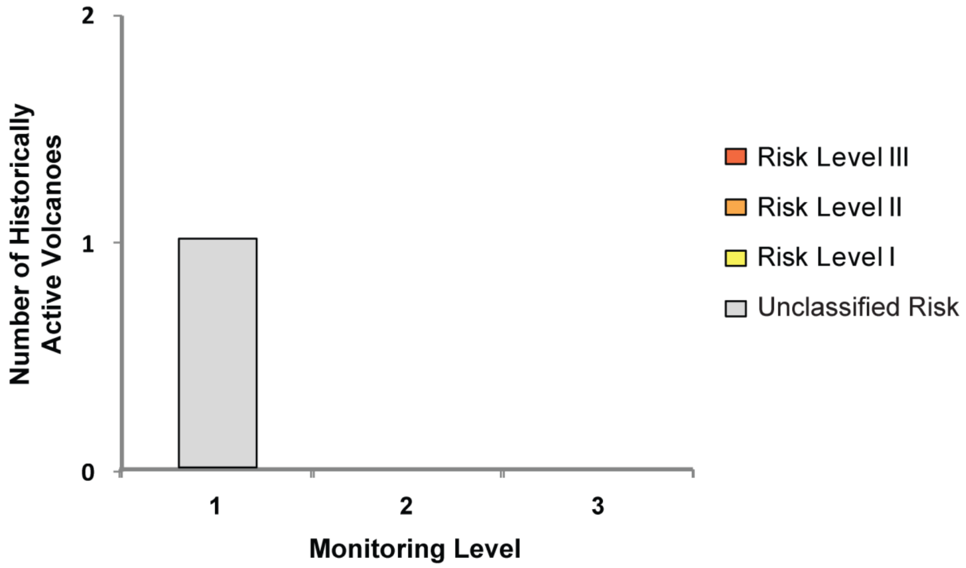


Figure 135: The monitoring and risk levels of the historically active volcanoes in Samoa. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

USA - American Samoa

See further volcanoes of the USA see Region 8 (the Marianas), Region 11 (Alaska), Region 12 (the contiguous states), and Region 13 (Hawaii).

American Samoa is a group of five islands that forms the eastern part of the Samoan Island Chain, whilst the western half of the chain is Samoa. Samoa and American Samoa have individual profiles.

Description

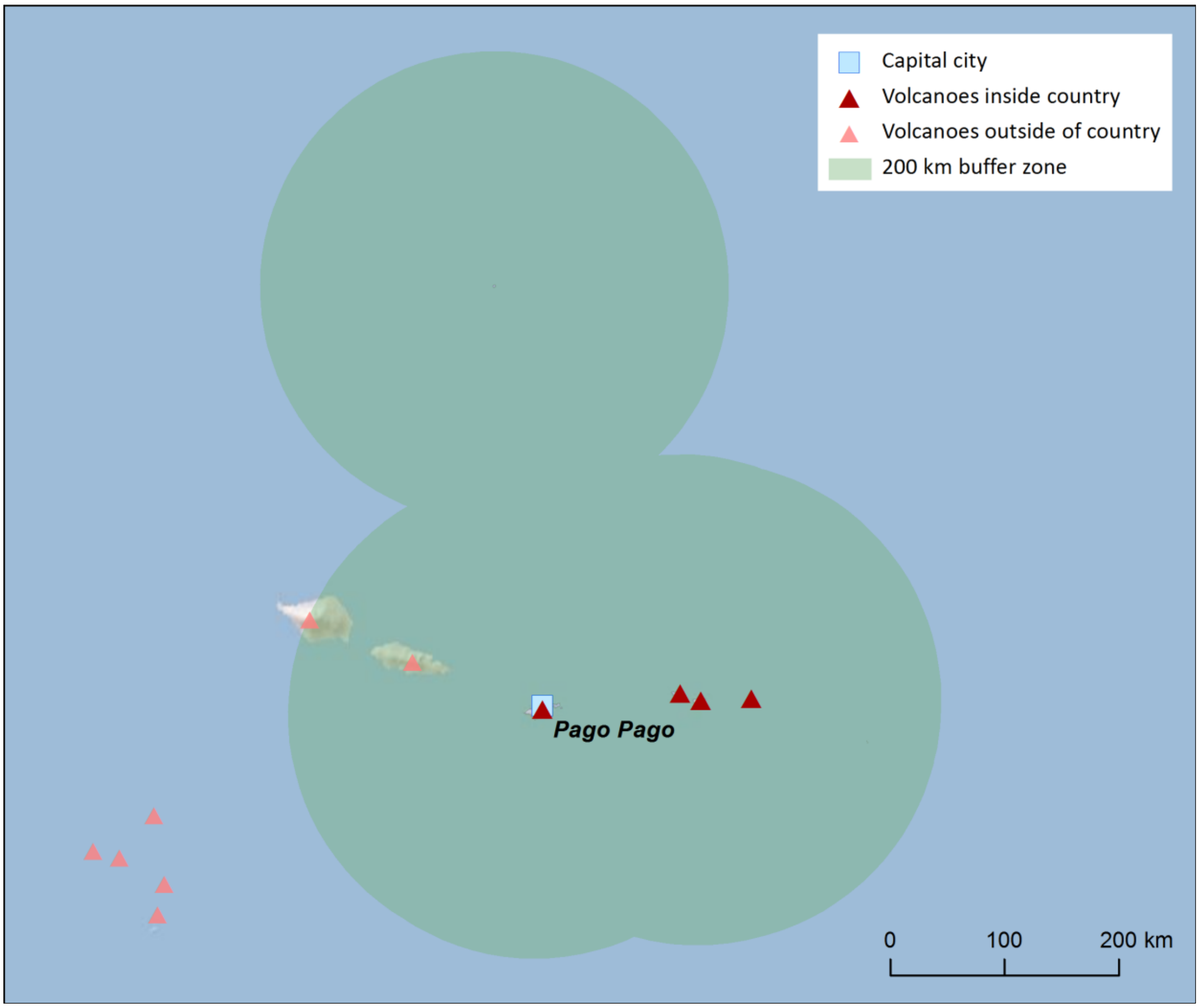


Figure 136: Location of American Samoa's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect American Samoa.

Four Holocene volcanoes are located in American Samoa. The easternmost volcano, Vailulu'u is a basaltic submarine volcano. Ta'u and Ofu-Olosega are two basaltic shield volcanoes located on the small Manu'a islands. Tutuila is a group of tuff cones located on the main island of the same name. Volcanism here is due the presence of the Samoan hotspot.

Four Holocene eruptions are recorded here between 1866 and 2003 from Vailulu'u and Ofu-Olosega. These eruptions measured VEI 0 to 2, indicating mild to moderate explosive activity. Lava flows are recorded in the two most recent eruptions of the submarine Vailulu'u.

About three quarters of the population of American Samoa live within 100 km of one or more Holocene volcano. Indeed, the capital Pago Pago, lies less than 2 km from Tutuila. Assessment of hazard at the volcanoes here is associated with considerable uncertainty given the very short eruption records, and further research is required to more fully understand activity. Being dominantly basaltic centres, mild activity as seen in historic times may be a likely feature of future activity, however larger eruptions cannot be ruled out.

Volcano Facts

Number of Holocene volcanoes	4
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The 1866 VEI 2 eruption of Ofu-Olosega.
Number of Holocene eruptions	4
Recorded Holocene VEI range	0 – 2
Number of historically active volcanoes	2
Number of historic eruptions	4

Number of volcanoes	Primary volcano type	Dominant rock type
1	Small cone(s)	Basaltic (1)
2	Shield(s)	Basaltic (2)
1	Submarine	Basaltic (1)

Table 127: The number of volcanoes in American Samoa, their volcano type classification and dominant rock type according to VOTW4.0.

Population Exposure

Capital city	Pago Pago
Distance from capital city to nearest Holocene volcano	1.7 km

Total population (2011)	67,242
Number (percentage) of people living within 10 km of a Holocene volcano	48,820 (72.6%)
Number (percentage) of people living within 30 km of a Holocene volcano	54,967 (81.8%)
Number (percentage) of people living within 100 km of a Holocene volcano	54,967 (81.8%)

Largest cities, as measured by population, and populations:

Pago Pago	4,196

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	-
Total length of railroads within 100 km of a volcano (km)	-

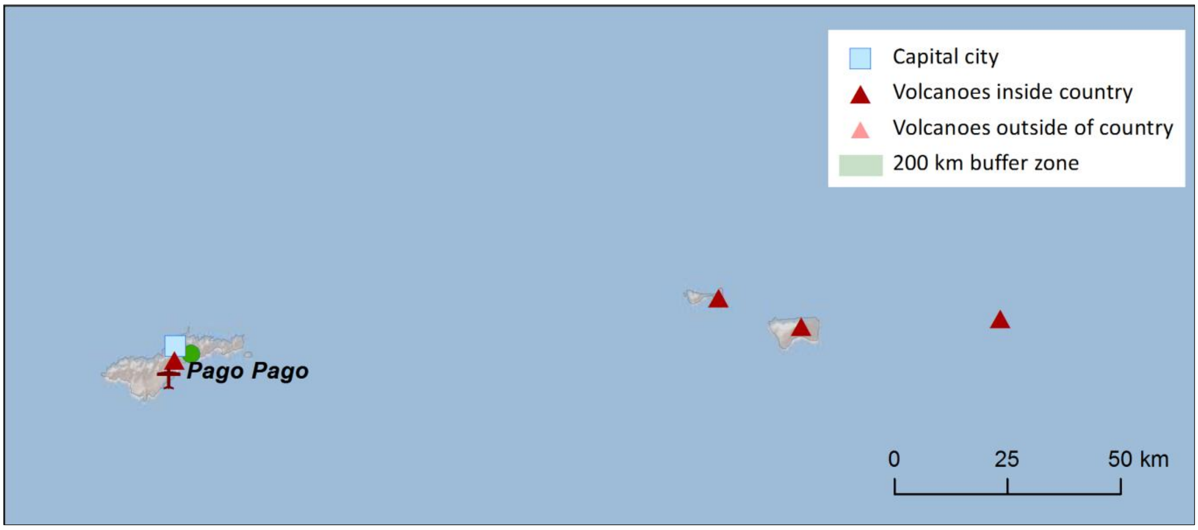


Figure 137: The location of American Samoa's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The Vailulu'u volcano is the most easterly of American Samoa and is a submarine volcano, hence no infrastructure is exposed. Ta'u and Ofu-Olosega volcanoes are located on the small Manu'a islands which measure no more than 15 km across, and therefore all infrastructure here is exposed. Tutuila volcano is located on the main island of the same name. This island also measures no more than 40 km across, and therefore all infrastructure and population lies within the 100 km radius of this volcano, including ports, an airport and the capital city, Pago Pago.

Hazard, Uncertainty and Exposure Assessments

All volcanoes in American Samoa lack an extensive eruptive history, which prevents the calculation of hazard without associated large uncertainties. These volcanoes are therefore unclassified. No confirmed Holocene eruptions are recorded at Ta'u and Tatuila, however historical eruptions are recorded at both Ofu-Olosega and Vailulu'u, as recently as 2003, all of VEI 0-2.

The PEI levels of American Samoa's volcanoes range from low to high, with three volcanoes having only a small local population and therefore being classed at PEI 2. Tutuila volcano however, has a population of nearly 50,000 within 10 km making this PEI 5, as this volcano is located on the largest island of American Samoa, which is populated with numerous settlements and the capital Pago Pago.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		**Vailulu'u;** Ofu-Olosega					
	U- HR							
	U- NHHR		Ta'u			Tatuila		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 128: Identity of American Samoa's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Two unclassified volcanoes have historical eruption records in American Samoa, Vailulu'u and Ofu-Olosega. No information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any of the volcanoes in American Samoa.

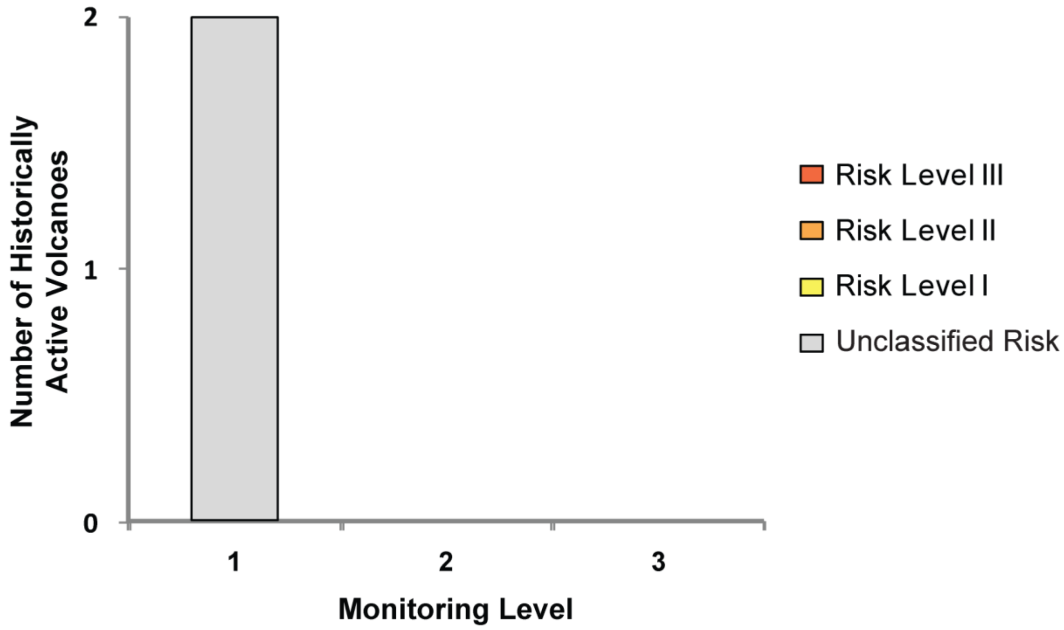


Figure 138: The monitoring and risk levels of the historically active volcanoes in American Samoa. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Tonga

Description

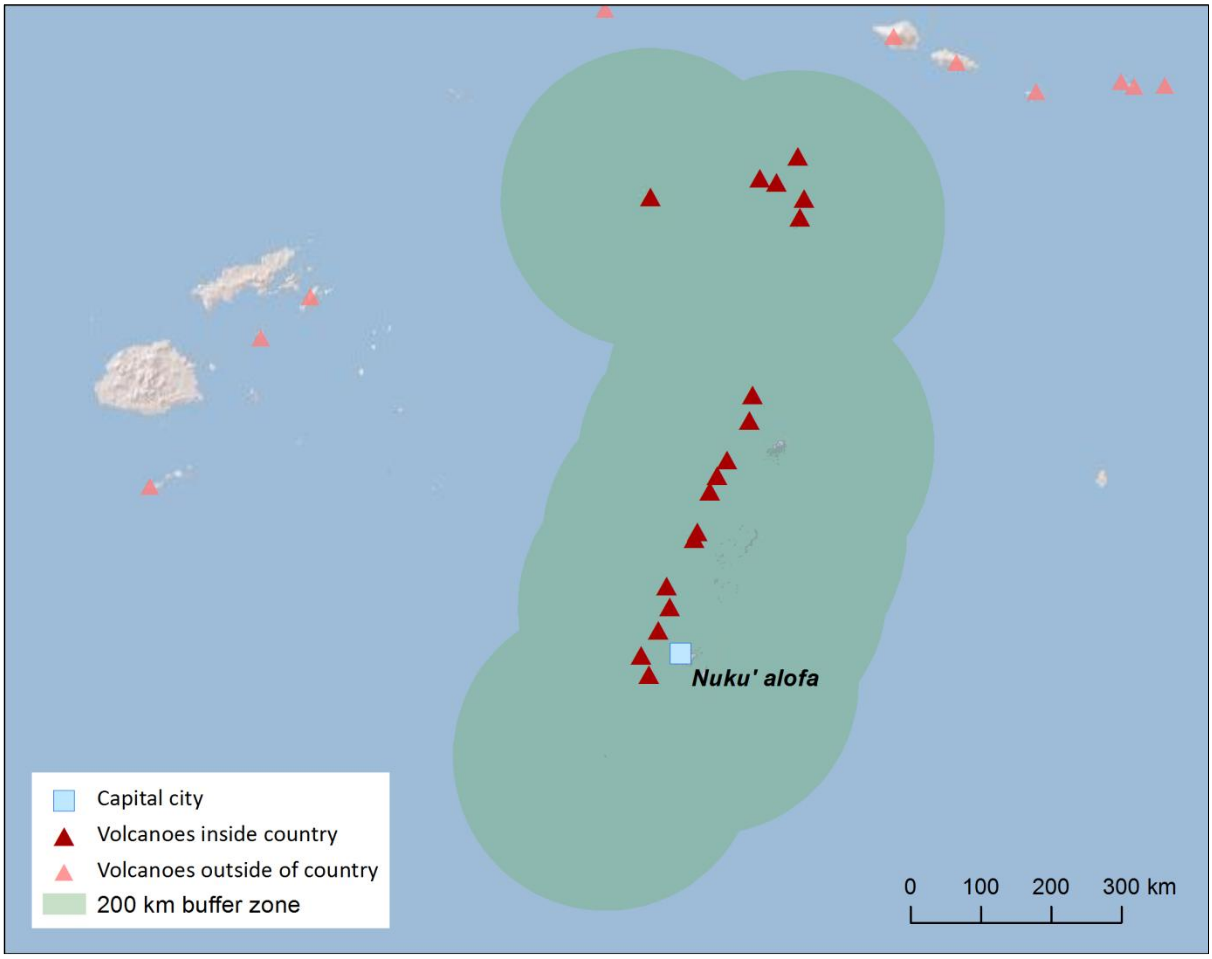


Figure 139: Location of Tonga's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Tonga.

Tonga comprises two parallel island belts. The belt to the east is populated, while the eighteen Holocene volcanoes of Tonga are mainly located in the less populated westerly belt. Volcanism here is due to the subduction of the Pacific Plate beneath the Indo-Australian plate. Most (11 out of 18) Tongan volcanoes are submarine. The subaerial volcanoes are stratovolcanoes, calderas and one shield. The composition is dominantly andesitic.

Of these eighteen Holocene volcanoes, just twelve have confirmed eruptions. All confirmed eruptions are recorded post-1500 AD and all through historical observations, meaning the full Holocene eruption history at all Tongan volcanoes is unknown.

Fifty-eight eruptions are recorded since 1774, the year after European contact was made with Tonga. These eruptions have ranged in size from VEI 0 to 4, indicating a range of activity styles from mild to significant explosive events. One of the largest eruptions was the VEI 4 eruption of Fonualei in 1846 which produced large pumice rafts, ashfall which damaged crops on the island of Vavua (56 km away) and was recorded up to 950 km away.

Evacuations due to eruptions of Fonualei and Niuafo’ou are recorded in four events, and property damage is recorded in ten eruptions of these volcanoes. Lives were lost in two eruptions of Niuafo’ou in 1886 and 1853.

Activity here has been dominantly mild with eruptions of VEI 0 – 2, but assessment of hazard at many of Tonga’s volcanoes is complicated by the absence of a comprehensive eruption history dating back into the Holocene.

Only a small population lives within 10 km of one or more Holocene volcano, as much of the population is focussed on the easterly islands. However the whole population lies within 100 km distance of the volcanoes, and as past events have shown, ash fall can affect the main Tongan islands.

Volcano Facts

Number of Holocene volcanoes	18
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	6
Number of fatalities caused by volcanic eruptions	36?
Tectonic setting	Subduction zone (17), Rift zone (1)
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Two eruptions both measuring M4.7 occurred here, the Fonualei and Niuafo’ou eruptions in 1846 AD and 1886 AD respectively.
Number of Holocene eruptions	58 confirmed eruptions. 13 uncertain eruptions and 1 discredited eruption.
Recorded Holocene VEI range	0 – 4 and unknown.
Number of historically active volcanoes	12
Number of historic eruptions	58

Number of volcanoes	Primary volcano type	Dominant rock type
2	Caldera(s)	Andesitic (1), Unknown (1)
4	Large cone(s)	Andesitic (3), Dacitic (1)
1	Shield(s)	Basaltic (1)
11	Submarine	Andesitic (4), Basaltic (1), Dacitic (4), Unknown (2)

Table 129: The number of volcanoes in Tonga, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	105,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,092
Gross National Income (GNI) per capita (2005 PPP $)	4,153
Human Development Index (HDI) (2012)	0.710 (Medium)

Population Exposure

Capital city	Nuku'alofa
Distance from capital city to nearest Holocene volcano	45.6 km
Total population (2011)	105,916
Number (percentage) of people living within 10 km of a Holocene volcano	1,002 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	2,564 (2.4%)
Number (percentage) of people living within 100 km of a Holocene volcano	105,084 (99.2%)

Largest cities, as measured by population, and populations:

Nuku' alofa	22,400

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	3

Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes of Tonga are mainly located to the west of the largest Tongan islands, however their 100 km radii extend to encompass this island chain in its entirety, therefore exposing all infrastructure to the volcanic hazard, including the capital, Nuku'alofa.

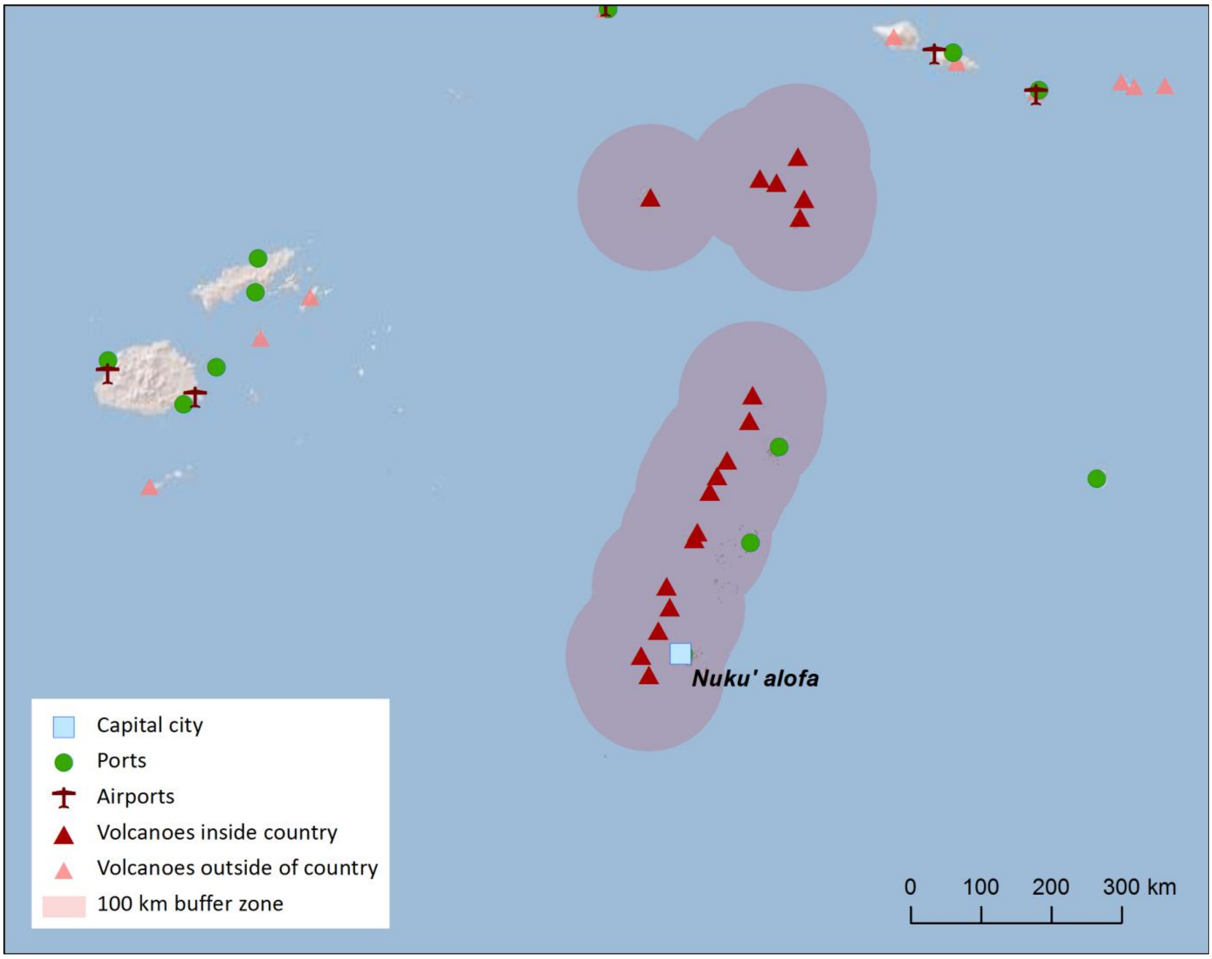


Figure 140: The location of Tonga's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying amounts of data available in the eruption records of Tonga's volcanoes. About 30% of these volcanoes have appropriate eruptive histories to define the hazard, and these volcanoes are classified at Hazard Levels I and II based on activity dominated by eruptions of VEI 0 – 2.

Of the unclassified volcanoes, four have no confirmed Holocene eruptions. Eight have historical eruptions, seven of which have had eruptions since 1900 AD.

All of the volcanoes in Tonga have a low PEI of 1 – 2. This, coupled with the hazard levels of the classified volcanoes makes these Risk Level I volcanoes.

CLASSIFIED	**Hazard III**							
	Hazard II		Hunga Tonga-Hunga Ha'apai; Fonualei; Niuafo'ou					
	Hazard I		Falcon Island; Tofua; Metis Shoal					
UNCLASSIFIED	**U – HHR**		**Unnamed (243010); Unnamed (243030); Home Reef;** Late; **Unnamed (243091); Curacoa; Tafu-Maka; West Mata**					
	U- HR							
	U- NHHR	Niua Tahi	Unnamed (243011); Kao; Tafahi					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 130: Identity of Tonga's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Falcon Island	2	I
Fonualei	2	I
Hunga Tonga-Hunga Ha'apai	2	I
Tofua	2	I
Metis Shoal	2	I
Niuafo'ou	2	I

Table 131: Classified volcanoes of Tonga ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 6 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

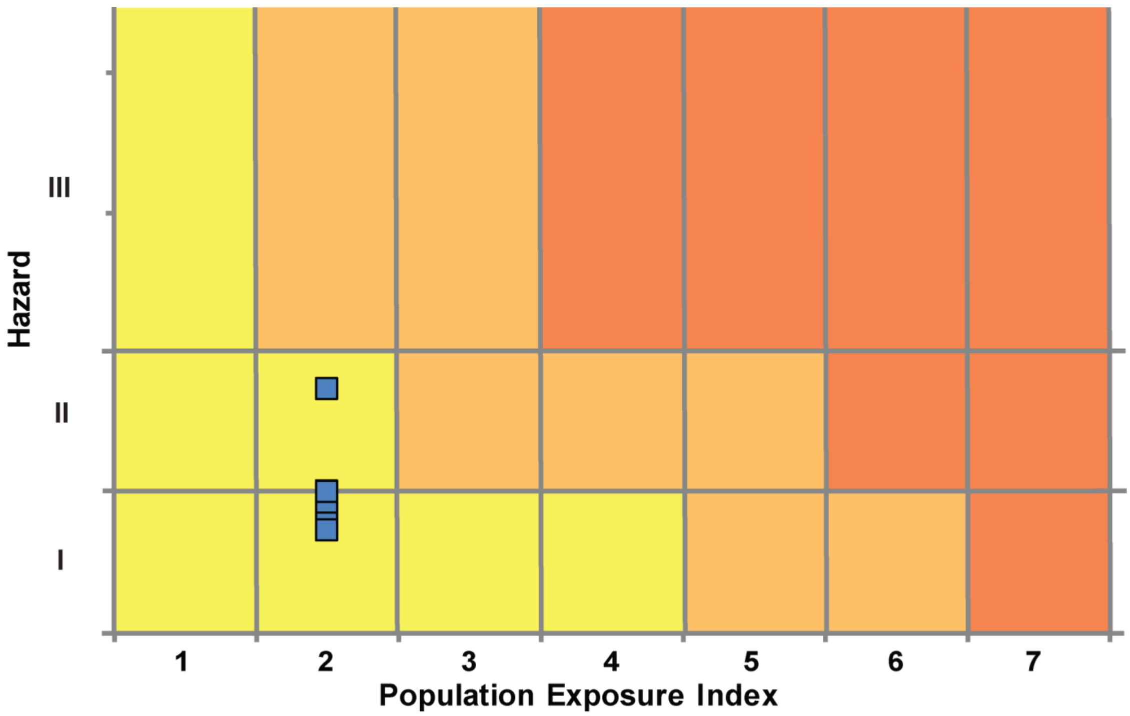


Figure 141: Distribution of Tonga's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Fourteen volcanoes have historical eruption records in Tonga, six of which are Risk Level I, 8 are unclassified. No information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any of the volcanoes in Tonga.

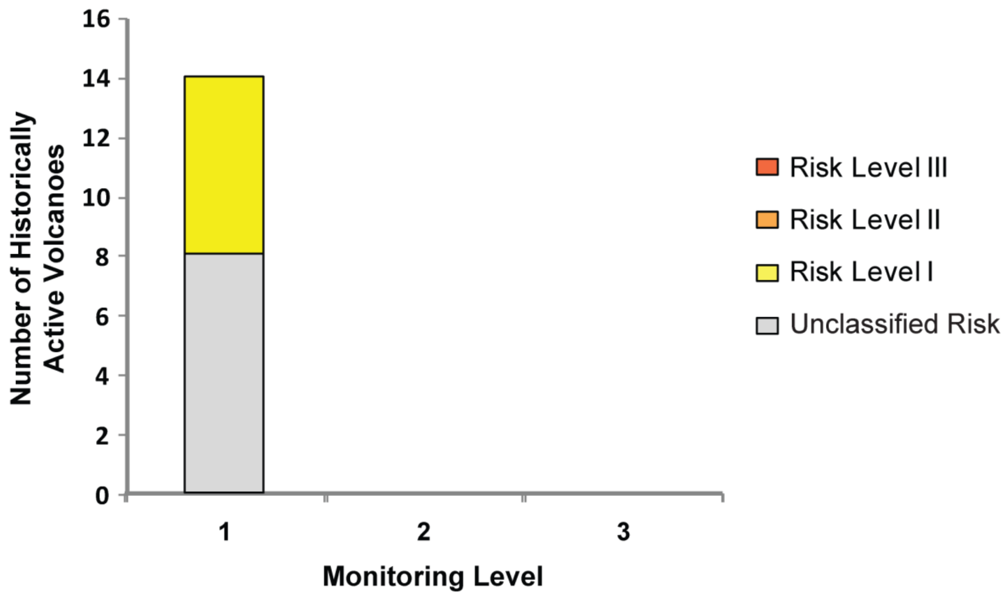


Figure 142: The monitoring and risk levels of the historically active volcanoes in Tonga. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 5: Melanesia and Australia

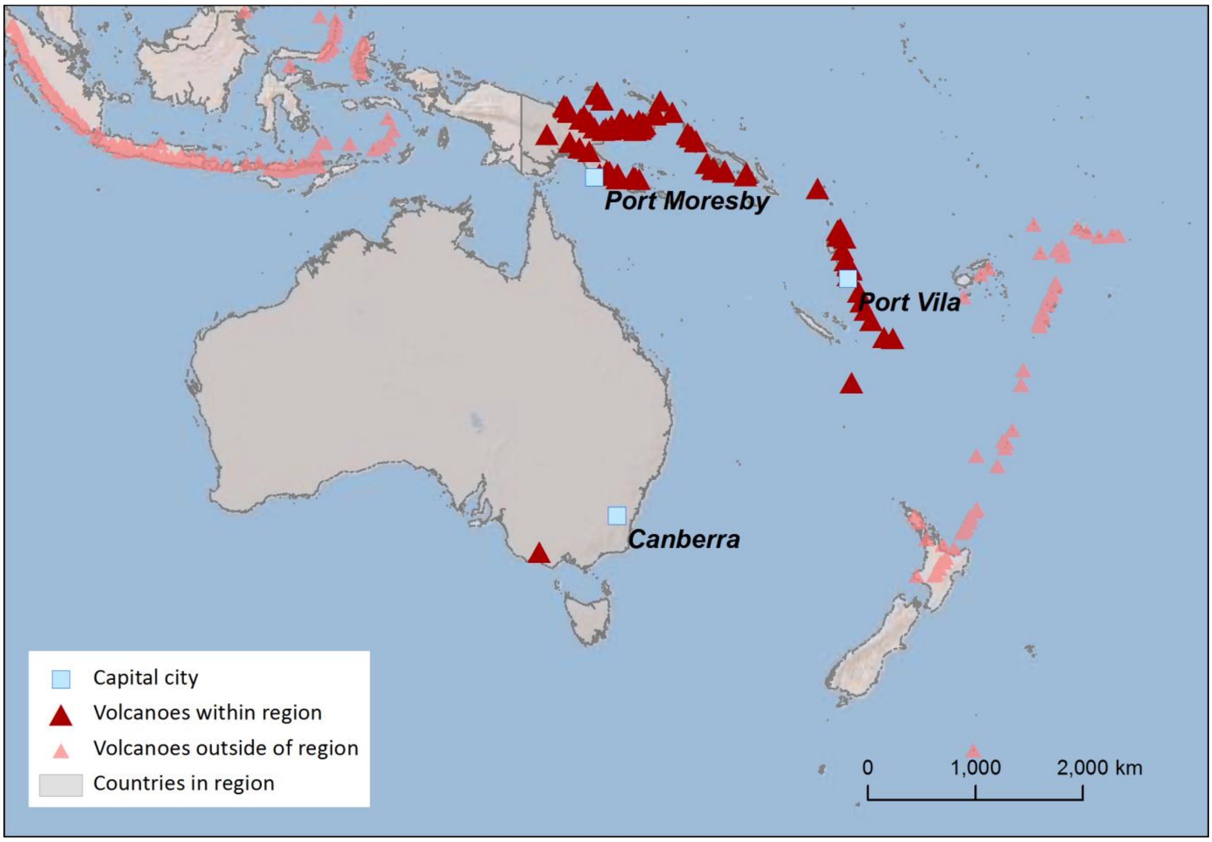


Figure 143: The distribution of Holocene volcanoes through the Melanesia and Australia region. The capital cities of the constituent countries are shown.

Description

Region 5, Melanesia and Australia, comprises volcanoes in five countries. Australia, France, Papua New Guinea, the Solomon Islands and Vanuatu. The volcanoes of France in this region are the overseas territories of Matthew and Hunter Islands and Eastern Gemini Seamount, located at the southern end of the Vanuatu chain. The details of these French islands are incorporated into the French Pacific Islands country profile of Region 13. Here, just one Australian volcano is classed as Region 5, but we present two further Australian volcanoes from Region 3 in the Australia profile.

Country	Number of volcanoes
Australia	1 + 2 from Region 3
France (See Region 13)	3
Papua New Guinea	56
Solomon Islands	8
Vanuatu	14

Table 132: The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

Volcanism in this region has arisen due to a complex system of plate interactions, with multiple micro-plates located throughout the region. Most volcanoes are due to subduction zone processes, dominantly with the subduction of the Pacific and Solomon Sea Plates. The singular volcano on mainland Australia is due to intra-plate processes. Most volcanoes here are of andesitic or basaltic composition, and a range of volcano types are present throughout the region. About 60% of all volcanoes are stratovolcanoes or types of large cones, with 11% of volcanoes classified as calderas.

Large explosive volcanism is recorded back into the Pleistocene, with seven volcanoes having Pleistocene records of VEI ≥4 eruptions. Despite this, the more recent record is sparse until historical times. 83 volcanoes have had confirmed or suspected Holocene activity, of which 37 have historical activity. Of a total of 449 Holocene eruptions, 400 are dated post-1500 AD, and 86% of events have been recorded through historical observations. The absence of a comprehensive record prior to recent centuries means that full understanding of activity and hazard here is difficult.

Holocene activity has comprised eruptions of VEI 0 to 6, indicating a range of small to very large explosive events. Explosive activity is relatively common with about 8% of eruptions of VEI ≥4, and with moderate to large explosive events occurring about every 13 years. Approximately 12% of historical eruptions have produced pyroclastic flows.

The population through this region is such that most volcanoes are classed with low to moderate PEI values. However, about 260,000 people live within 10 km of one or more Holocene volcano, within the distance where many of the hazardous flows are concentrated. 25 historical eruptions have resulted in fatalities (6% of historical eruptions here), with most deaths attributed to pyroclastic flows and tsunamis. This region ranks third for the number of tsunami-generating eruptions historically.

Dedicated volcano monitoring is in place in Papua New Guinea, Vanuatu and the Solomon Islands, though most frequently using few seismic stations. The only Risk Level III volcano in the region, Rabaul in Papua New Guinea, is monitored by the Rabaul Volcano Observatory, with multiple dedicated ground-based monitoring systems.

Volcano facts

Number of Holocene volcanoes	83
Number of Pleistocene volcanoes with M≥4 eruptions	7
Number of volcanoes generating pyroclastic flows	24 (69 eruptions)
Number of volcanoes generating lahars	13 (17 eruptions)
Number of volcanoes generating lava flows	20 (110 eruptions)
Number of eruptions with fatalities	28
Number of fatalities attributed to eruptions	10,445
Largest recorded Pleistocene eruption	The M7.4 Kiau Ignimbrite eruption at Long Island at 19,245 BP.

Largest recorded Holocene eruption	The largest recorded Holocene eruption in this region was the 998 BP Dk eruption of Dakataua at M7.4.
Number of Holocene eruptions	449 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 6 and unknown.
Number of historically active volcanoes	37
Number of historical eruptions	400

Number of volcanoes	Primary volcano type	Dominant rock type
9	Caldera(s)	Andesitic (3), Basaltic (3), Dacitic (2), Rhyolitic (1)
1	Hydrothermal field	Andesitic (1)
48	Large cone(s)	Andesitic (24), Basaltic (20), Dacitic (1), Phonolitic (2), Rhyolitic (1)
1	Lava dome(s)	Andesitic (1)
2	Shield(s)	Basaltic (2)
11	Small cone(s)	Andesitic (6), Basaltic (2), Dacitic (1), Rhyolitic (2)
9	Submarine	Andesitic (2), Dacitic (1), Unknown (6)

Table 133: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	10

Table 134: Average recurrence interval (years between eruptions) for small and large eruptions in Melanesia and Australia.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 10 years.

Eruption Size

Eruptions are recorded through the Melanesia and West Asia region of VEI 0 to 6, representing a range of eruption styles from gentle effusive events to very large explosive eruptions. VEI 2 events dominate the record, with nearly 60% of all Holocene eruptions classed as such. Of the eruptions here, 7.6% are of VEI ≥4.

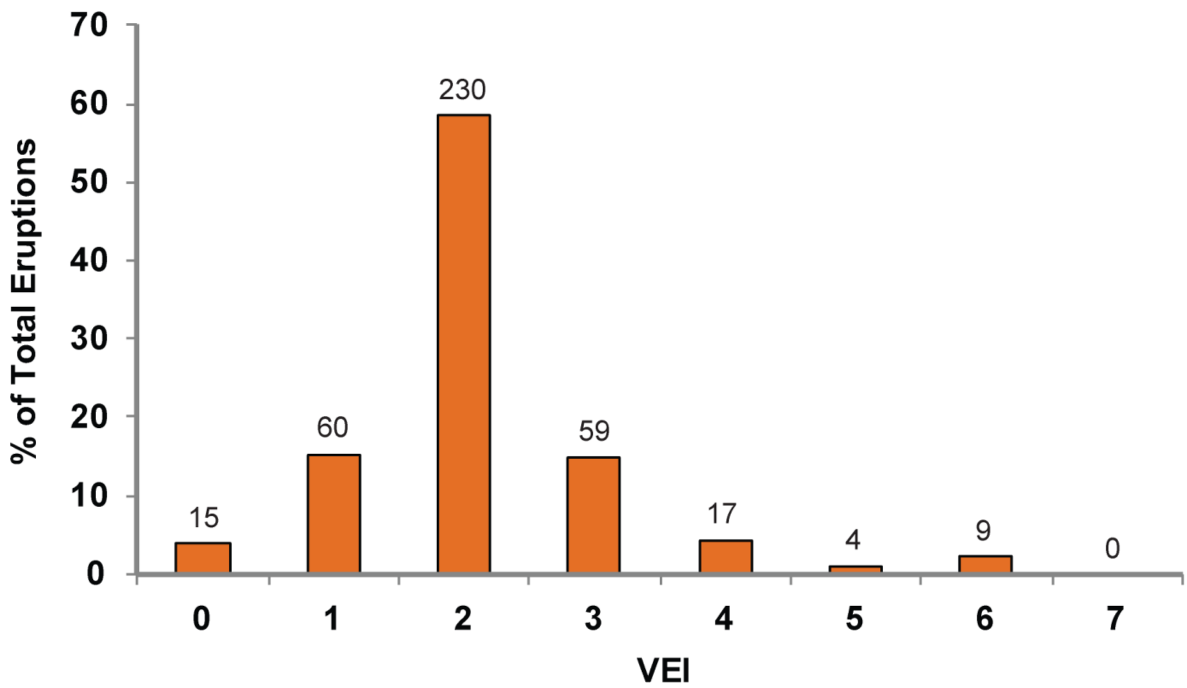


Figure 144: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 55 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	7,187,689
Gross Domestic Product (GDP) per capita (2005 PPP $)	2,363 – 34,548 (Mean 10,889)
Gross National Income (GNI) per capita (2005 PPP $)	2,172 – 34,340 (Mean 10,715)
Human Development Index (HDI) (2012)	0.466 – 0.938 (Low to Very High, Mean 0.64 Medium)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	257,684 (3.59 %)
Number (percentage) of people living within 30 km of a Holocene volcano	1,252,172 (17.42 %)
Number (percentage) of people living within 100 km of a Holocene volcano	5,869,560 (81.66 %)

CLASSIFIED	**Hazard III**		Long Island; Ulawun; Bagana; Aoba	Manam; Karkar		Rabaul		
	Hazard II		Ambrym; Lopevi	Yasur	Pago			
	Hazard I		Bam; Ritter Island; Kavachi; Tinakula; Gaua; Epi; Kuwae	Langila				
UNCLASSIFIED	**U – HHR**	**Eastern Gemini Seamount; Hunter Island; Unnamed (258030)**	**St. Andrew Strait**; **Unnamed (250030)**; Dakataua; **Bamus**; **Victory**; **Waiowa**; Billy Mitchell; **Simbo**; Traitor's Head; **Matthew Island**	**Garbuna Group**; **Lolobau**; **Lamington**; Savo; **Suretamatai**				
	U- HR		**Loloru**	Hargy; **Dawson Strait Group**; Ambitle		Tavui		Newer Volcanics Province
	U- NHHR		Baluan; Blup Blup; **Kadovar**; Boisa; **Unnamed (252001)**; Yomba; **Umboi**; Sakar; Unnamed; Mundua; Bola; **Sulu Range**; Unnamed; Madilogo; Hydrographers Range; Musa River; Iamalele; Lihir; Tore; **Balbi**; Kana Keoki; Coleman Seamount; Unnamed; Motlav; Mere Lava; **Unnamed (255061)**; Aneityum	Garove; Doma Peaks; Crater Mountain; **Yelia**; Managlase Plateau; Sessagara; Goodenough; Takuan Group; North Vate	Garua Harbour; Lolo; Koranga; Gallego			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 135: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
1	7
0	6
2	5
5	4
21	3
51	2
3	1

Table 136: The number of volcanoes in Melanesia and Australia classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
1	III
8	II
10	I
18	Unclassified

Table 137: The number of volcanoes in the Melanesia and Australia region classified at each Risk Level.

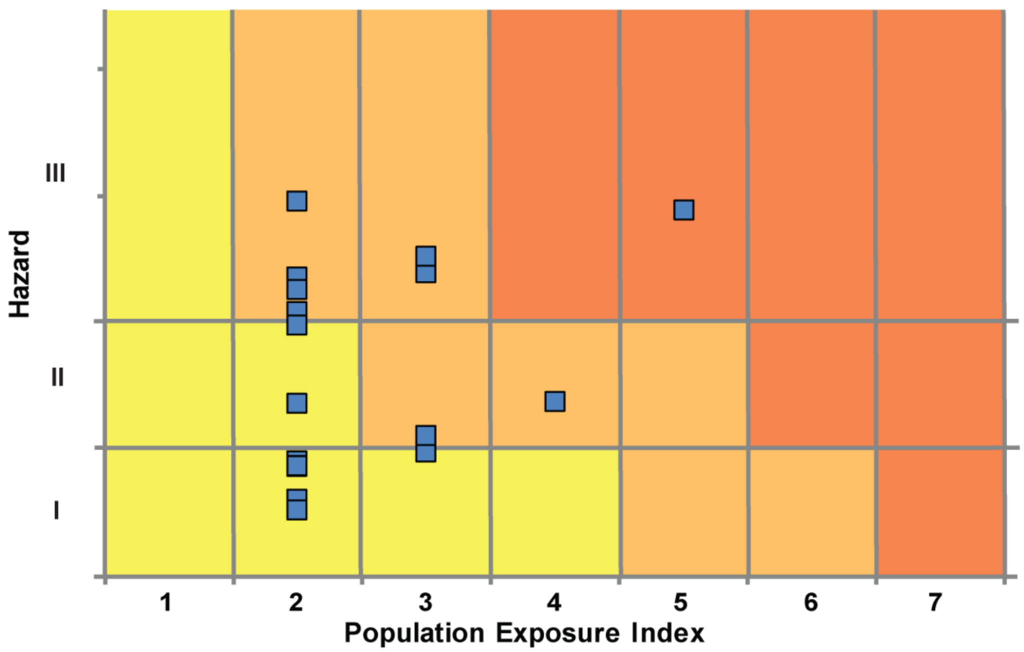


Figure 145: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

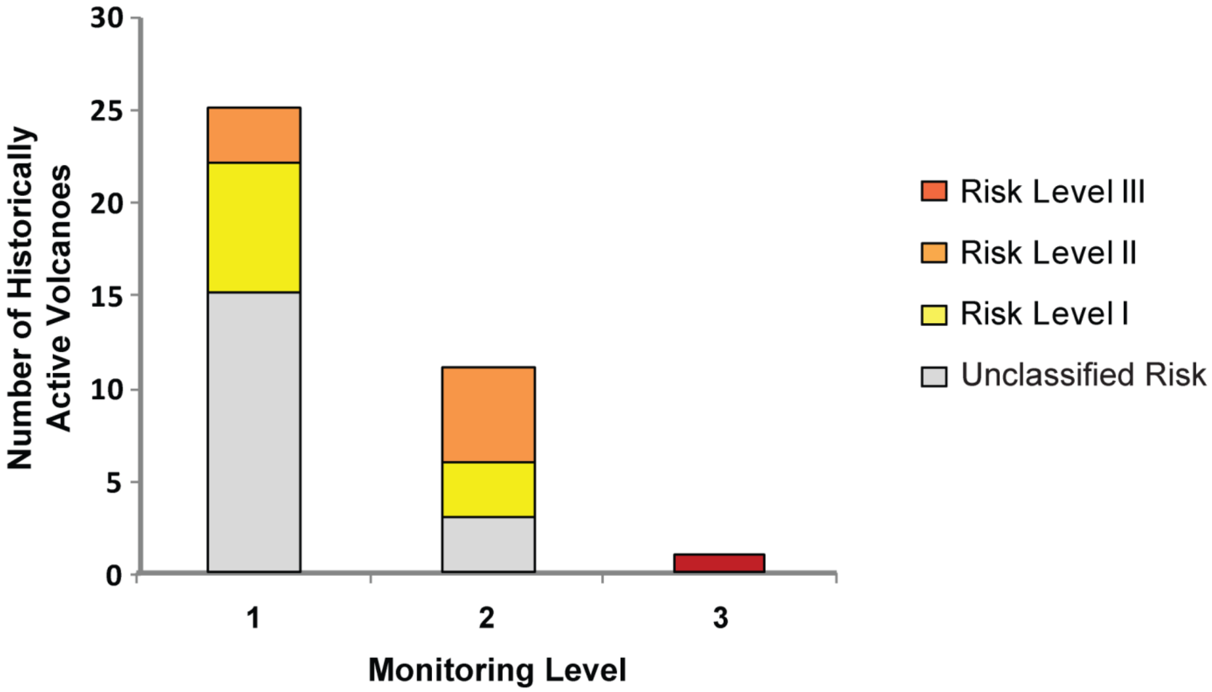


Figure 146: The monitoring and risk levels of the historically active Australian volcanoes of the Heard and McDonald Islands. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Australia

Note that we include here the two Australian volcanoes located in the Indian Ocean, which are included in the Region 3 "Middle East and Indian Ocean" description, as defined in this region by the Global Volcanism Program.

Description

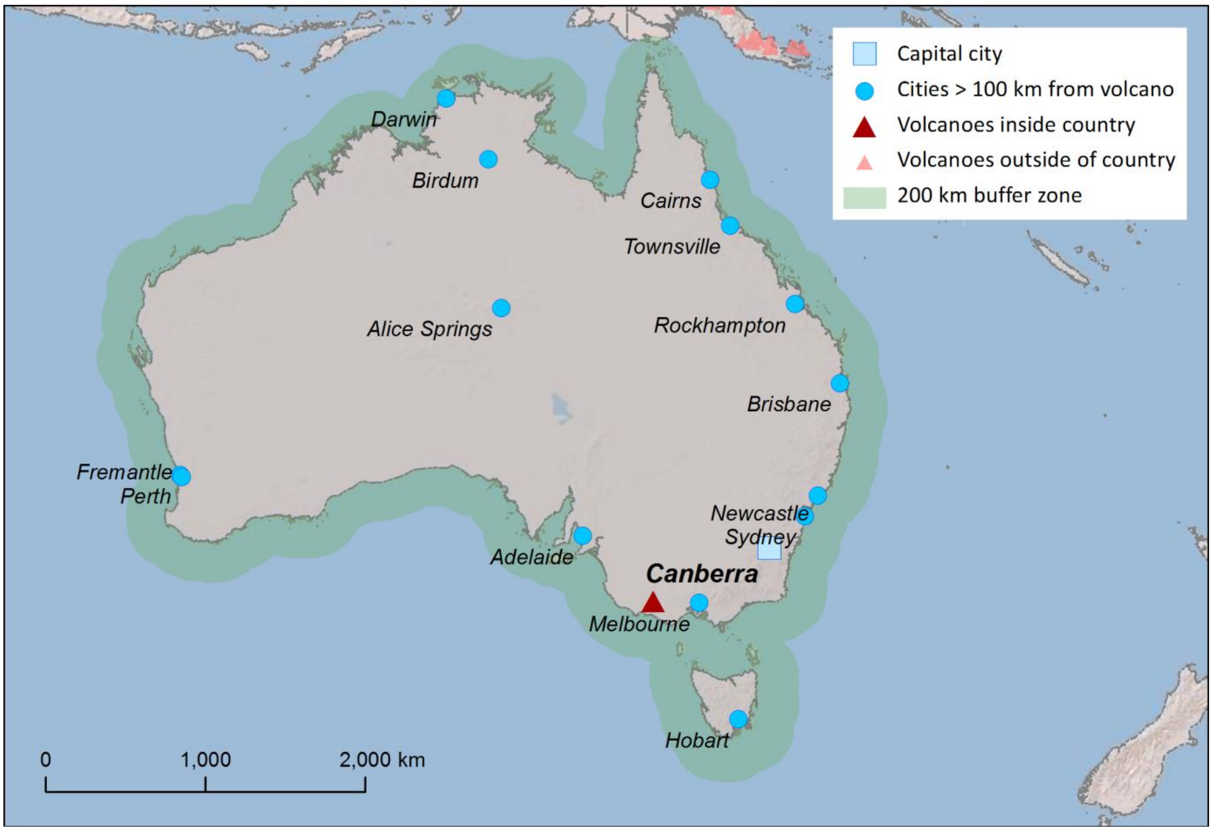


Figure 147: Location of Australia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Australia.

Australia has three Holocene volcanoes: Mount Gambier in the Newer Volcanic Province of south-eastern Australia, and the Heard and McDonald Islands volcanoes in the southern Indian Ocean. These volcanoes are related to hot spot volcanism.

All three of Australia's Holocene volcanoes have Holocene records of lava flows, and two of these volcanoes – those in the Indian Ocean – have records of historical activity, with eruptions as recent as 2012. These volcanoes are basaltic to Phonolitic in composition, with a Holocene record of eruptions of VEI 0 to 2, indicating predominantly effusive to mildly explosive activity.

Less than 1% of the total Australian population lives within 100 km of the Holocene volcanoes, although this represents over 600,000 people living within 10 km of the Newer Volcanics Province. This suggests that even small eruptions could cause extensive damage to property and infrastructure here

There is no dedicated regular ground-based monitoring of Australia's volcanoes. Geoscience Australia (GA) is the national agency for geoscientific information and would be responsible for monitoring efforts. GA have experience monitoring, through a twinning programme with the Rabaul Volcanological Observatory in Papua New Guinea. There are seismometers available for deployment should volcanic unrest be detected which can telemeter data back to GA in real-time and access to satellite data can be arranged. Were an emergency event to occur in the Newer Volcanics Province, GA would provide information and advice to the Crisis Coordination Centre of Emergency Management Australia.

Volcano Facts

Number of Holocene volcanoes	3
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1 (Explosive activity at Mount Gambier about 5,000 years ago)
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	3
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	7 eruptions are recorded as VEI 2 from Heard volcano from 1881 to 2000 AD.
Number of Holocene eruptions	19 confirmed eruptions. 3 uncertain eruptions.
Recorded Holocene VEI range	0 – 2 and unknown.
Number of historically active volcanoes	2
Number of historical eruptions	15

Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Basaltic (1), Phonolitic (1)
1	Shield(s)	Basaltic (1)

Table 138: The number of volcanoes in Australia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	23,052,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	34,548
Gross National Income (GNI) per capita (2005 PPP $)	34,340
Human Development Index (HDI) (2012)	0.938 (Very High)

Population Exposure

Capital city	Canberra
Distance from capital city to nearest Holocene volcano	652.2 km
Total population (2011)	21,766,711
Number (percentage) of people living within 10 km of a Holocene volcano	157 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	4,416 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	119,951 (<1%)

Ten largest cities, as measured by population, and populations:

Sydney	4,394,576
Melbourne	3,730,206
Perth	1,446,704
Adelaide	1,074,159
Brisbane	958,504
Newcastle	497,955
Canberra	327,700
Cairns	154,225
Townsville	138,954
Darwin	93,080

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	2,577
Total length of railroads within 100 km of a volcano (km)	267

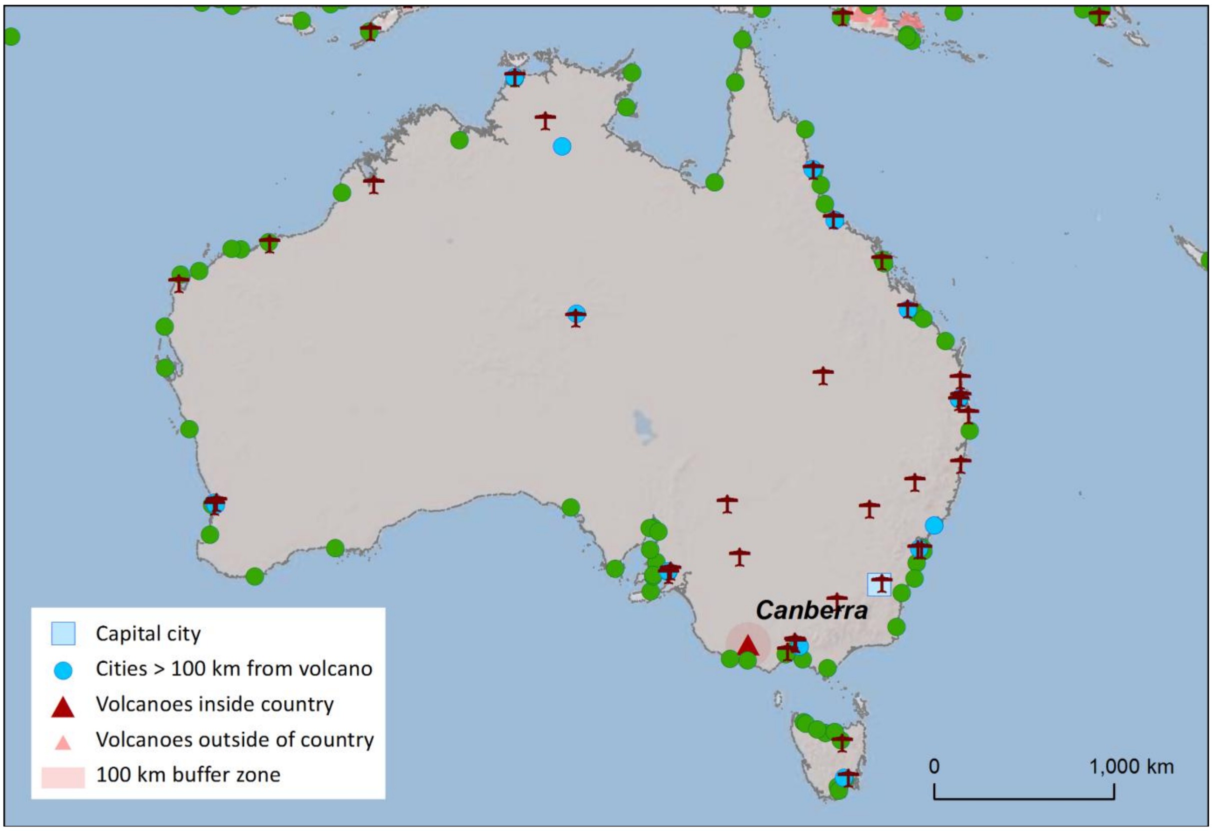


Figure 148: The location of Australia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The Newer Volcanics Province is situated in Victoria in the south of Australia, about 200 km from the city of Melbourne. Being located near the coast, one port lies within 100 km of this province. Many small communities lie in this radius, exposing their infrastructure, including an extensive road and rail network. The capital, Canberra, is located more than 600 km from this volcanic province.

Hazard, Uncertainty and Exposure Assessments

Although there is a Holocene record of eruptions for all three Australian volcanoes, the size of the eruptions at Newer Volcanics Province is unknown and the hazard cannot therefore be assessed at this volcano without large associated uncertainties. Newer Volcanics Province is therefore unclassified. . A large population is present close to the Newer Volcanics Province, comprising over 600,000 people within 10 km as this field covers a broad area of SE Australia. This makes Newer Volcanics Province a PEI 7 volcano, which in turn categorises it as Risk Level III regardless of the hazard. Heard and McDonald Islands are assigned a Hazard Level of I, based on their eruptive history of events no larger than VEI 2. These volcanoes have no permanent population living within 100 km, and are therefore a PEI of 1 making these Risk Level I volcanoes.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I	Heard; McDonald Islands						
UNCLASSIFIED	**U – HHR**							
	U- HR							Newer Volcanics Province
	U- NHHR							
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 139: Identity of Australia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Heard	1	I
McDonald Islands	1	I

Table 140: Classified volcanoes of Australia ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 2 volcanoes; Risk Level II –0 volcanoes; Risk Level III – 0 volcanoes.

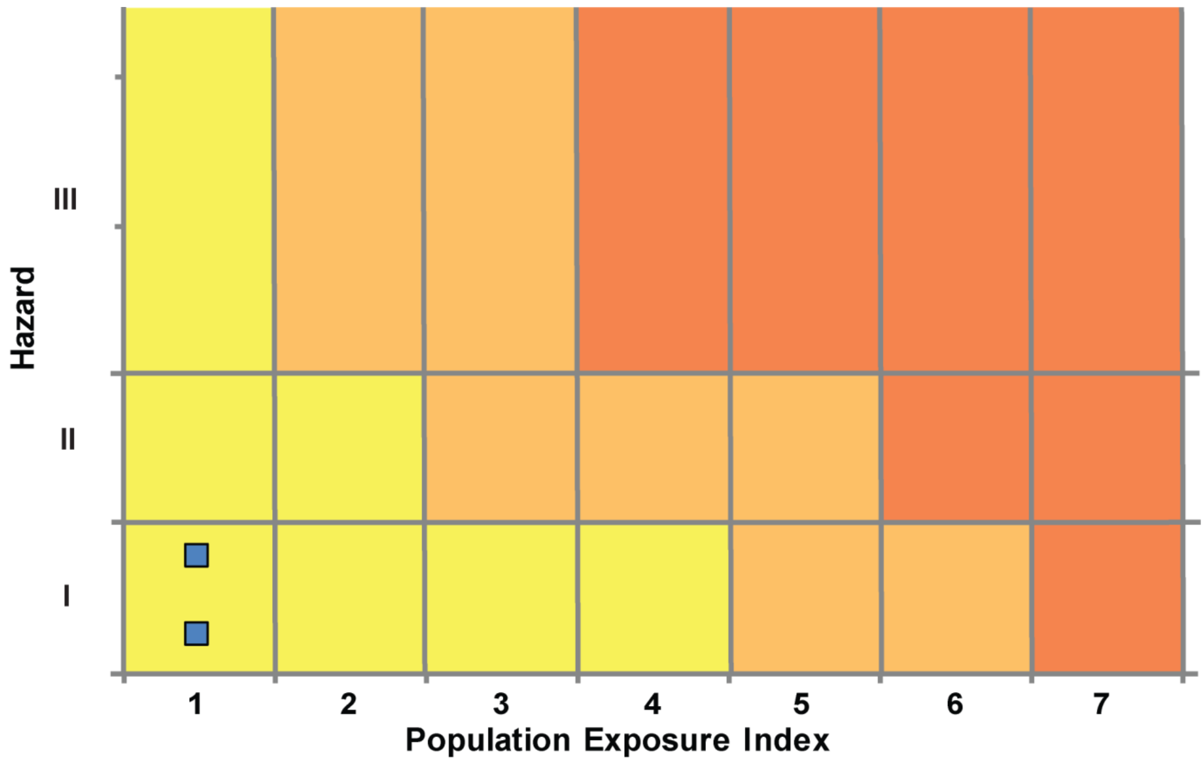


Figure 149: Distribution of Australia's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

No volcanoes in mainland Australia have recorded historical eruptions. No regular ground-based monitoring is undertaken at the historically active Heard and McDonald Islands volcanoes in the Indian Ocean.

Papua New Guinea

Description

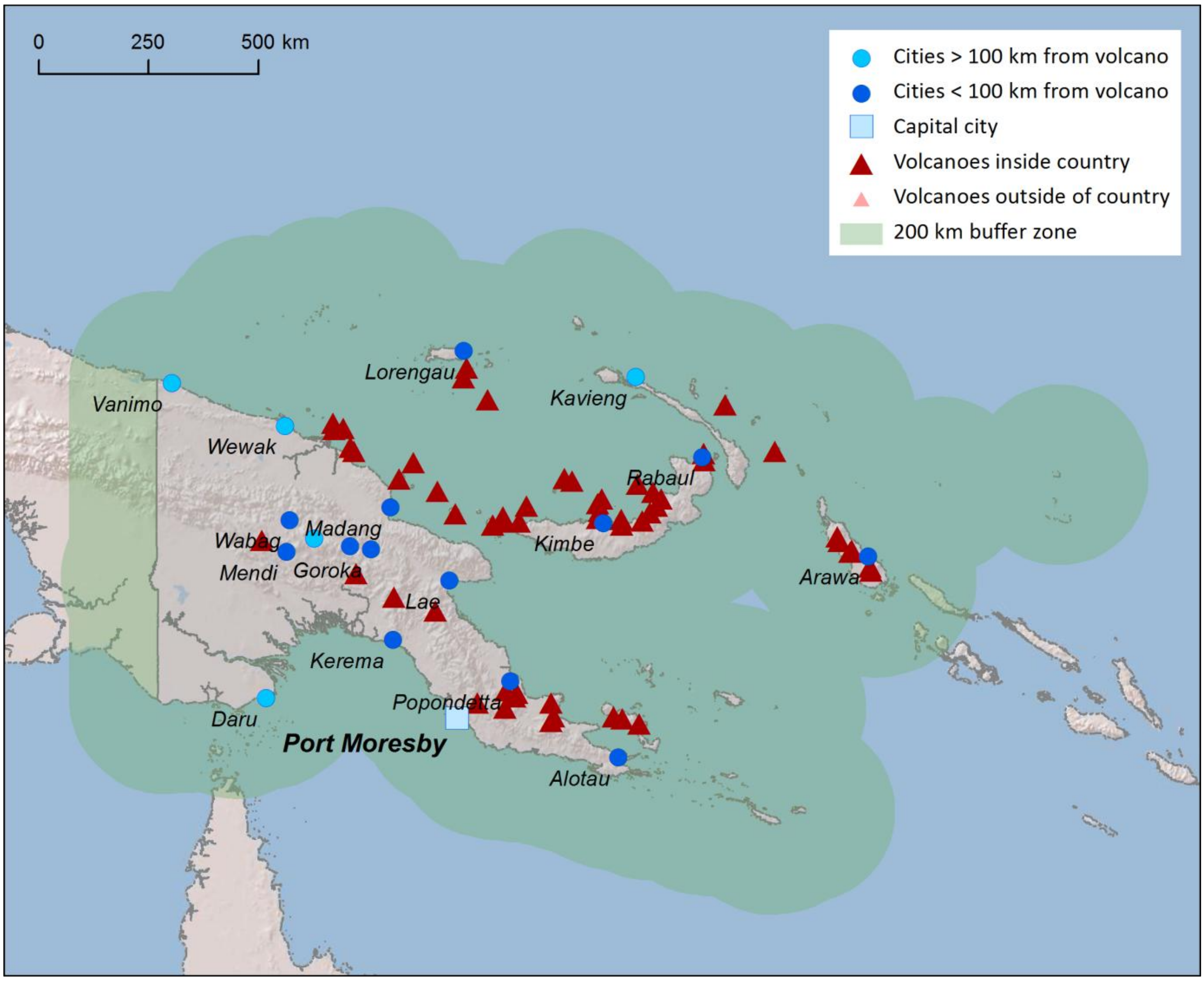


Figure 150: Location of Papua New Guinea's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Papua New Guinea.

Papua New Guinea has 56 Holocene volcanoes distributed throughout the country: from the Doma Peaks near the Indonesian border in the west to Loloru on Bougainville Island in the east, and from St. Andrew Strait in the Admiralty Islands in the north to Dawson Strait Group in the D'Entrecasteaux Islands in the south. Papua New Guinea is located within one of the world's most complex tectonic settings, with seven different plates interacting within the region. The main volcanoes of Papua New Guinea are related to the subduction of the Solomon Sea in the south, and of the Pacific Plate beneath the North Bismarck Plate in the north.

The volcanoes of Papua New Guinea are dominantly stratovolcanoes and large cones and are largely andesitic, with common explosive activity. Large explosive eruptions are recorded into the Pleistocene, with four volcanoes having records of eruptions of VEI/M ≥4. During the Holocene a range of activity has been recorded, from VEI 0 to 6, with 28 explosive eruptions of VEI ≥4. 17 volcanoes have Holocene records of generating pyroclastic flows and 8 have triggered lahars.

The most active volcano in Papua New Guinea is Bagana, located in the central part of Bougainville Island, with frequent ongoing lava effusion from its summit crater. However, due to the quiet nature of effusive activity and relatively low threat level, it normally goes unnoticed compared to the next two most active volcanoes of Manam and Ulawun. These two volcanoes have had frequent mild to moderate sized historical eruptions and occasional large eruptions with pyroclastic flows.

Much of Papua New Guinea is situated within 100 km of one or more Holocene volcanoes, including many of the largest cities in the country, thus over 80% of the population live within this distance. Port Moresby lies within 55 km of the poorly known Madilogo volcano. Popondetta, home to 28,000, is located 25 km north northeast of Lamington, and Kokopo, which has a population of roughly 21,000, is situated about 15 km southeast from the two most active volcanic cones in Rabaul Caldera; Tavurur and Vulcan.

Of the volcanoes in Papua New Guinea only one, Rabaul, is classed at Risk Level III, with a large proximal population and a high calculated Hazard score. Most volcanoes are classed at Risk Level I, with a relatively low PEI.

The most renowned eruption of a Papua New Guinean volcano is probably that of Lamington in 1951. The peak was not recognised as a volcano before it erupted in January 1951, with a VEI 4 eruption that generated pyroclastic flows and surges that covered all sides of the volcano. The eruption caused 2,492 fatalities and extensive damage. Rabaul is also notable for recent destructive activity. A VEI 4 eruption in 1937 which triggered pyroclastic flows, lahars, and tsunami caused 507 deaths, whilst powerful explosive eruptions in 1994 caused the temporary evacuation of Rabaul City. Five deaths from indirect causes were reported in 1994.

Whilst Lamington and Rabaul are well known for fairly recent, high impact eruptions, in terms of loss of life the largest volcanic disaster in Papua New Guinea was the 1888 eruption of Ritter Island. Located off the western tip of New Britain, this eruption caused massive slope failure that triggered tsunamis that devastated the coastline of mainland Papua New Guinea and claimed approximately 3,000 lives. Along with these three volcanoes, Manam is notable for its persistent activity with forty-three eruptions recorded since 1616. Though activity at Manam is typically mild to moderate, some larger eruptions have impacted populated areas through generation of pyroclastic flows and lavas that have reached low-lying coastal villages. The 2005 VEI 4 eruption at Manam devastated about 70% of the island. 90% of the population was evacuated to the mainland weeks prior to the eruption. Only one death was reported.

The Rabaul Volcanological Observatory is the national institution for monitoring volcanoes in Papua New Guinea. It was established in 1950 to carry out this task and conduct scientific research. It is part of the Department of Mineral Policy and Geohazards Management. The institute is funded by the government of Papua New Guinea and external donors. The institution has 16 staff members, and about 75% have experience of responding to an eruption. Eight volcanoes are regularly monitored and six have dedicated ground-based monitoring networks in place. Mobile equipment and funding resources are available for responding to unrest that may arise at any unmonitored volcano, however these resources are limited.

The Rabaul Volcanological Observatory has been working with certain donor-funded programs with international agencies to conduct risk assessments. It is also involved in risk management and mitigation. As part of its mandate, the observatory provides advice to provincial and national governments on volcano-related issues. A donor-funded program is currently in place to educate vulnerable communities living around volcanoes about volcanic hazards and the disasters they pose and how to mitigate them. The main aim of the program is to empower communities to be self-reliant and respond spontaneously during volcanic disasters while they await properly organised relief services from government sources and non-government organisations.

Volcano Facts

Number of Holocene volcanoes	56
Number of Pleistocene volcanoes with M≥4 eruptions	4
Number of volcanoes generating pyroclastic flows	17
Number of volcanoes generating lahars	8
Number of volcanoes generating lava flows	12
Number of fatalities caused by volcanic eruptions	?8,899
Tectonic setting	Subduction zone (55 volcanoes), Rift zone (1 suspected volcano – unnamed - in the Bismarck Sea)
Largest recorded Pleistocene eruption	The M6.7 caldera formation at Lolobau in 12 ka.
Largest recorded Holocene eruption	M7.4 Dk eruption of Dakataua in 998 BP.
Number of Holocene eruptions	246 confirmed eruptions. 38 uncertain eruptions and 11 discredited eruptions.
Recorded Holocene VEI range	0 – 6 and unknown.
Number of historically active volcanoes	20
Number of historical eruptions	207

Number of volcanoes	Primary volcano type	Dominant rock type
7	Caldera(s)	Andesitic (3), Basaltic (1), Dacitic (2), Rhyolitic (1)
1	Hydrothermal field	Andesitic (1)
32	Large cone(s)	Andesitic (18), Basaltic (11), Dacitic (1), Phonolitic (1), Rhyolitic (1)
1	Lava dome(s)	Andesitic (1)
10	Small cone(s)	Andesitic (5), Basaltic (2), Dacitic (1), Rhyolitic (2)
5	Submarine	Unknown (5)

Table 141: The number of volcanoes in Papua New Guinea, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	7,187,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	2,363
Gross National Income (GNI) per capita (2005 PPP $)	2,386
Human Development Index (HDI) (2012)	0.466 (Low)

Population Exposure

Capital city	Port Moresby
Distance from capital city to nearest Holocene volcano	52.9 km
Total population (2011)	6,187,591
Number (percentage) of people living within 10 km of a Holocene volcano	226,536 (3.7%)
Number (percentage) of people living within 30 km of a Holocene volcano	1,029,276 (16.6%)
Number (percentage) of people living within 100 km of a Holocene volcano	5,232,230 (84.6%)

Ten largest cities, as measured by population, and populations:

Port Moresby	254,158 (2002 Census)
Lae	76,255
Arawa	40,266
Mount Hagen	33,623
Popondetta	28,198
Madang	27,419
Mendi	26,252
Kokopo	20,262 (PNG Census 2000)
Kimbe	18,847
Goroka	18,503
Wewak	18,230

Infrastructure Exposure

Number of airports within 100 km of a volcano	14
Number of ports within 100 km of a volcano	13
Total length of roads within 100 km of a volcano (km)	643

Total length of railroads within 100 km of a volcano (km) 0

The numerous volcanoes of Papua New Guinea are distributed throughout much of the country, meaning that a large proportion of the country lies within 100 km of a volcano. Twelve of the largest cities in the country lie within these radii, including the capital, Port Moresby, thus much of the critical infrastructure in Papua New Guinea is exposed to volcanic hazards. Being a nation with many islands, multiple ports and airports are exposed.

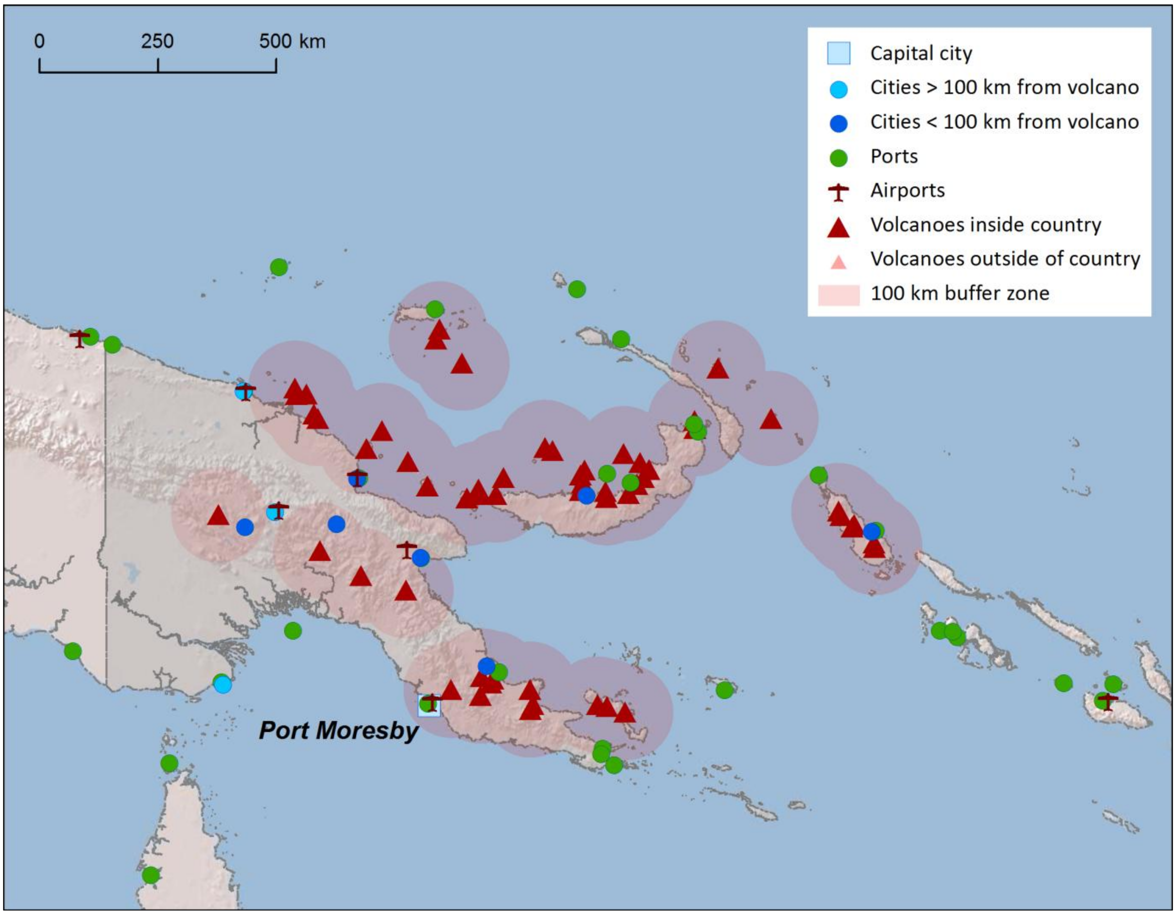


Figure 151: The location of Papua New Guinea's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of data available in the eruption records of Papua New Guinea's volcanoes. Under 20% of the volcanoes here have an appropriate eruptive history for calculation of the hazard. These 10 volcanoes are classified at Hazard Levels I, II and III, with six at Hazard Level III. This could indicate a trend towards particularly hazardous volcanoes in Papua New Guinea, or improved studies and therefore records at volcanoes thought to be hazardous; or a combination of these factors.

Of the unclassified volcanoes 31 have no confirmed eruptions recorded in the Holocene. Five have Holocene records but no historical activity and ten have historical (post 1500 AD) activity. Seven unclassified volcanoes have erupted since 1900 AD. Eight unclassified volcanoes have records of unrest above background levels since 1900 AD.

The PEI in Papua New Guinea ranges from 2 to 5, low to high. Most classified volcanoes have a low PEI of 2, which in combination with Hazard Levels of I – III, classifies these volcanoes as Risk Levels I and II. Only one volcano, Rabaul, is categorised as Risk Level III in Papua New Guinea, with a high PEI of 5 and a Hazard Level of III.

CLASSIFIED	**Hazard III**		Long Island; Ulawun; Bagana	Manam; Karkar		Rabaul		
	Hazard II				Pago			
	Hazard I		Bam; Ritter Island	Langila				
UNCLASSIFIED	**U – HHR**		**St. Andrew Strait; Unnamed (250030);** Dakataua; **Bamus**; **Victory**; **Waiowa**; Billy Mitchell	**Garbuna Group;** **Lolobau**; **Lamington**				
	U- HR		**Loloru**	Hargy; **Dawson Strait Group**; Ambitile		Tavui		
	U- NHHR		Baluan; Blup Blup; **Kadovar**; Boisa; Unnamed; Yomba; **Umboi**; Sakar; **Unnamed (252001);** Mundua; Bola; **Sulu Range;** Unnamed; Madilogo; Hydrographers Range; Musa River; Iamalele; Lihir; Tore; **Balbi**	Garove; Doma Peaks; Crater Mountain; **Yelia**; Managlase Plateau; Sessagara; Goodenough; Takuan Group	Garua Harbour; Lolo; Koranga			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 142: Identity of Papua New Guinea's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Rabaul	5	III
Pago	4	II
Manam	3	II
Karkar	3	II
Langila	3	I
Long Island	2	II
Ulawun	2	II
Bagana	2	II
Bam	2	I
Ritter Island	2	I

Table 143: Classified volcanoes of Papua New Guinea ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 3 volcanoes; Risk Level II – 6 volcanoes; Risk Level III – 1 volcano.

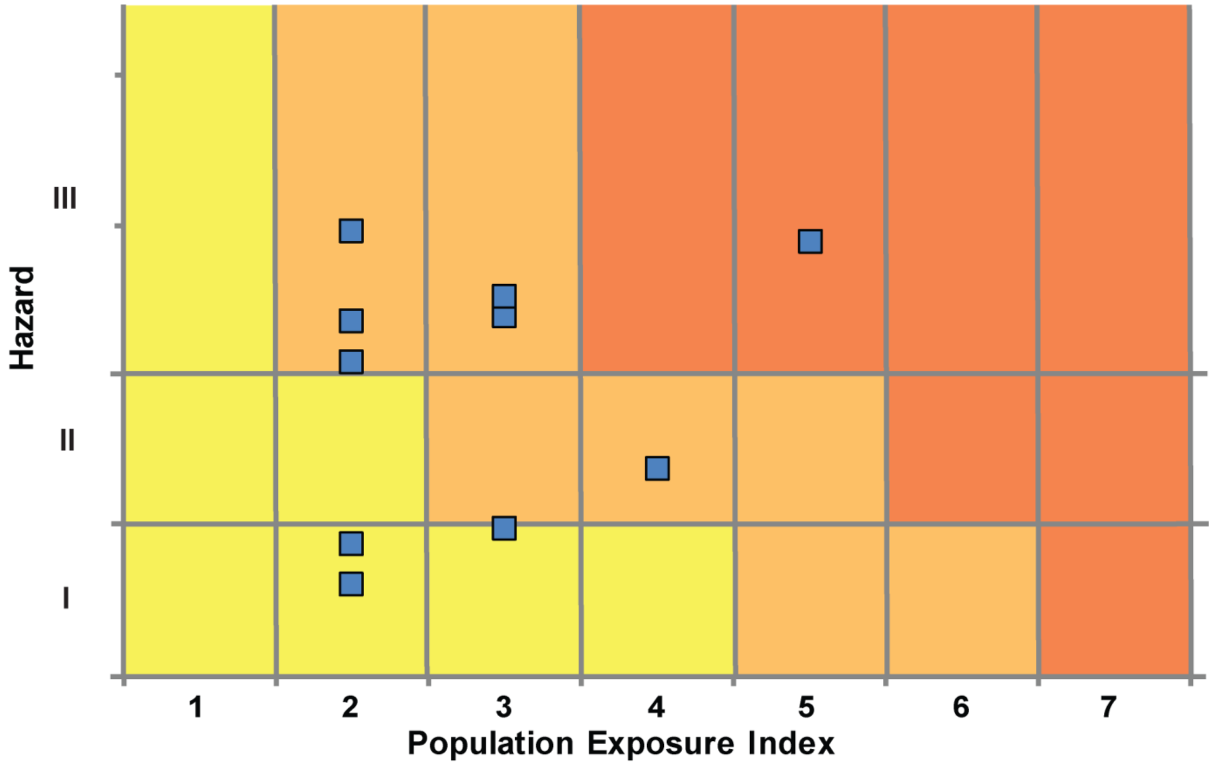


Figure 152: Distribution of Papua New Guinea's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The Rabaul Volcanological Observatory is responsible for the monitoring of the volcanoes in Papua New Guinea, twenty of which have historical records of activity. Eight volcanoes are regularly monitored and six have dedicated ground-based monitoring systems in place, including five volcanoes with one seismometer and Rabaul volcano with seismic and deformation networks and gas monitoring. Rabaul, as the only Risk Level III volcano in Papua New Guinea, has the greatest level of monitoring. Three Risk Level II volcanoes are not currently monitored through ground-based equipment. The Risk Level II Bagana and Risk Level I Langila have dedicated volcano observers who report in daily and the Rabaul Volcanological Observatory has some resources in place to respond to developing situations.

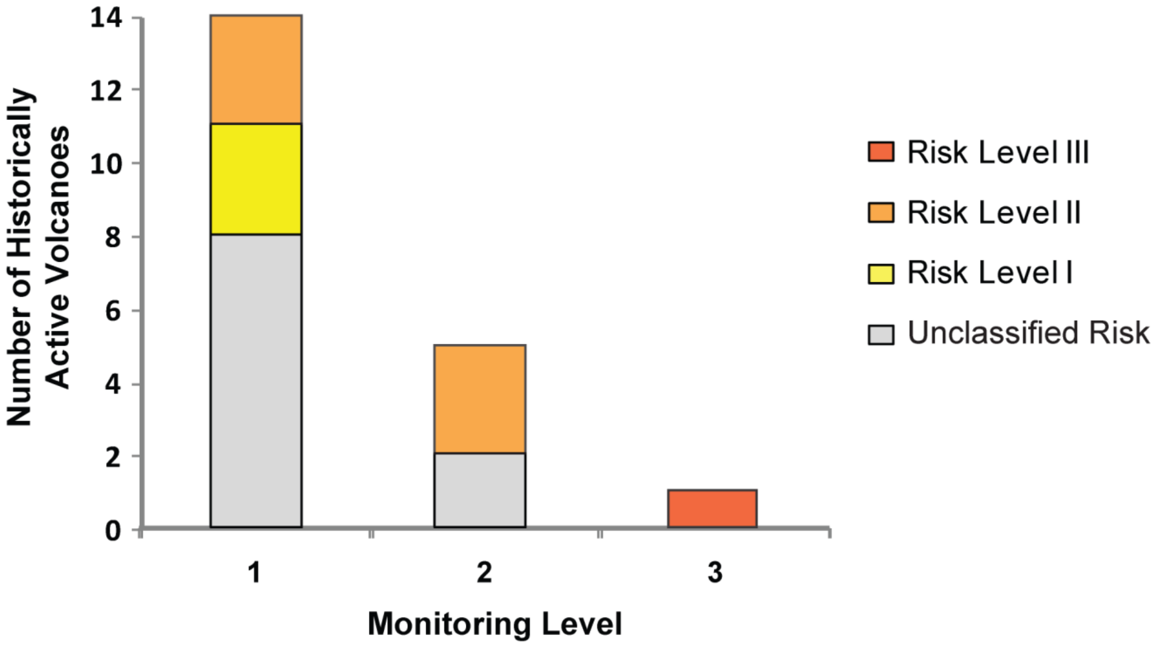


Figure 153: The monitoring and risk levels of the historically active volcanoes in Papua New Guinea. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Solomon Islands

Description

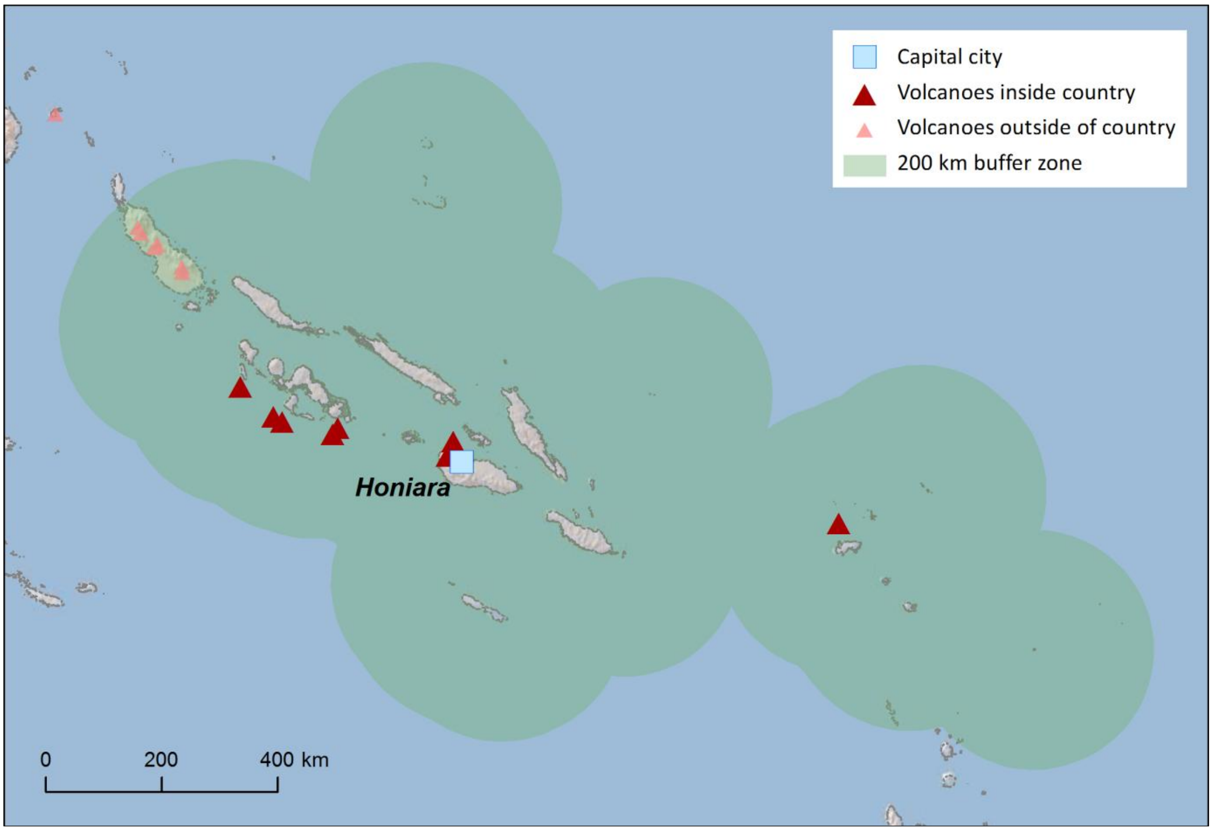


Figure 154: Location of Solomon Islands' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Solomon Islands.

Eight Holocene volcanoes are located in the Solomon Islands. These are associated with the subduction of the Solomon Sea Plate beneath the Pacific Plate and a spreading centre at the southeast margin of the Solomon Sea Plate responsible for volcanism at Kavachi. All but Tinakula volcano lie in a north-west to south-east trending line, forming islands to the west of the archipelago. Tinakula is located 600 km to the east of this chain.

The Solomon Islands' volcanoes are made up of four submarine volcanoes, three subaerial stratovolcanoes, and one volcanic field. Two, Savo and Tinakula, have generated pyroclastic flows, and only eruptions of Savo have triggered lahars.

Four volcanoes have 56 historical eruptions of VEI 0 to 3. Six VEI 3 eruptions are recorded at Savo and Tinakula between 1568 and 1965. Tinakula is the most frequently active volcano in the Solomon Islands.

A considerable proportion of the island chain lies within 100 km of one or more Holocene volcanoes and about 50% of the population of the Solomon Islands live within this distance. Most volcanoes have only a small proximal population.

Two eruptions from Savo have had major impacts, namely those in 1568 and 1840; the 1568 eruption generated pyroclastic flows that killed the island's approximately 1,000 inhabitants, whilst ash and ballistics killed many during the 1840 eruption.

Other noteworthy volcanoes in the Solomon Islands are Tinakula and Kavachi. Tinakula is the only other Solomon Islands volcano known to have caused fatalities, when a VEI 3 eruption in 1840 produced pyroclastic flows that swept all sides of the island and killed its inhabitants. Kavachi is one of the most active submarine volcanoes in the entire southwest Pacific, with thirty eruptions recorded since 1939. Kavachi has produced twelve island-forming eruptions in this time, though the volcano's isolated position away from major shipping lanes and airport routes reduces the hazard it poses to people and infrastructure.

Volcano Facts

Number of Holocene volcanoes	8
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	2
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	2
Number of fatalities caused by volcanic eruptions	?1,200
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	6 eruptions of VEI 3 are recorded at Savo and Tinakula between the years of 1568 and 1965 AD.
Number of Holocene eruptions	57 confirmed eruptions. 5 uncertain eruptions.
Recorded Holocene VEI range	0 – 3 and unknown.
Number of historically active volcanoes	4
Number of historical eruptions	56

Number of volcanoes	Primary volcano type	Dominant rock type
3	Large cone(s)	Andesitic (3)
1	Small cone(s)	Andesitic (1)
4	Submarine	Andesitic (2), Dacitic (1), Unknown (1)

Table 144: The number of volcanoes in the Solomon Islands, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	551,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	2,581
Gross National Income (GNI) per capita (2005 PPP $)	2,172
Human Development Index (HDI) (2012)	0.530 (Low)

Population Exposure

Capital city	Honiara
Distance from capital city to nearest Holocene volcano	21.7 km
Total population (2011)	571,890
Number (percentage) of people living within 10 km of a Holocene volcano	4,545 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	98,612 (17.2%)
Number (percentage) of people living within 100 km of a Holocene volcano	286,531 (50.1%)

Largest cities, as measured by population, and populations:

Honiara	56,298

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	6
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes of the Solomon Islands are mainly located to the west of the largest islands. A considerable proportion of the island chain lies within 100 km of a Holocene volcano. Many ports are located in these radii, and an airport in the capital, Honiara, which lies at less than 25 km from Gallego volcano, and less than 40 km from the historically active Savo volcano. This places much of the country's critical infrastructure within 100 km of Holocene volcanoes. The northern tip of northernmost Choiseul Island lies within 100 km of volcanoes on Bougainville Island, an autonomous region of Papua New Guinea.

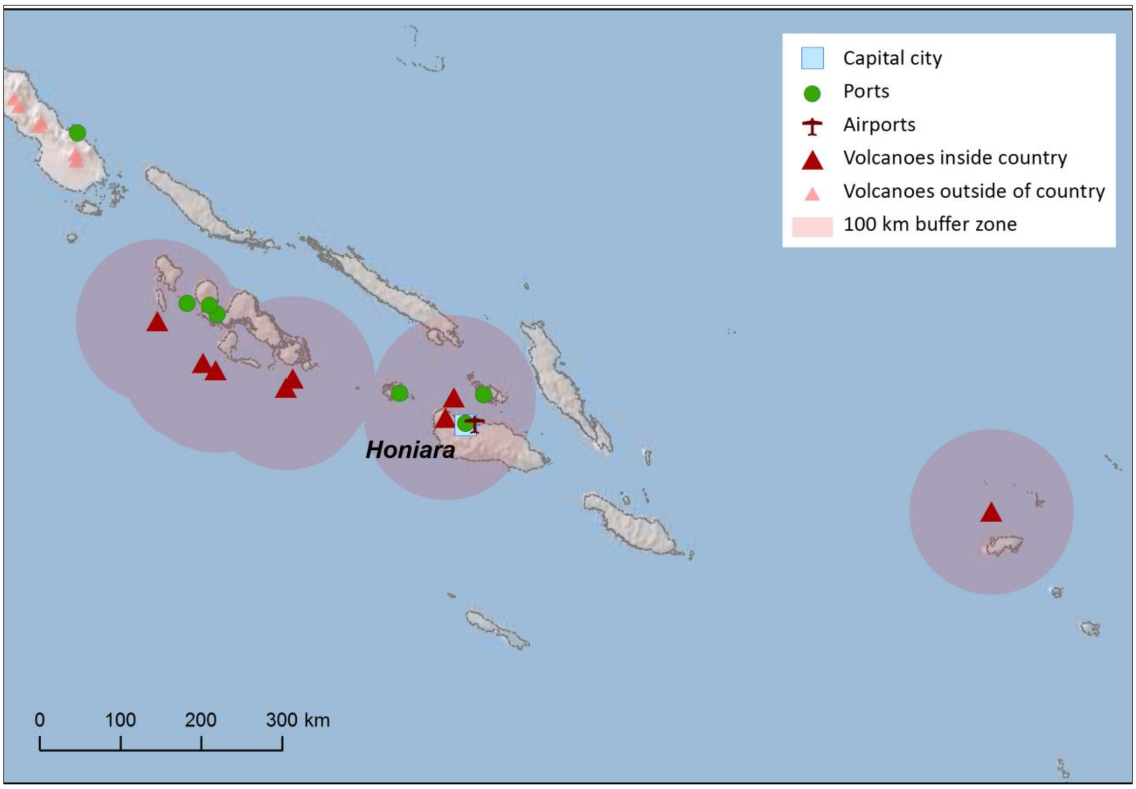


Figure 155: The location of the Solomon Islands' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Six of the eight volcanoes of the Solomon Islands lack sufficiently extensive eruptive histories for calculation of the hazard without large associated uncertainties. These volcanoes are therefore unclassified. Of these, just two have records of eruptions; Simbo and Savo both have historical eruptions.

Kavachi and Tinakula volcanoes have 53 confirmed Holocene eruptions, most commonly of VEI 1-2. These volcanoes are classified at Hazard Level I.

Most Solomon Island volcanoes are PEI 2, and indeed both classified volcanoes are categorised as such, classifying these as Risk Level I. The highest PEI in the Solomon Islands is PEI 4 at Gallego volcano which lies within 100 km of the capital, Honiara.

		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7
CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I		Kavachi; Tinakula					
UNCLASSIFIED	U – HHR		**Simbo**	Savo				
	U- HR							
	U- NHHR		Kana Keoki; Coleman Seamount; **Unnamed (255061)**		Gallego			

Table 145: Identity of the volcanoes in the Solomon Islands in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Kavachi	2	I
Tinakula	2	I

Table 146: Classified volcanoes of the Solomon Islands ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 2 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

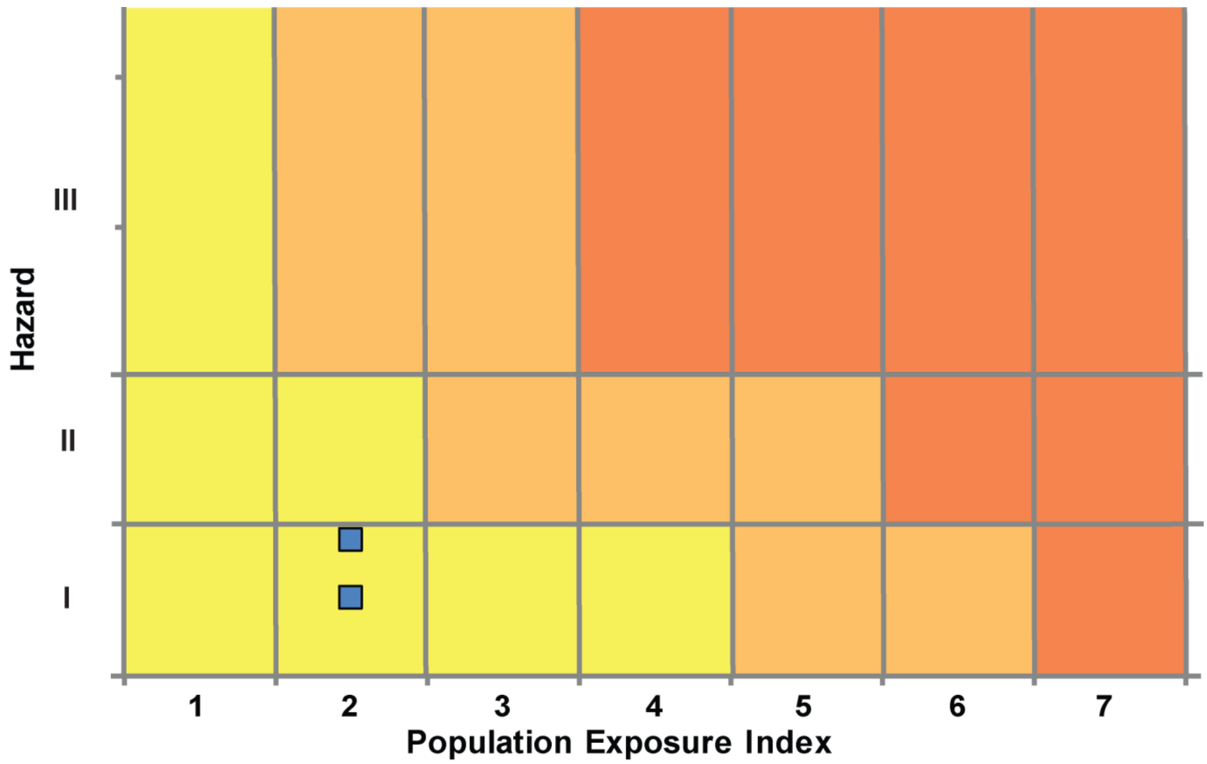


Figure 156: Distribution of the Solomon Islands' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Four volcanoes have records of historical eruptions: Kavachi, Tinakula, Simbo and Savo. Of these, the latter two are unclassified for hazard and risk. The World Organisation of Volcano Observatories (WOVO) indicates that of the volcanoes in the Solomon Islands, only one volcano, Savo, has a dedicated monitoring system in place, comprising an irregularly monitored 3-component seismometer. No other information was available at the time of the writing of this report to suggest further monitoring takes place in the Solomon Islands.

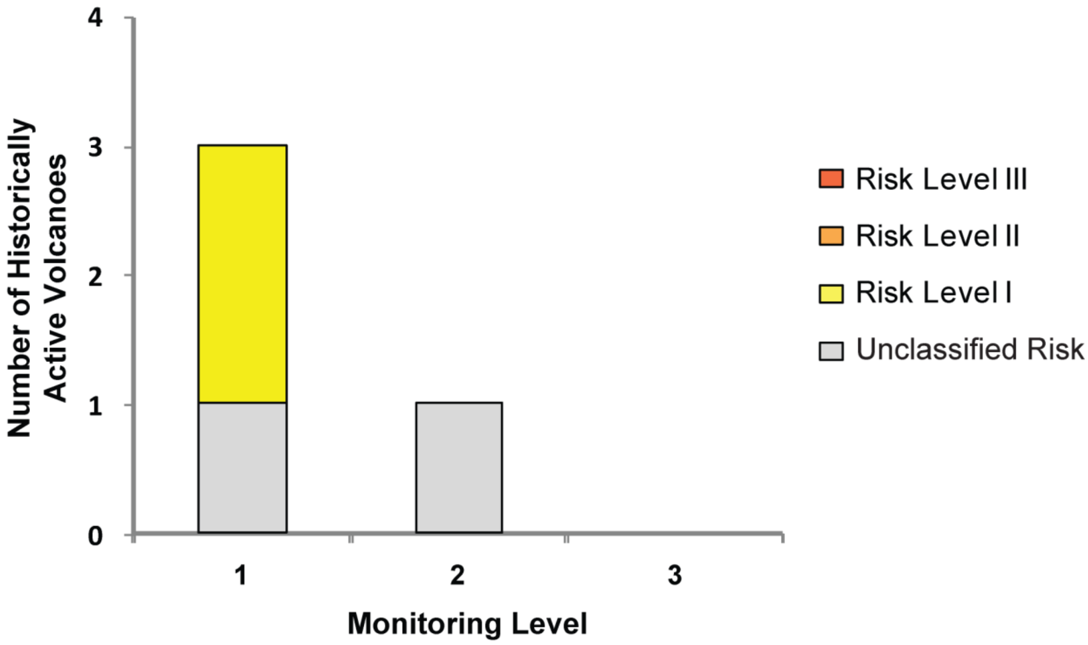


Figure 157: The monitoring and risk levels of the historically active volcanoes in the Solomon Islands. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Vanuatu

Description

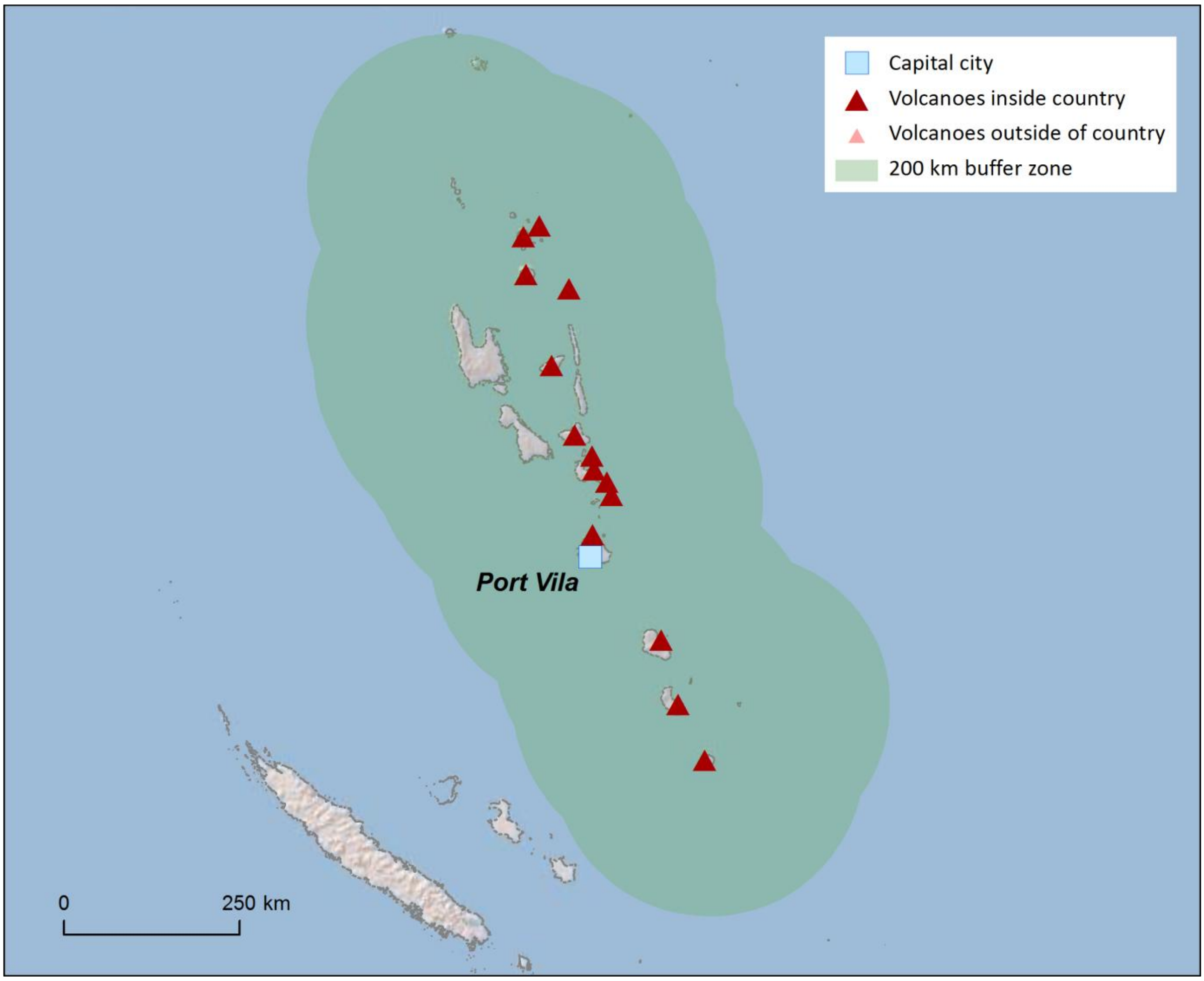


Figure 158: Location of Vanuatu's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Vanuatu.

Fourteen Holocene volcanoes are located throughout Vanuatu. These lie in a north-south trending line between Tinakula volcano of the Solomon Islands in the north, and the French Eastern Gemini Seamount in the south. These volcanoes result from the subduction of the Australian Plate beneath the Pacific Plate.

The volcanoes of Vanuatu are predominantly basaltic in composition, though most are stratovolcanoes or another edifice type usually associated with explosive activity. Pyroclastic flows are recorded at five volcanoes, including the only shield volcano in Vanuatu, Aoba. Lahars have been generated at three volcanoes. Eruptions of VEI 0 – 6 are recorded during the Holocene, indicating a range of activity styles. Nine volcanoes have had historical activity, producing 128 eruptions since 1500 AD. The record prior to this is sparse, however there is a record of large explosive eruptions at two volcanoes during the Pleistocene, including the M6.9 eruption of the Efaté Pumice formation at North Vate, at 1 Ma.

The most frequently active volcano in Vanuatu is the basaltic caldera, Ambrym, which has had 53 historical eruptions.

An eruption of Aoba in 1870 triggered a lahar that destroyed villages on the southeast flank and killed over 100 people, whilst a flank eruption in 1670 destroyed populated areas near the western coast. Numerous lahar deposits can be seen on the coasts. The Vanuatu Geohazards Observatory suggests that Aoba can be considered the most dangerous volcano in Vanuatu, due to the presence of a large lake in the main crater.

With the exception of the almost persistently active Yasur volcano, Gaua is the most recently active of Vanuatu's volcanoes. An eruption commencing on 27th September 2009 led to explosions and high dense ash plumes on 18th November 2009, with the evacuation of over 300 people following on 26th November 2009. Activity carried on into 2010, and increased in April 2010; plans were made to evacuate a further 3,000 people. Seismic tremors, as well as ash and gas emissions, continued throughout the first 8 months of 2010. The Vanuatu Geohazards Observatory reported on 21st December 2010 that activity from Gaua had been low since September and activity ceased in October 2010.

The eruptive history is sufficiently detailed to determine the hazard with minimal uncertainties at about half of Vanuatu's volcanoes. Aoba is classed with the highest Hazard Levels in Vanuatu. The volcanoes are distributed through the island chain and as such, the whole population lives within 100 km of one or more Holocene volcano and almost all infrastructure is exposed. Despite this overall total exposure, small to moderate sized populations are located close to individual volcanoes.

The Vanuatu Geohazards Observatory operates a national seismic network and an additional volcano monitoring network. Permanent seismic monitoring is undertaken at Yasur, Ambrym, Aoba and Gaua. The Vanuatu Geohazards Observatory also run a website accessible to all, where alert levels for the volcanoes are provided. Alert levels range from 0 to 4 with increasing activity, and include "Level ?" where there is insufficient monitoring data to make an assessment. This alert level system is linked with a hazards map which indicates danger areas. The Observatory also has plans in place for evacuations dependent on the activity observed.

See also:

Vanuatu Geohazards Observatory, http://www.geohazards.gov.vu/index.php/home

Volcano Facts

Number of Holocene volcanoes	14
Number of Pleistocene volcanoes with M≥4 eruptions	2
Number of volcanoes generating pyroclastic flows	5
Number of volcanoes generating lahars	3
Number of volcanoes generating lava flows	3

Number of fatalities caused by volcanic eruptions	?>346
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M6.9 eruption of the Efaté Pumice formation at North Vate, at 1 Ma.
Largest recorded Holocene eruption	Two M6.8 eruptions are recorded here, the 1760 BP eruption of Ambrym and 520 BP eruption of Kuwae.
Number of Holocene eruptions	133 confirmed eruptions. 18 uncertain eruptions.
Recorded Holocene VEI range	0 – 6 and unknown.
Number of historically active volcanoes	9
Number of historical eruptions	128

Number of volcanoes	Primary volcano type	Dominant rock type
2	Caldera(s)	Basaltic (2)
11	Large cone(s)	Andesitic (3), Basaltic (8)
1	Shield(s)	Basaltic (1)

Figure 159: The number of volcanoes in Vanuatu, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	248,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,062
Gross National Income (GNI) per capita (2005 PPP $)	3,960
Human Development Index (HDI) (2012)	0.626 (Medium)

Population Exposure

Capital city	Port Vila
Distance from capital city to nearest Holocene volcano	30.2 km
Total population (2011)	224,564
Number (percentage) of people living within 10 km of a Holocene volcano	26,446 (11.8%)

Number (percentage) of people living within 30 km of a Holocene volcano	119,868 (53.4%)
Number (percentage) of people living within 100 km of a Holocene volcano	230,848 (>100%)

Largest cities, as measured by population, and populations:

Port Vila	35,901

Infrastructure Exposure

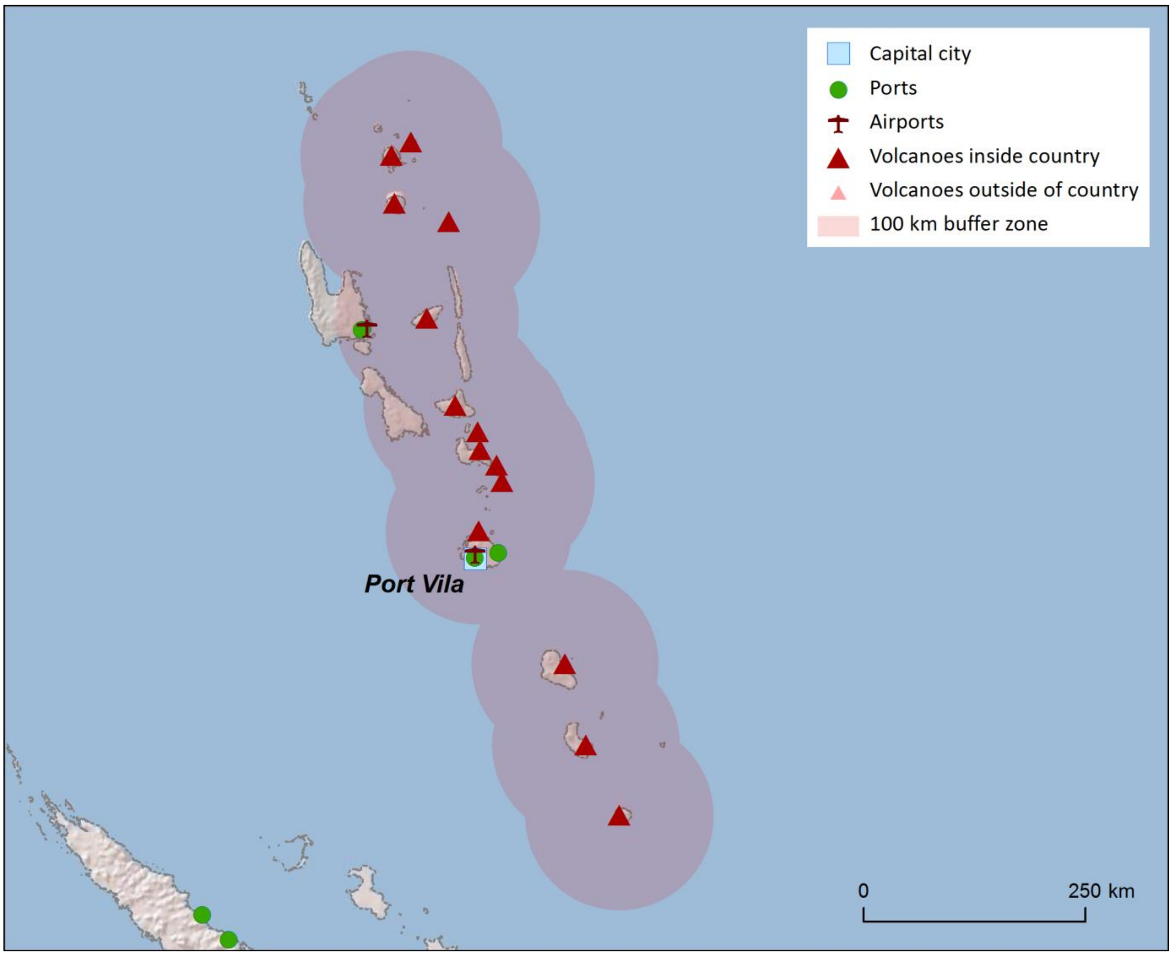


Figure 160: The location of Vanuatu's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes of Vanuatu are located throughout the island chain, with almost the entire country lying within 100 km of Holocene volcanoes. A number of ports and airports are exposed, and much of the critical infrastructure of the country is located in these 100 km radii. The capital, Port Vila, lies just over 30 km from the nearest Holocene volcano, North Vate.

Hazard, Uncertainty and Exposure Assessments

Half of the volcanoes of Vanuatu have detailed eruptive histories allowing the calculation of hazard. These seven volcanoes are classified at Hazard Levels I, II and III. The only Hazard Level III volcano is Aoba, with a history of pyroclastic flow producing eruptions.

Of the seven unclassified volcanoes, only two have confirmed Holocene eruptions: Traitor’s Head and Suretamatai. These volcanoes have erupted historically, as recently as 1965.

The PEI in Vanuatu ranges between 2 and 3 indicative of small to moderate populations. This, in combination with the Hazard Levels classifies the volcanoes here at Risk Levels I – II.

CLASSIFIED	Hazard III		Aoba					
	Hazard II		Ambrym; Lopevi	Yasur				
	Hazard I		Gaua; Epi; Kuwae					
UNCLASSIFIED	U – HHR		Traitor's Head	**Suretamatai**				
	U- HR							
	U- NHHR		Motlav; Mere Lava; Unnamed; Aneityum	North Vate				
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 147: Identity of Vanuatu’s volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed “classified” (top). Those without sufficient data are “Unclassified” (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Yasur	3	II
Aoba	2	II
Lopevi	2	I
Ambrym	2	I
Epi	2	I
Gaua	2	I
Kuwae	2	I

Table 148: Classified volcanoes of Vanuatu ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 5 volcanoes; Risk Level II – 2 volcanoes; Risk Level III – 0 volcanoes.

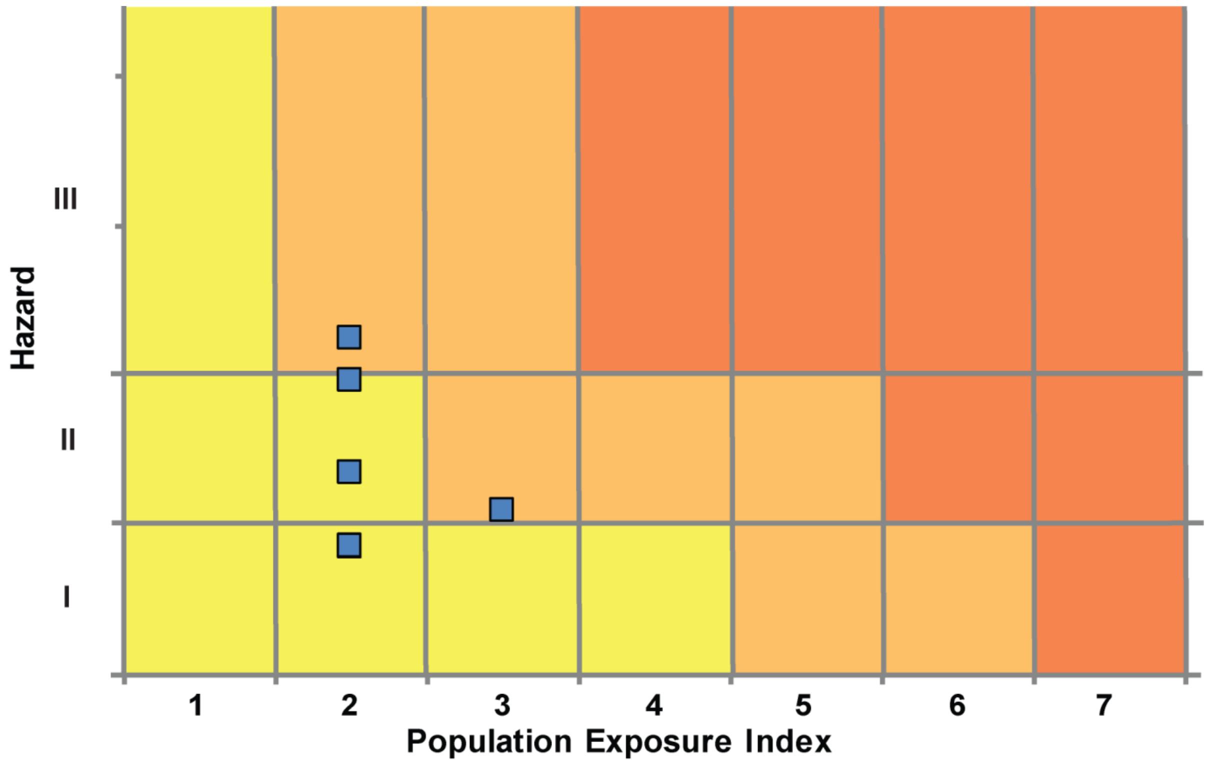


Figure 161: Distribution of Vanuatu's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Volcanism in Vanuatu is monitored by the Vanuatu Geohazards Observatory. A national seismic network (the Vanuatu Seismic Network) is distributed across the islands of the country measuring activity in real-time or near real-time. A further volcano monitoring network is in place including: permanent seismic monitoring at the Risk Level II volcanoes Yasur and Aoba, and Risk Level I Ambrym and Gaua volcanoes, with non-continuous monitoring used at Lopevi. The Risk Level I volcanoes Epi and Kuwae and the unclassified Suretamatai and Traitor's Head volcanoes do not currently have a dedicated monitoring network in place.

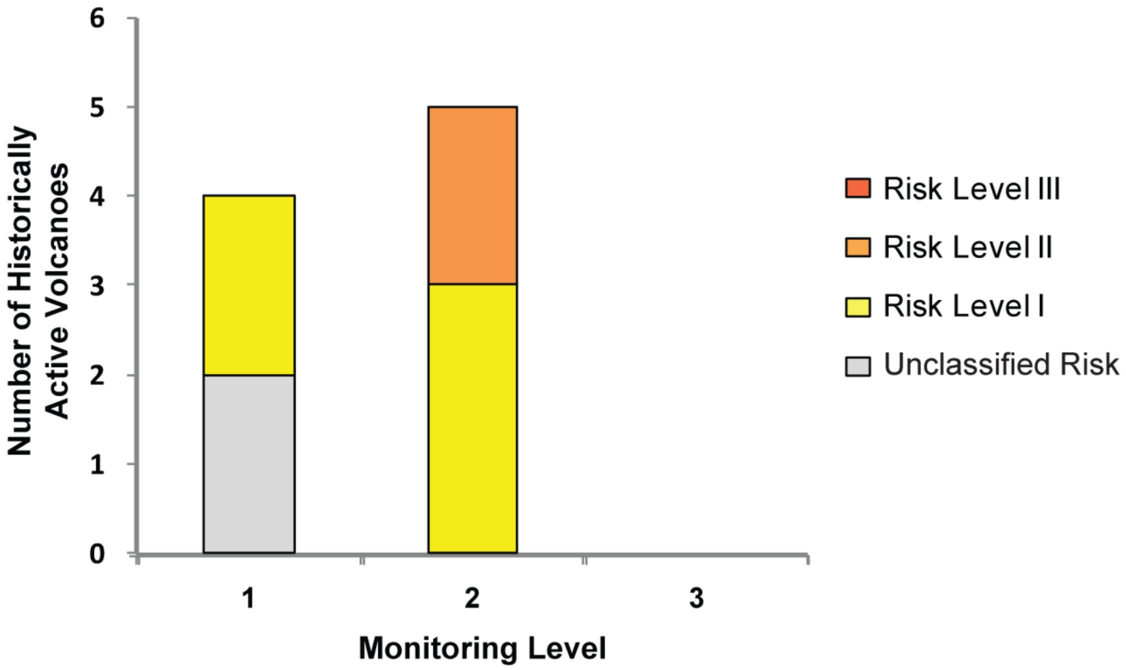


Figure 162: The monitoring and risk levels of the historically active volcanoes in Vanuatu. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 6: Indonesia

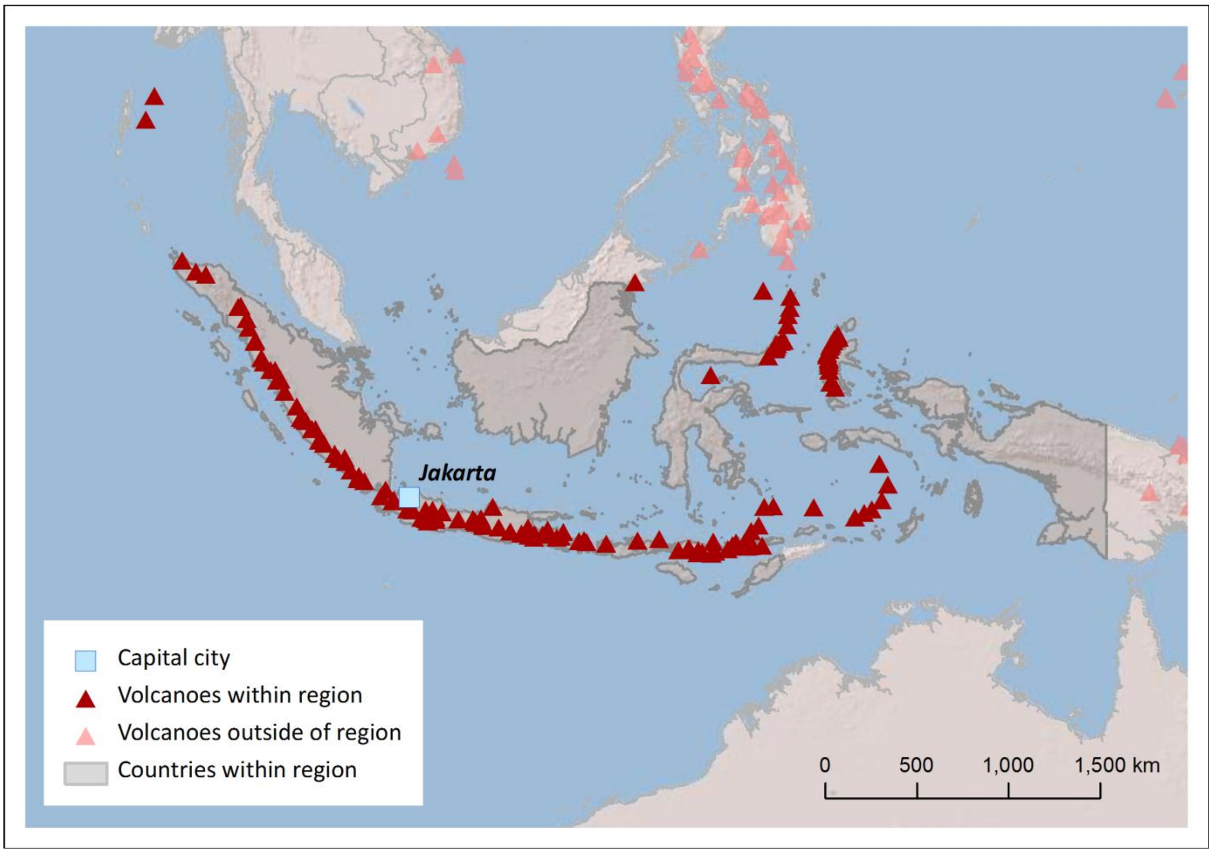


Figure 163: The distribution of Holocene volcanoes through the Melanesia and Australia region. The capital cities of the constituent countries are shown.

Description

Region 6, Indonesia, comprises volcanoes distributed throughout Indonesia itself, the Indian Andaman Islands in the north of the Indonesian arc, and one volcano in Malaysia.

Country	Number of volcanoes
India	2 + 1 from Region 3
Indonesia	142
Malaysia	1

Table 149: The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

About 80% of this region's volcanoes are situated in the Sunda Arc, stretching from north-west Sumatra to the Banda Sea, east of Papua New Guinea. This arc results from the subduction of the Indo-Australian Plate beneath the Eurasian Plate. The remaining volcanoes, on either end of this arc result from more complex tectonic interactions. The Andaman Islands in the north result from short spreading centres. The Banda Arc, at the southern end of the Sunda Arc and turning back towards Borneo, results broadly from the subduction of the Pacific crust. Multiple subduction zones and micro-plates north of this produce the Sulawesi-Sangihe volcanoes and Halmahera volcanoes in roughly north-south lineaments on either side of the collision zone. About 79% of volcanoes in this region are stratovolcanoes or other large-cone types, and 10% are calderas. This and the dominantly andesitic composition of volcanism here are associated with explosive activity.

Records of large magnitude eruptions date back into the Pleistocene, with 8 volcanoes having Pleistocene records of VEI≥4 eruptions. The largest eruption recorded globally during the Quaternary (the last 2.5 million years), is recorded in this region. The Younger Toba Tuff eruption of Toba in Indonesia occurred 74,000 years ago. This was a magnitude 8.8 eruption which produced extensive pyroclastic flows and voluminous ashfall.

Despite records of large events extending back millennia, most activity in this region is under-recorded. 145 Holocene volcanoes are located in this region, with records of 1,277 confirmed Holocene eruptions. However, of these, 1,203 eruptions (94%) are recorded in historical times, illustrating that the eruptive activity prior to 1500 AD is relatively poorly known. Indeed, 96% of eruptions in this region are recorded through historical observations. Whilst recent activity is very well documented, the absence of comprehensive eruptive histories back in time makes assessment of hazard and full understanding of activity difficult and associated with significant uncertainties. There may be unrecognised volcanoes or volcanoes with long-recurrence periods of large activity that pose particular hazards.

Activity ranges from small to extremely large explosive eruptions in this region. Small VEI 2 eruptions dominant the record, however the history indicates that moderate to large explosive eruptions of VEI ≥3 occur roughly every 15 years. A large number of historical eruptions (10%) have produced pyroclastic flows and many have resulted in lahars.

This is a very populous region, dominated by the large population of Indonesia. Over 8.6 million people live within 10 km of one or more Holocene volcano, the highest of any region. Direct hazards such as lava flows and pyroclastic flows can commonly extend over this distance. Over 180 million people live within 100 km of one or more volcano. 18 volcanoes (~31% of classified volcanoes) are deemed at Risk Level III, due to the combination of high hazard and high local population. Largely due to this high proximal population, a large number of eruptions have resulted in fatalities (roughly 10% of historical events). However comprehensive monitoring now undertaken in Indonesia has led to a good record of evacuations prior to eruption. Regular monitoring is undertaken at many of the regions volcanoes, with focussed dedicated monitoring at many of the volcanoes of highest risk.

Volcano facts

Number of Holocene volcanoes	145
Number of Pleistocene volcanoes with M≥4 eruptions	8
Number of volcanoes generating pyroclastic flows	33 (153 eruptions)
Number of volcanoes generating lahars	31 (108 eruptions)
Number of volcanoes generating lava flows	39 (176 eruptions)
Number of eruptions with fatalities	125
Number of fatalities attributed to eruptions	142,903

Largest recorded Pleistocene eruption	The largest Quaternary explosive eruption globally is recorded in this region: The Younger Toba Tuff was erupted in a M8.8 eruption from Toba in Indonesia at 74 ka.
Largest recorded Holocene eruption	The largest recorded Holocene eruption was the 416 AD M7.1 eruption of Krakatau.
Number of Holocene eruptions	1,277 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 7 and unknown
Number of historically active volcanoes	79
Number of historical eruptions	1,203

Number of volcanoes	Primary volcano type	Dominant rock type
14	Caldera(s)	Andesitic (7), Dacitic (4), Unknown (3)
2	Hydrothermal field	Andesitic (1), Unknown (1)
114	Large cone(s)	Andesitic (92), Basaltic (18), Dacitic (2), Unknown (2)
2	Lava dome(s)	Andesitic (2)
4	Small cone(s)	Andesitic (1), Basaltic (2), Unknown (1)
6	Submarine	Andesitic (1), Unknown (5)
4	Unknown	Andesitic (1), Dacitic (1), Unknown (2)

Table 150: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	20

Table 151: Average recurrence interval (years between eruptions) for small and large eruptions in the Indonesia region.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 20 years.

Eruption Size

Eruptions of VEI 0 to 7 are recorded through the Indonesia region, representing a range of eruption styles from gentle effusive events to very large explosive eruptions. VEI 2 events dominate the record, with nearly 70% of all Holocene eruptions classed as such. Just under 3% of eruptions here are explosive at VEI≥4.

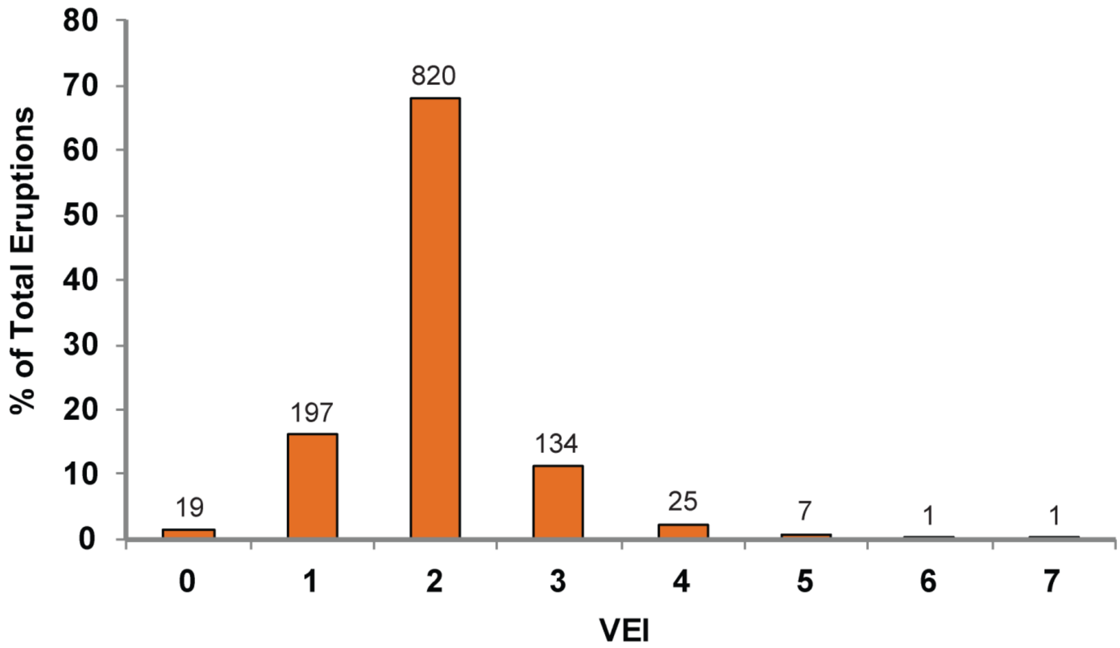


Figure 164: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 73 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	1,463,514,556
Gross Domestic Product (GDP) per capita (2005 PPP $)	3,203 – 13,672
	(Mean 6,990)
Gross National Income (GNI) per capita (2005 PPP $)	3,285 – 13,676
	(Mean 7,038)
Human Development Index (HDI) (2012)	0.554 – 0.769 (Medium to High, Mean 0.651 Medium)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	8,631,561 (0.59 %)
Number (percentage) of people living within 30 km of a Holocene volcano	68,995,316 (4.71 %)
Number (percentage) of people living within 100 km of a Holocene volcano	180,040,137 (12.30 %)

CLASSIFIED	**Hazard III**		Teon, Ruang	Karangetang [Apu Siau], Makian	Tambora, Awu	Semeru, Soputan	Galunggung, Kelut, Lokon-Empung	Merapi
	Hazard II		Paluweh, Serua	Peuet Sague, Sorikmarapi, Sangeang Api, Iliwerung	Krakatau, Ebulobo, Gamkonora	Kaba, Raung, Ijen, Rinjani, Iya, Tongkoko	Cereme, Tengger Caldera, Mahawu, Gamalama	
	Hazard I		Nila, Banua Wuhu; Barren Island	Banda Api	Dempo, Lewotolo, Sirung, Ibu	Bur ni Telong, Marapi, Talang, Kerinci, Lewotobi, Leroboleng, Iliboleng, Egon	Perbakti-Gagak, Salak, Papandayan, Slamet, Lamongan	Gede, Tankubanparahu, Guntur, Dieng Volcanic Complex, Sundoro, Batur
UNCLASSIFIED	**U – HHR**		**Batu Tara, Colo [Una Una],** Wurlali, Gunungapi Wetar	**Sumbing (261180)**, **Besar**, **Suoh**, **Dukono**	**Seulawah Agam, Kelimutu**	Sibayak, **Sinabung, Tandikat, Ranakah, Inielika, Ambang**	**Lawu, Arjuno-Welirang, Agung**	Sumbing (263220), Merbabu
	U- HR				**Inierie**	Muria		
	U-NHHR	Manuk, Unnamed (267050); Narcondum	Yersey, Emporor of China, Nieuwerkerk, Amasing; Unnamed (235010)	Malintang, Hutapanjang, Pendan, Kunyit, Belirang-Beriti, **Patah,** Bukit Lumut Balai, Sekincau Belirang, Tobaru, Moti, Tigalalu, Bibinoi	Sibualbuali, Libukraya, Talakmau, Ranau, Ndete Napu, Ililabalekan, Tarakan, Todoko-Ranu, Jailolo, Hiri, Mare; Bombalai	Imun, Sarik-Gajah, Bukit Daun, Hulubelu, Iyang-Argapura, Baluran, Poco Leok, Sukaria Caldera, Ilimuda, Klabat, Tidore	Toba, Rajabasa, Pulosari, Karang, Patuha, Wayang-Windu, Kendang, **Talagabodas,** ngaran, Telomoyo, Wilis, Kawi-Butak, Lurus, Wai Sano, Sempu	Malabar, Tampomas, **Kawah Karaha,** Penanggungan, Malang Plain, Bratan, Tondano Caldera
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 152: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of volcanoes	Population Exposure Index
16	7
30	6
34	5
24	4
23	3
15	2
3	1

Table 153: The number of volcanoes in the Indonesia region classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
18	III
30	II
10	I
87	Unclassified

Table 154: The number of volcanoes in the Indonesia region classified at each Risk Level.

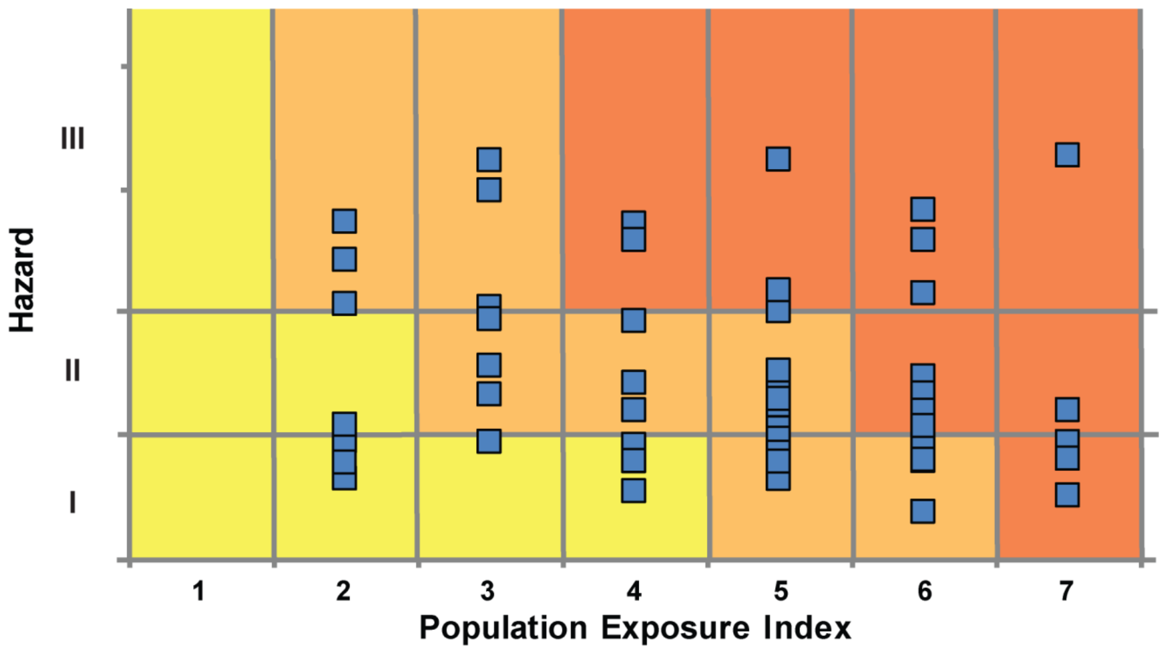


Figure 165: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III..

Regional monitoring capacity

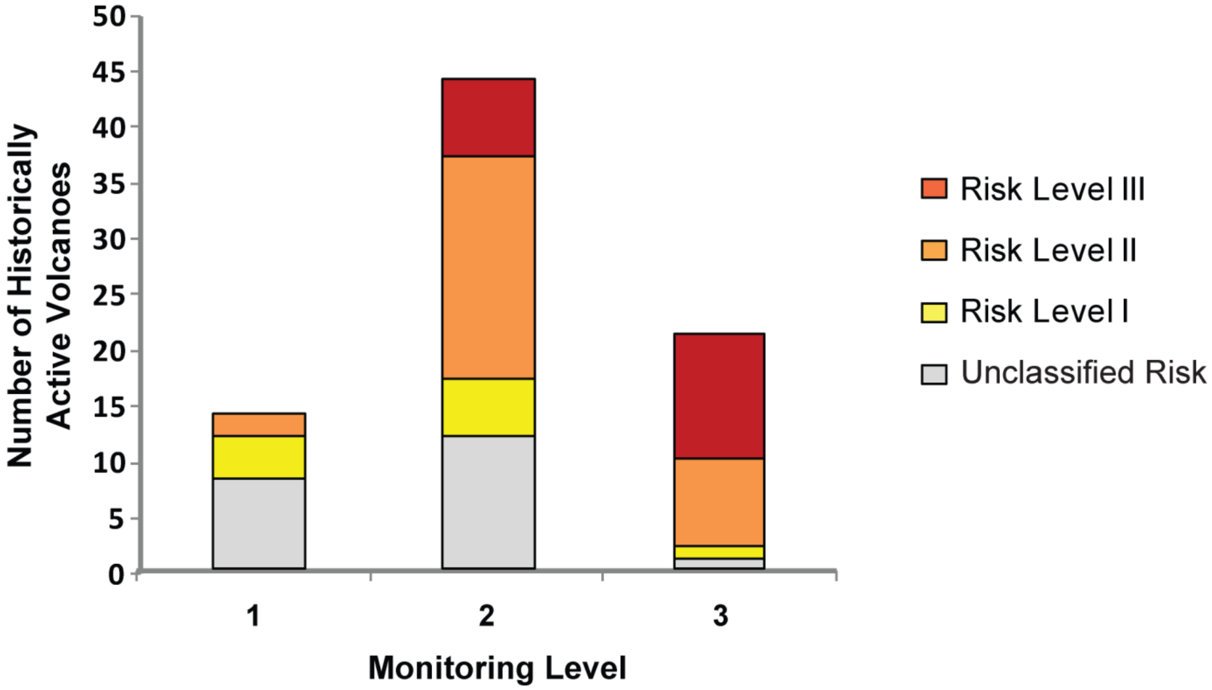


Figure 166: The monitoring and risk levels of the historically active volcanoes in the Indonesia region. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers

India

Note that we include the Indian unnamed submarine volcano located east of Chennai here, which is included in the Region 3 “Middle East and Indian Ocean” description as defined in this region by the Global Volcanism Program.

Description

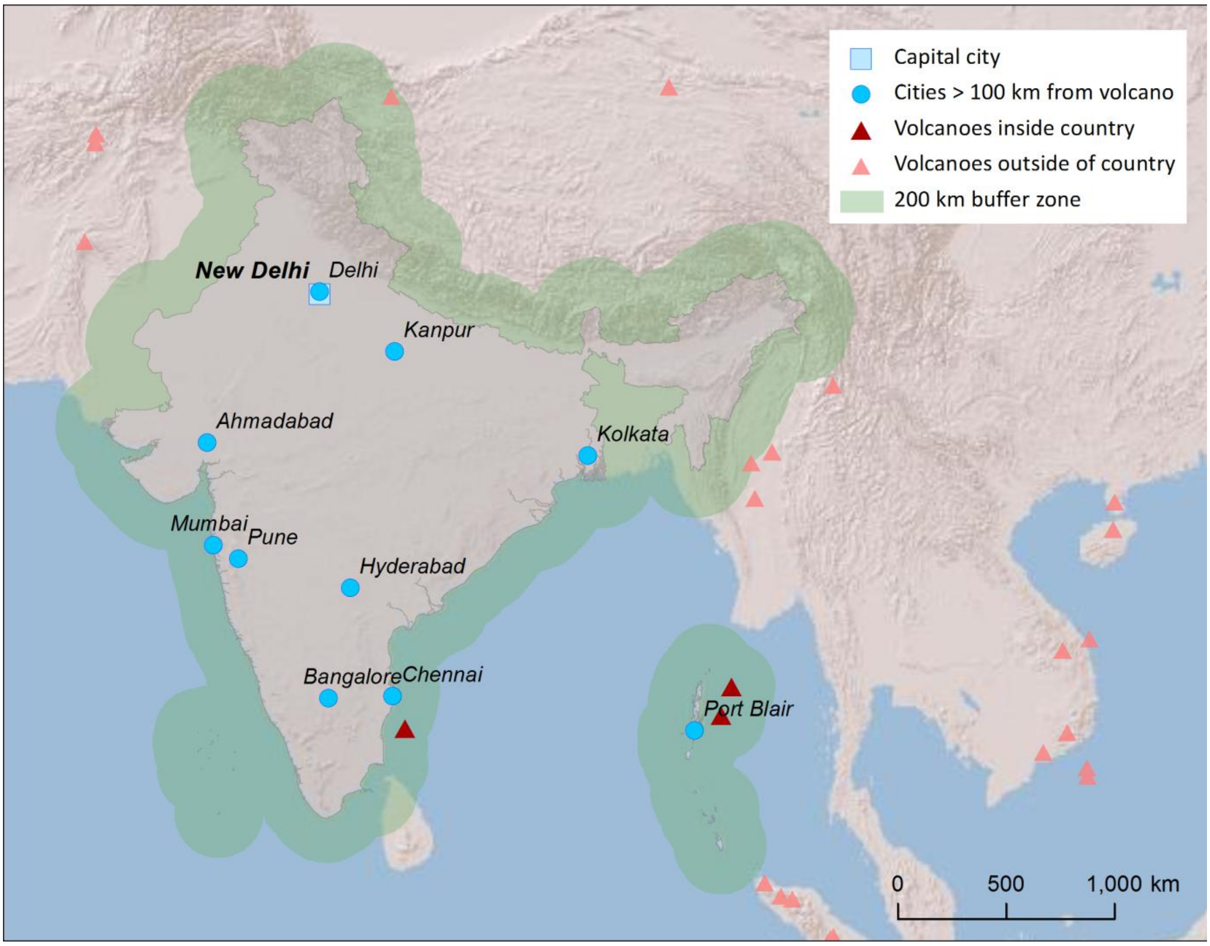


Figure 167: Location of India’s volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect India.

There are three Indian Holocene volcanoes: one unnamed submarine volcano related to intra-plate hotspot processes off the south-east coast of India, and Barren Island and Narcondum in the Andaman Islands in the north of the volcanic arc stretching through Sumatra. These two stratovolcanoes are broadly related to the subduction of the Indian Plate under the Eurasian Plate.

Of the three volcanoes, only Barren Island has confirmed activity recorded in the Holocene. The unnamed volcano and Narcondum are suspected to have had Holocene activity. However, the existence of the unnamed volcano is uncertain. Barren Island has been frequently active in historical times, with 11 eruptions from 1787 to 2010 of VEI 2. No eruptions greater than VEI2 are recorded, suggesting dominantly effusive to moderately explosive activity, however deposits are identified which suggest a history of large explosive eruptions generating pyroclastic flows back into the

Pleistocene. Large explosive eruptions often have long recurrence intervals and may occur again in the future.

Both Barren Island and Narcundum form small, uninhabited islands of less than 5 km across. There is no permanent infrastructure or population on these islands, with the exception of a permanent police outpost on Narcondum manned by 10-20 personnel at any given time. Barren Island is classed at Hazard Level I, based on its historical record. The population may increase in the future, as a permanent field base is proposed for Barren Island to permit studies of the volcano and the potential as a site for geotourism is considered in Sheth et al. (2010).

At the time of the writing of this report one GPS monitoring system had been installed on Barren Island, though no other dedicated ground-based monitoring is in operation at any other Holocene volcano in India. The National Geophysical Research Institute hope to install a seismic station on Barren Island in 2014. The Geological Survey of India are the responsible organisation for providing information and monitoring in times of activity, and indeed have responded to past eruptions sending field parties to investigate activity. The Indian Coast Guard located at Port Blair in the Andaman Islands reports activity of Barren Island, but not regularly.

The Asian Disaster Reduction Center (ADRC) produced a report on the hazards in India in 2012, with a further five such reports dating back to 1998. In this they do not consider volcanic hazards. They describe how India has moved from a system of reactive relief efforts to proactive risk reduction, particularly in relation to the seismic hazard. The ADRC discuss how a Disaster Mitigation Fund and Disaster Response Fund are provided for following the enactment of the Disaster Management Act 2005 and provides for the establishment of Disaster Management Authorities on several levels – National (NDMA), State (SDMA) and District (DDMA). For full details of the disaster management and preparedness see the ADRC report.

See also:

Ray, J. S., Pande, K., and Awasthi, N. (2013) A minimum age for the active Barren Island volcano, Andaman Sea. Current Science, 104:7

Sheth, H.C., Ray, J.S., Bhutani, R., Kumar, A., and Awasthi, N. (2010) The latest (2008-09) eruption of Barren Island volcano, and some thoughts on its hazards, logistics and geotourism aspects. Current Science, 98:5.

Asian Disaster Reduction Center: India:
http://www.adrc.asia/nationinformation.php?NationCode=356&Lang=en&NationNum=02

Volcano Facts

Number of Holocene volcanoes	3
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-

Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	The submarine volcano is located in an intra-plate setting whilst the large cones are in a subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	There are 11 eruptions recorded at VEI 2 from Barren Island between 1787 and 2010 AD.
Number of Holocene eruptions	12 confirmed eruptions. 3 uncertain eruptions.
Recorded Holocene VEI range	2 and Unknown.
Number of historically active volcanoes	1
Number of historical eruptions	11

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
2	Large cone(s)	Andesitic (1), Basaltic (1)
1	Submarine	Unknown (1)

Table 155: The number of volcanoes in India, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	1,238,700,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	3,203
Gross National Income (GNI) per capita (2005 PPP $)	3,285
Human Development Index (HDI) (2012)	0.554 (Medium)

Population Exposure

Capital city	New Delhi
Distance from capital city to nearest Holocene volcano	811.6 km

Total population (2011)	1,189,172,906
Number (percentage) of people living within 10 km of a Holocene volcano	278 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	278 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	893,001 (<1%)

Largest cities, as measured by population, and populations:

Mumbai	12,691,836
Delhi	10,927,986
Bangalore	5,104,047
Kolkata	4,631,392
Chennai	4,328,063
Ahmadabad	3,719,710
Hyderabad	3,597,816
Pune	2,935,744
Kanpur	2,823,249
Jaipur	2,711,758

Infrastructure Exposure

The Indian volcanoes of Narcondum and Barren Island lie in the Andaman Islands. Both islands measure less than 5 km across, therefore the entirety of these are exposed to volcanic hazards, however no permanent settlements or infrastructure exist here. The 100 km radius of Barren Island marginally encroaches on the much larger and inhabited Smith Island. An airport at Port Blair, the capital of the Andaman and Nicobar Islands is located about 135 km from Barren Island.

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

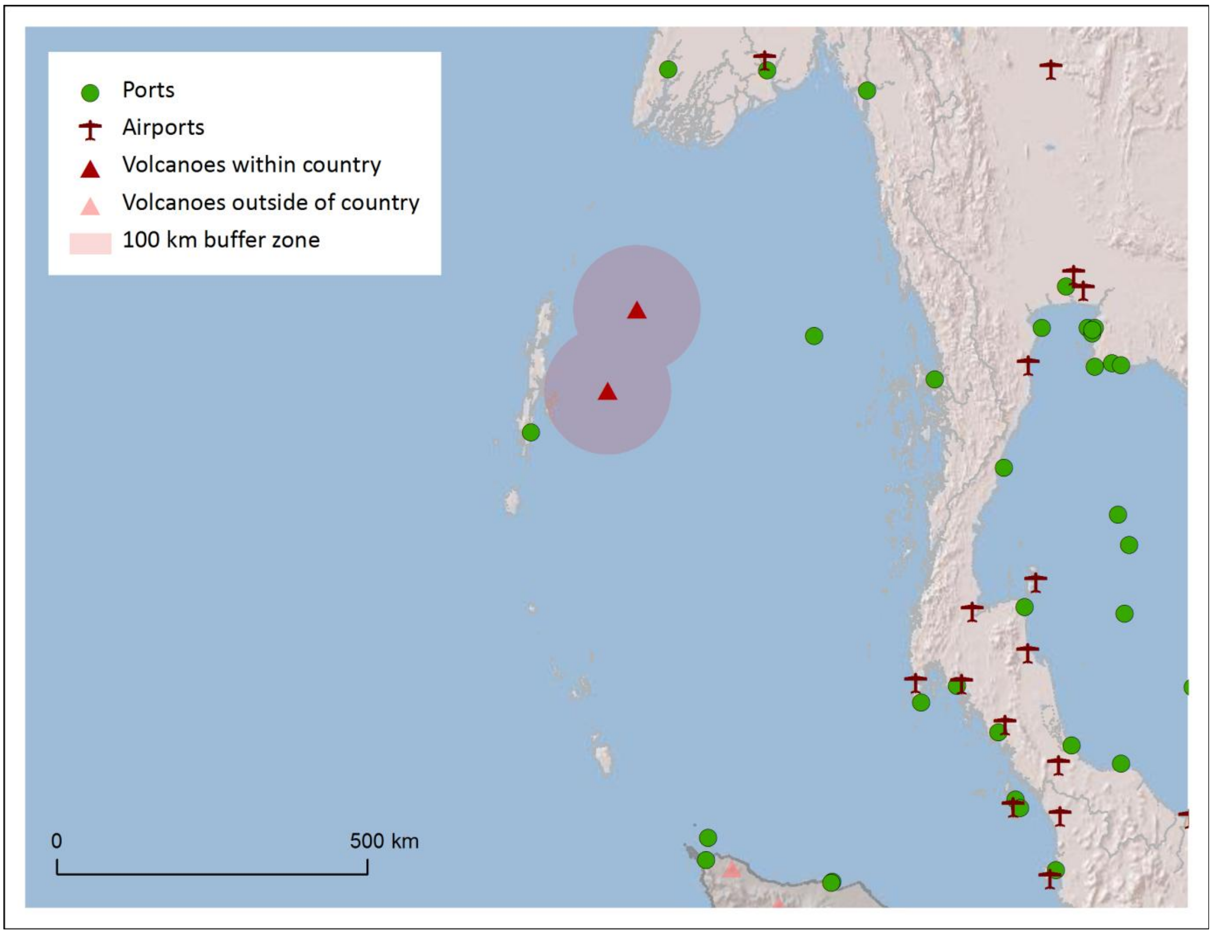


Figure 168: The location of India's volcanoes in the Andaman Islands and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Of the three Indian volcanoes, only Barren Island has a sufficiently detailed eruption record for calculation of the hazard. This volcano is characterised by lava flow production and eruptions of VEI 2 and is classed at Hazard Level I.

Narcondum and an unnamed volcano are unclassified, as no confirmed eruptions are recorded during the Holocene.

All volcanoes in India are classed at PEI 1 and 2, with only small populations within 100 km. Narcondum has no permanent population living within this distance however there is a police outpost with 10-20 personnel at any given time. The low PEI of Narcondum suggests a risk level of I, regardless of the hazard. Barren Island is classified at Risk Level I.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I		Barren Island					
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR	Narcondum	Unnamed (235010)					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 156: Identity of India's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Barren Island	2	I

Table 157: Classified volcanoes of India ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

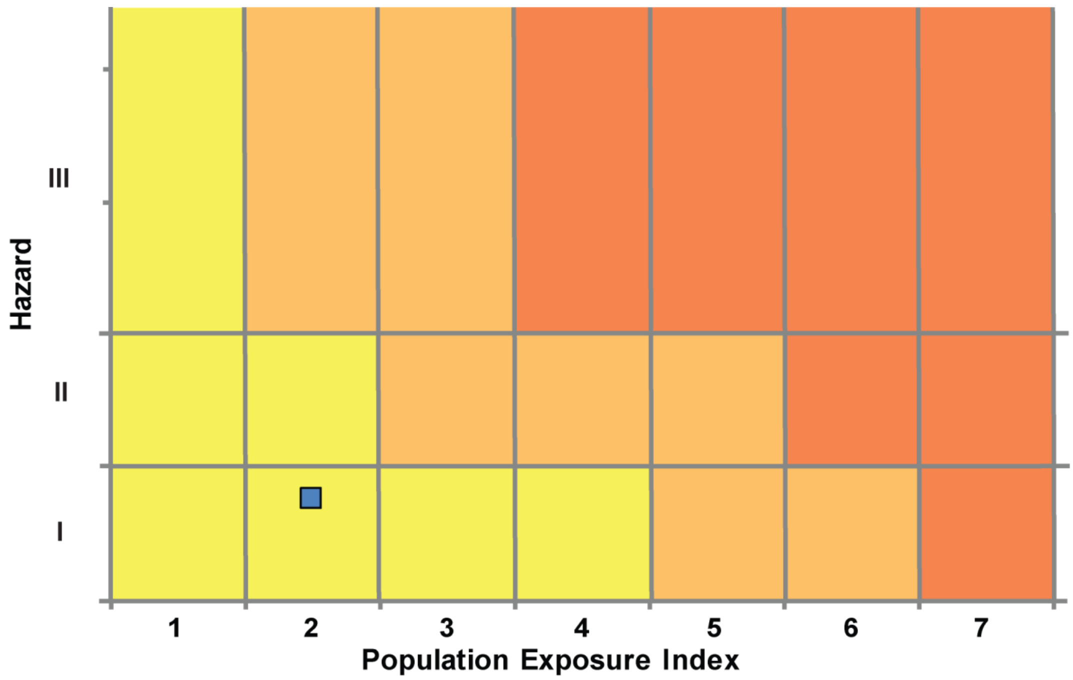


Figure 169: Distribution of India's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

One GPS station has been installed on Barren Island, but with no real-time data transmission. It is hoped that a seismic station will be installed in 2014 (V. Gahalaut, National Geophysical Research Institute, India, pers. Comm. 2014).

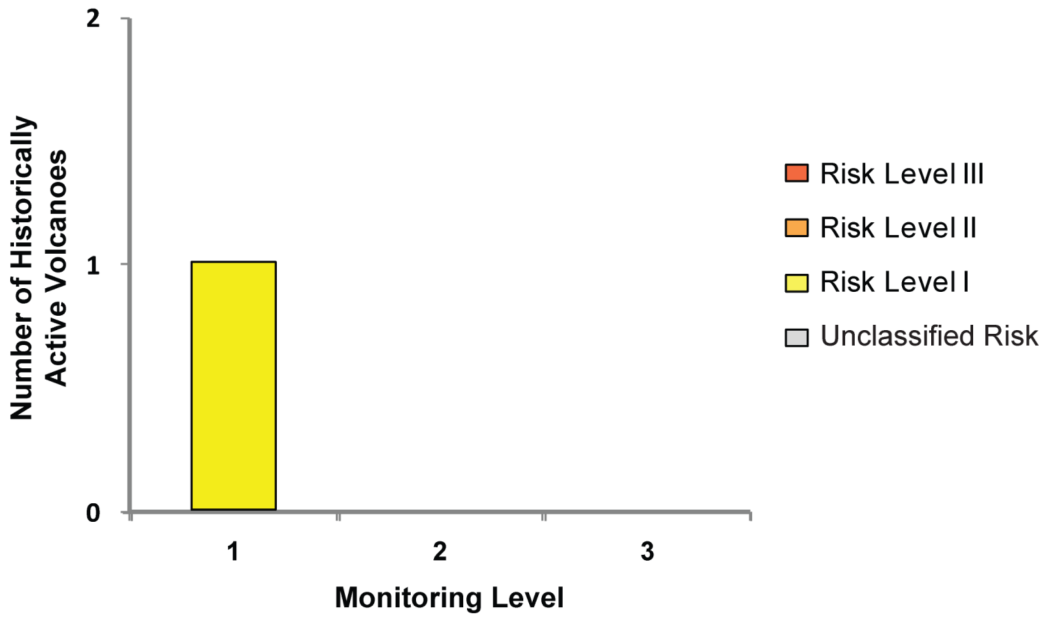


Figure 170: The monitoring and risk levels of the historically active volcanoes in India. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Indonesia

Description

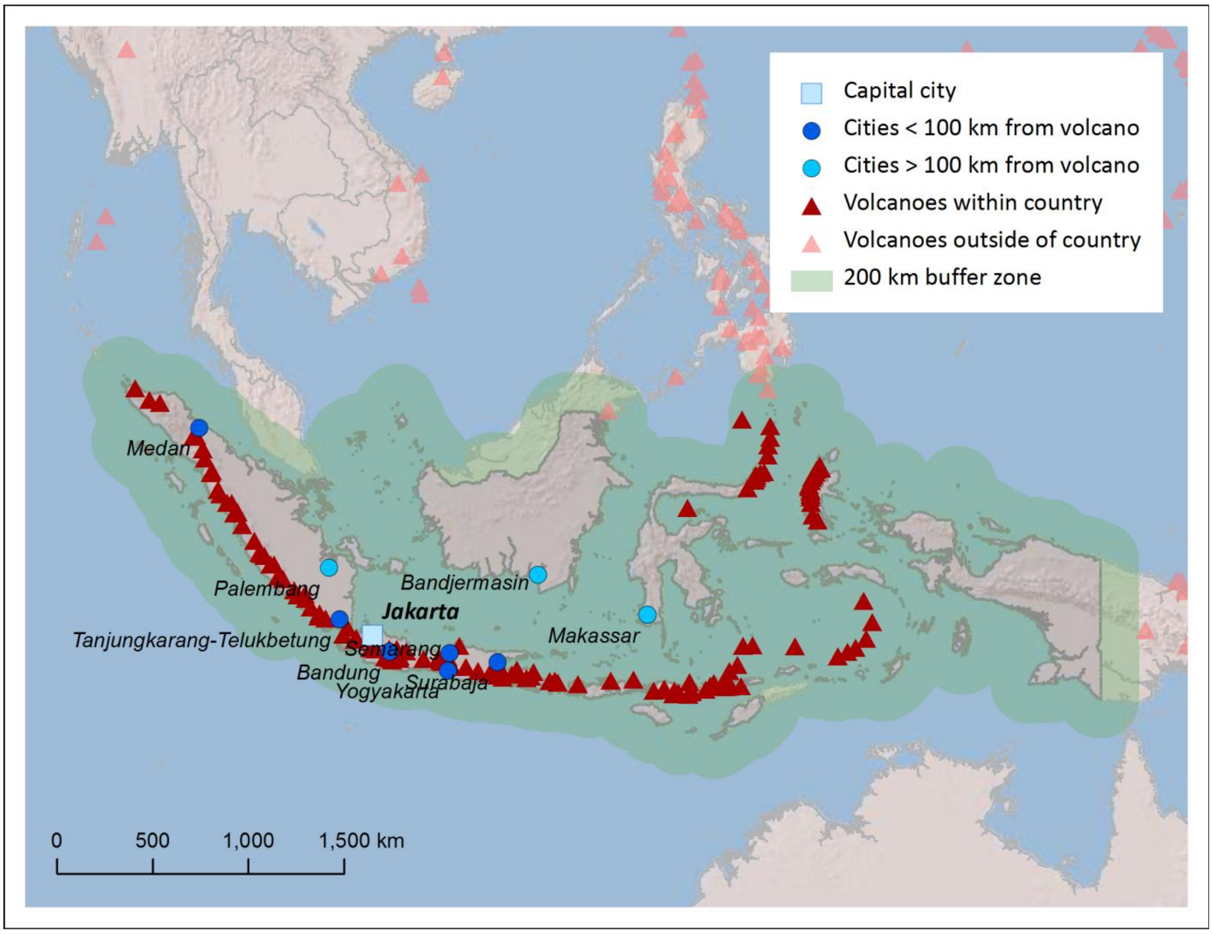


Figure 171: Location of Indonesia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Indonesia.

The Smithsonian's Volcanoes of the World 4.0 database records 142 Holocene volcanoes distributed throughout much of Indonesia. Of these, 77 have a record of historical eruptions. Indonesia as a country and volcanic region covers a vast area, formed of over 13,000 islands stretching 5,271 km east-west and 2,210 km north-south. Volcanoes are spread across Java, Sumatra, Bali, Molluca, Nusa Tenggara and are located in the Celebes seas. The majority of these volcanoes lie along the Sunda Arc, caused by subduction of the Indo-Australia Plate below the Eurasian Plate. The Arc stretches over 3,000 km from northwest Sumatra in the east to the Banda Sea in the west, and accounts for 108 (76%) of the country's volcanoes. The tectonic setting north of the Sunda Arc is more complex, with converging plate fragments west of the Pacific Plate which itself is subducting to the west, creating multiple subduction zones that give rise to the volcanoes of Halmahera and Sulawesi-Sangihe. A wide range of volcano types are present in Indonesia, however stratovolcanoes are the dominant form with a dominantly andesitic composition.

The density of active volcanoes in Indonesia means that eruptions are frequent. 1,265 eruptions are recorded through the Holocene in VOTW4.22. 94% of these are recorded post-1500 AD, indicating good historical records and severe under-recording with increasing age. Holocene eruptions of VEI 0

– 7 are recorded, indicating a range of activity styles from small, effusive events to catastrophic explosive eruptions. These large explosive eruptions are recorded back into the Pleistocene, with 8 Indonesian volcanoes with records of M≥4 eruptions, including the largest eruption recorded in the Pleistocene worldwide: the M8.8 Younger Toba Tuff eruption at Toba about 74,000 years ago. The Tambora eruption of 1815 is the largest magnitude historical eruption worldwide.

The widespread distribution of volcanoes throughout Indonesia means that much of the country lies within the 100 km radii of these Holocene volcanoes. Nearly 80% of the population live within these radii and much of the critical infrastructure is exposed, with many of the largest cities, including the capital, Jakarta, falling within this distance. Indeed, Jakarta lies within about 65 km of three Holocene volcanoes, Gede, Salak and Perbakti-Gagak, all of which have had eruptions as recently as the 1900s. Densely populated rural communities, particularly on Java, further increase population exposure; 28 of Indonesia's volcanoes have over 100,000 people living within 10 km of their summits, with over 8.6 million living at this distance throughout Indonesia. 91 volcanoes have over 100,000 living within 30 km.

A range of hazards are posed by Indonesia's volcanoes, with many volcanoes hosting explosive eruptions. 30 volcanoes have produced pyroclastic flows during 115 historical eruptions, and 31 have produced lahars during 102 historical eruptions. Hazard classifications range from Level I to III, and nearly 60% of Indonesian volcanoes have considerable uncertainties associated with the assignment of the hazard levels and are therefore unclassified here. Of the classified volcanoes in Indonesia, 18 are classed as Risk Level III, due to the high hazard and high local populations.

Three events, at Tambora in 1815, Krakatau in 1883, and Kelut in 1919, stand out in terms of devastating loss of life and these three events alone account for roughly a fifth of historic fatalities from worldwide volcanism. The largest historical eruption, the VEI 7 eruption of Tambora in 1815, caused approximately 60,000 deaths. Direct deaths resulted from tsunamis, bomb impacts, tephra falls, and pyroclastic flows that reached all but the west coast, with roughly 50,000 indirect deaths on Sumbawa and Lombok islands owing to starvation following the destruction of farmland. The caldera collapse eruption of Krakatau, situated in the Sunda Strait between Java and Sumatra, in 1883 was the second largest during historical time in Indonesia (after that of Tambora). The VEI 6 eruption destroyed Krakatau island, triggering tsunamis that swept the coastlines of Sumatra and Java and killed approximately 34,000; further deaths resulted from pyroclastic surges that travelled 40 km across the Sunda Strait to the coast of Sumatra. Kelut, a stratovolcano on west Java, highlights the potential hazard posed by crater lakes. Kelut's often short but violent eruptions have frequently released volumes of water from the crater lake that generate devastating lahars; lahars following the VEI 4 event in 1919 claimed 5,110 lives, and destroyed 9,000 homes and 104 villages. Tunnels draining the crater lake have been engineered to decrease this hazard. The February 2014 VEI 4 eruption of Kelut resulted in lahars following heavy rainfall. The CVGHM (Center for Volcanology and Geological Hazard Mitigation) monitors Kelut and from increases in seismicity, crater lake temperature and inflation were able to raise the alert level and evacuate many from a 10 km radius prior to this eruption.

An eruption of Merapi, beginning in October and November 2010, is one of Indonesia's most recent volcanic crises. The CVGHM raised the alert level to its highest possible on 25th October 2010, and recommended immediate evacuation for communities within a 10 km radius of the volcano (between 11,000 and 19,000 people). A day later, an explosive eruption generating pyroclastic flows began; on 27th October, reports noted roughly twenty-five deaths and several more injured. The eruption continued throughout November, with further pyroclastic flows and avalanches, and a particularly violent explosion on 5th November; ash caused diversions and cancellations at Solo and Yogyakarta airports. Activity began to decline in early December, with the CVGHM reducing the alert level to 3 (on a scale of 1 to 4) on 4th December, and to 2 on 9th January 2011. The overall death toll exceeded 380, over 400,000 people were temporarily evacuated, and financial losses were estimated at Rp 7.1 trillion (approximately US$781 million). Lahars are an ongoing hazard.

The CVGHM was founded in 1920 to monitor the Indonesian volcanoes. CVGHM is part of the Ministry of Energy and Mineral Resources and is funded by the Indonesian government. Of a staff of over 220, about 70% have experience of responding to an eruption. The CVGHM has a number of volcano observatories distributed throughout Indonesia, responsible for monitoring the volcanoes and collecting data. Members of the public are encouraged to report unusual signs at volcanoes to CVGHM. Monitoring is undertaken at 68 volcanoes, all with at least one seismic station. Many of the high risk volcanoes have multiple seismic stations and other monitoring systems in place. Those monitored have baseline seismic data available which permits observations of unusual activity. Not all volcanoes in Indonesia are continuously monitored, however CVGHM has plans and some resources available to respond to an increase in activity at currently unmonitored volcanoes.

The CVGHM categorise Indonesia's volcanoes using a different classification system to that used in this report. The CVGHM consider 127 volcanoes to be active. These are classified into three groups: Type A volcanoes have had magmatic eruptions since 1600, Type B volcanoes had eruptions before 1600, and Type C volcanoes only exhibit fumarolic activity. The CVGHM focuses monitoring efforts at the Type A volcanoes, with 68 out of 77 of these volcanoes have continuous monitoring with at least one seismometer.

The CVGHM have a set protocol for responding to an increase in activity and they inform the local government, the BNPB (the National Disaster Management Agency) and BPBD (the Local Disaster Management Agency), local authorities and the population located in the hazard area. The CVGHM also communicates observations and advice to multiple agencies including the Indonesian National Armed Forces, National Police, Ministry of Transportation, Ministry of Health and Ministry of Social Affairs. The CVGHM are responsible for providing risk assessments and declaring alerts, with regular communication of the alert levels.

See also:

CVGHM: http://www.vsi.esdm.go.id/

Volcano Facts

Number of Holocene volcanoes	142
Number of Pleistocene volcanoes with M≥4 eruptions	8
Number of volcanoes generating pyroclastic flows	33

Number of volcanoes generating lahars	31
Number of volcanoes generating lava flows	38
Number of fatalities caused by volcanic eruptions	?>142,903
Tectonic setting	142 subduction zone
Largest recorded Pleistocene eruption	The M8.8 eruption of the Younger Toba Tuff from Toba at 74 ka.
Largest recorded Holocene eruption	The M7.1 eruption of Krakatau in 416 AD.
Number of Holocene eruptions	1265 confirmed eruptions. 121 uncertain eruptions.
Recorded Holocene VEI range	0 – 7 and unknown.
Number of historically active volcanoes	77
Number of historical eruptions	1,192

Number of volcanoes	Primary volcano type	Dominant rock type
14	Caldera(s)	Andesitic (7), Dacitic (4), Unknown (3)
2	Hydrothermal field	Andesitic (1), Unknown (1)
112	Large cone(s)	Andesitic (91), Basaltic (17), Dacitic (2), Unknown (2)
2	Lava dome(s)	Andesitic (2)
3	Small cone(s)	Andesitic (1), Basaltic (1), Unknown (1)
5	Submarine	Andesitic (1), Unknown (4)
4	Unknown	Andesitic (1), Dacitic (1), Unknown (2)

Table 158: The number of volcanoes in Indonesia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	247,273,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,094
Gross National Income (GNI) per capita (2005 PPP $)	4,154
Human Development Index HDI) (2012)	0.629 (Medium)

Population Exposure

Capital city	Jakarta
Distance from capital city to nearest Holocene volcano	65.6 km
Total population (2011)	245,613,043
Number (percentage) of people living within 10 km of a Holocene volcano	8,631,283 (3.5%)
Number (percentage) of people living within 30 km of a Holocene volcano	68,995,038 (28.1%)
Number (percentage) of people living within 100 km of a Holocene volcano	179,107,855 (72.9%)

Ten largest cities, as measured by population, and populations:

Jakarta	8,540,121
Surabaja	2,374,658
Medan	1,750,971
Bandung	1,699,719
Palembang	1,441,500
Makassar	1,321,717
Semarang	1,288,084
Tanjungkarang-Telukbetung	800,348
Yogyakarta	636,660
Bandjermasin	572,837

Infrastructure Exposure

Number of airports within 100 km of a volcano	10
Number of ports within 100 km of a volcano	41
Total length of roads within 100 km of a volcano (km)	11,312
Total length of railroads within 100 km of a volcano (km)	3,178

The numerous Indonesian volcanoes are distributed throughout the country, placing much of the country within 100 km of these volcanoes. This means that an extensive proportion of the population and major cities, including the capital Jakarta, are exposed to volcanic hazards. Much of the critical infrastructure lies within the 100 km radii, including numerous airports and international airports, and over 40 ports. An extensive road and rail network is also exposed.

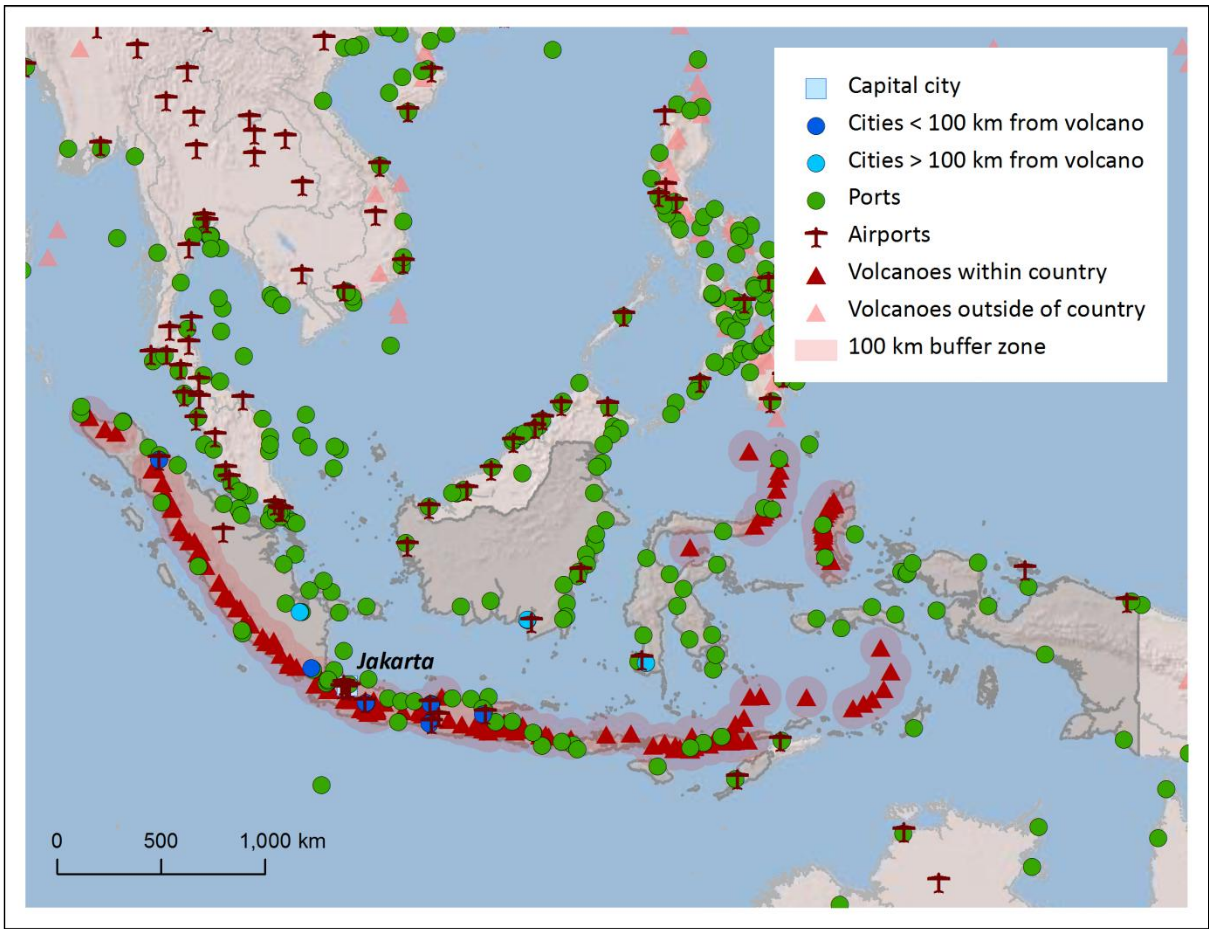


Figure 172: The location of Indonesia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard and Uncertainty Assessments

The volcanoes of Indonesia have varying levels of data available in the eruption record. Just over 40% of volcanoes have appropriate eruptive histories to define the hazard. 54 of these classified volcanoes are 'active' having had eruptions since 1900. Three classified volcanoes are 'semi-active', with historical eruptions between 1500 and 1900 and unrest recorded above background levels since 1900 (Guntur, Lamongan and Tongkoko). The classified volcanoes are classed at all three hazard levels: 26 at Hazard Level I, 19 at Hazard Level II and 12 at Hazard Level III.

Of the unclassified volcanoes, 13 have experienced eruptions since 1900; a further 10 have had Holocene age eruptions and 62 have had no confirmed Holocene eruptions. 36 unclassified volcanoes have fumarolic activity ongoing or recorded since 1900, however seven of these have exhibited periods of unrest since 1900 in which fumarolic emissions, seismicity or other activity has been above background levels.

CLASSIFIED	**Hazard III**		Teon, Ruang	Karangetang [Apu Siau], Makian	Tambora, Awu	Semeru, Soputan	Galunggung, Kelut, Lokon-Empung	Merapi
	Hazard II		Paluweh, Serua	Peuet Sague, Sorikmarapi, Sangeang Api, Iliwerung	Krakatau, Ebulobo, Gamkonora	Kaba, Raung, Ijen, Rinjani, Iya, Tongkoko	Cereme, Tengger Caldera, Mahawu, Gamalama	
	Hazard I		Nila, Banua Wuhu	Banda Api	Dempo, Lewotolo, Sirung, Ibu	Bur ni Telong, Marapi, Talang, Kerinci, Lewotobi, Leroboleng, Iliboleng, Egon	Perbakti-Gagak, Salak, Papandayan, Slamet, Lamongan	Gede, Tankubanparahu, Guntur, Dieng Volcanic Complex, Sundoro, Batur
UNCLASSIFIED	**U – HHR**		**Batu Tara, Colo [Una Una],** Wurlali, Gunungapi Wetar	**Sumbing (261180)**, **Besar**, **Suoh**, **Dukono**	**Seulawah Agam, Kelimutu**	Sibayak, **Sinabung**, **Tandikat**, **Ranakah**, **Inielika**, **Ambang**	**Lawu, Arjuno-Welirang, Agung**	Sumbing (263220), Merbabu
	U- HR				**Inierie**	Muria		
	U- NHHR	Manuk, Unnamed (267050)	Yersey, Emporor of China, Nieuwerkerk, Amasing	Malintang, Hutapanjang, Pendan, Kunyit, Belirang-Beriti, **Patah,** Bukit Lumut Balai, Sekincau Belirang, Tobaru, Moti, Tigalalu, Bibinoi	Sibualbuali, Libukraya, Talakmau, Ranau, Ndete Napu, Ililabalekan, Tarakan, Todoko-Ranu, Jailolo, Hiri, Mare	Imun, Sarik-Gajah, Bukit Daun, Hulubelu, Iyang-Argapura, Baluran, Poco Leok, Sukaria Caldera, Ilimuda, Klabat, Tidore	Toba, Rajabasa, Pulosari, Karang, Patuha, Wayang-Windu, Kendang, **Talagabodas,** ngaran, Telomoyo, Wilis, Kawi-Butak, Lurus, Wai Sano, Sempu	Malabar, Tampomas, **Kawah Karaha,** Penanggungan, Malang Plain, Bratan, Tondano Caldera
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 159: Identity of Indonesia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Banua Wuhu	2	I
Nila	2	I
Paluweh	2	I
Ruang	2	II
Serua	2	I
Teon	2	II
Banda Api	3	I
Iliwerung	3	II
Karangetang [Api Siau]	3	II
Makian	3	II
Peuet Sague	3	II
Sangeang Api	3	II
Sorikmarapi	3	II
Awu	4	III
Dempo	4	I
Ebulobo	4	II
Gamkonora	4	II
Ibu	4	I
Krakatau	4	II
Lewotolo	4	I
Sirung	4	I
Tambora	4	III
Egon	5	II
Ijen	5	II
Iliboleng	5	II
Iya	5	II
Kaba	5	II
Kerinci	5	II
Leroboleng	5	II
Lewotobi	5	II
Marapi	5	II
Raung	5	II
Rinjani	5	II
Semeru	5	III
Soputan	5	III
Talang	5	II
Telong, Bur ni	5	II
Tongkoko	5	II
Cereme	6	III
Galunggung	6	III
Gamalama	6	III
Kelut	6	III
Lamongan	6	II

Lokon-Empung	6	III
Mahawu	6	III
Papandayan	6	II
Perbakti-Gagak	6	II
Salak	6	II
Slamet	6	II
Tengger Caldera	6	III
Batur	7	III
Dieng Volcanic Complex	7	III
Gede	7	III
Guntur	7	III
Merapi	7	III
Sundoro	7	III
Tangkubanparahu	7	III

Table 160: The classified volcanoes of Indonesia ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 9 volcanoes; Risk Level II – 30 volcanoes; Risk Level III – 18 volcanoes.

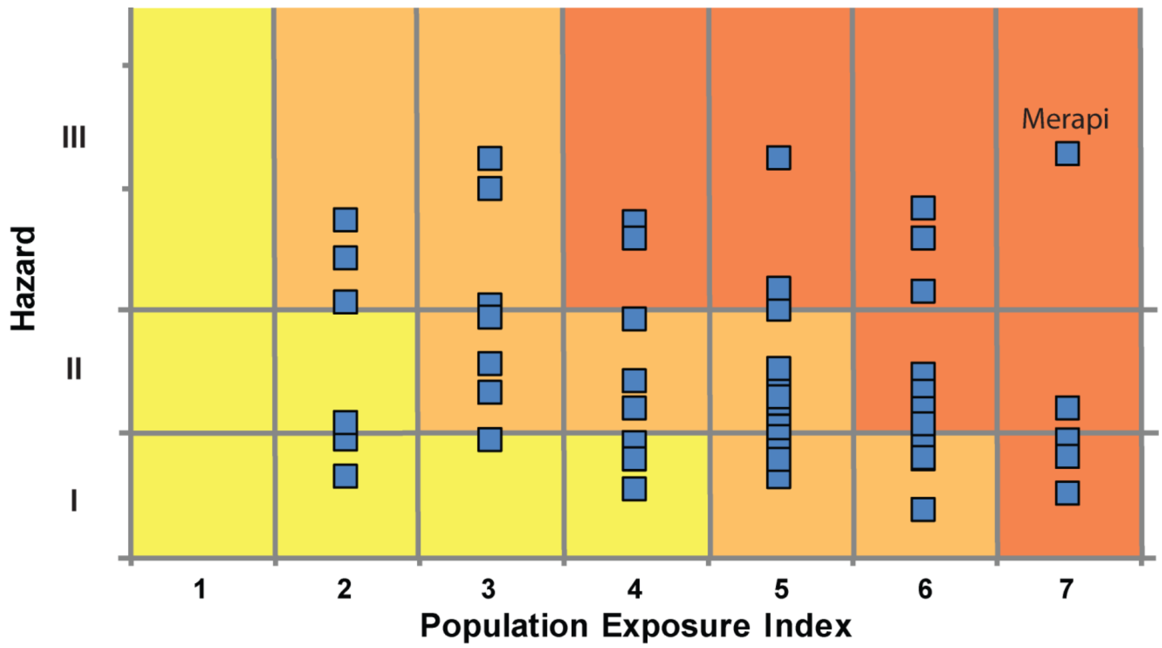


Figure 173: Distribution of Indonesia's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

The population of Indonesia is high and this is reflected in the PEI classifications, with only 16 volcanoes having a low PEI of 1 or 2, 46 with a moderate PEI of 3 or 4, and 80 with a high PEI ≥5. The classified volcanoes are found across the Risk Levels, with 9 Risk Level I volcanoes, 30 Risk Level II volcanoes and 18 Risk Level III volcanoes. Merapi, with the highest Hazard classification in Indonesia, has a very large local population with over 185,000 living within 10 km and is hence classified at Risk Level III.

National Capacity for Coping with Volcanic Risk

The Center for Volcanology and Geological Hazard Mitigation (CVGHM) is responsible for the monitoring of the volcanoes in Indonesia. Multiple observatories are in place and at 68 volcanoes have monitoring systems. The level of monitoring varies, with most volcanoes having fewer than three seismic stations and about 20 having seismic networks or seismic networks and deformation stations. All Risk Level III volcanoes are monitored to some degree, with 11 being designated monitoring level 3.

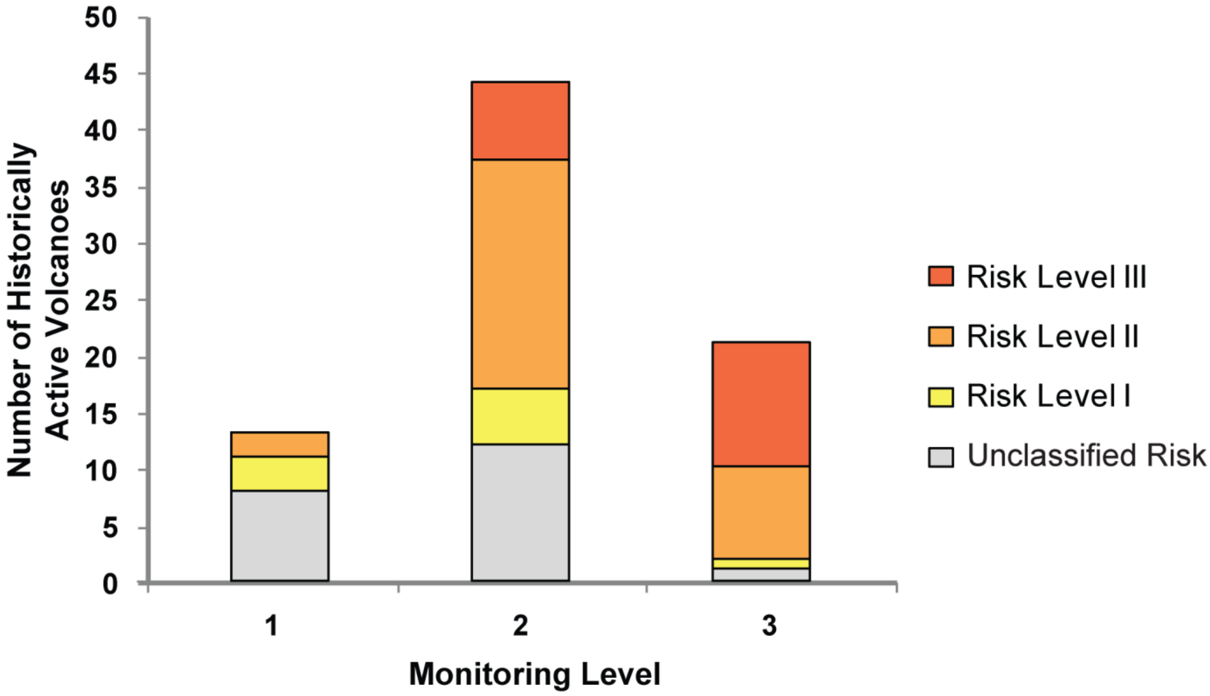


Figure 174: The monitoring and risk levels of the historically active volcanoes in Indonesia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Malaysia

Description

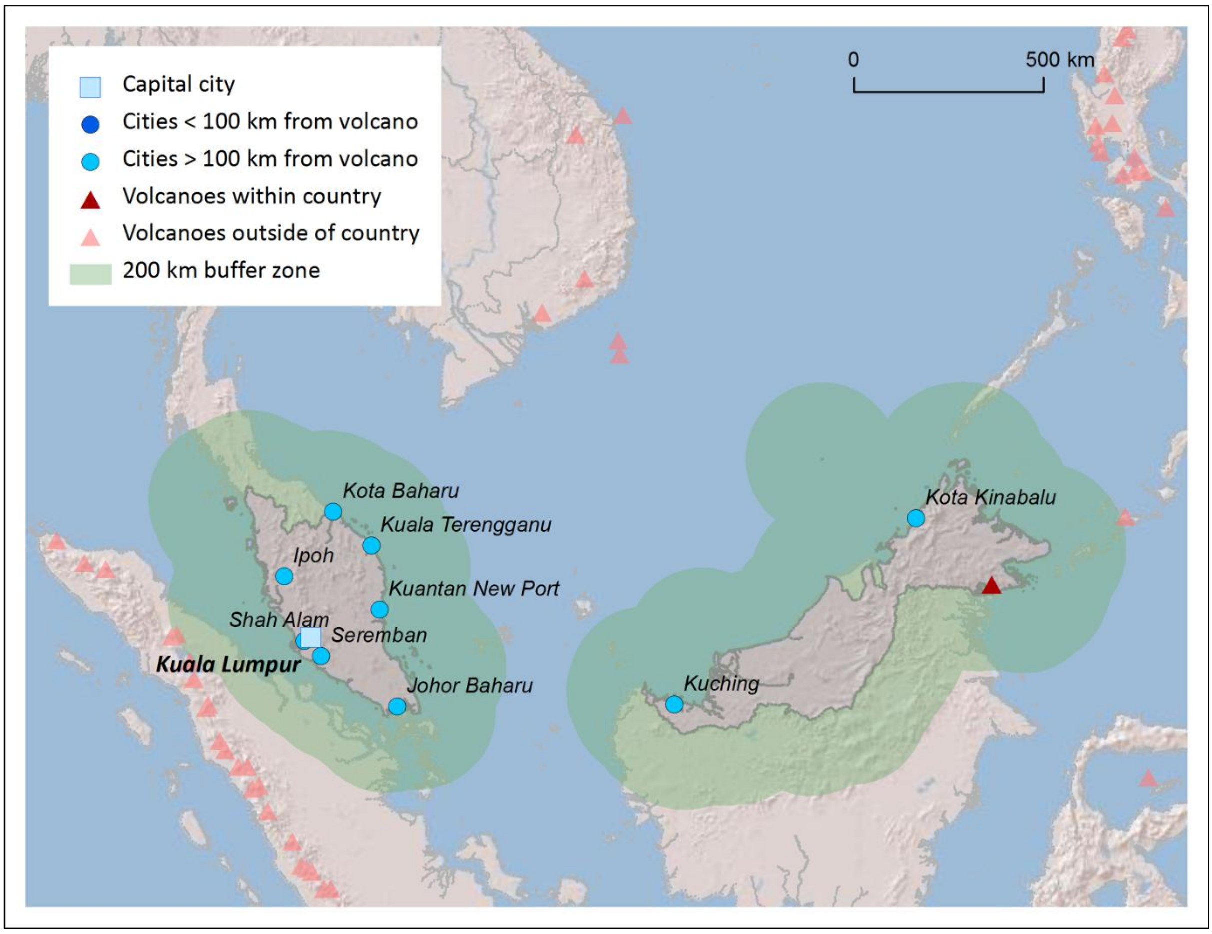


Figure 175: Location of Malaysia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Malaysia.

One volcano with suspected Holocene age activity is identified in Malaysia. Mount Bombalai is situated in north-eastern Borneo, on the border with Indonesia. Volcanism here is broadly related to the subduction of the Philippine plate under the Eurasian plate.

Bombalai is a basaltic pyroclastic cone in a volcanic field. No confirmed eruptions are recorded in the Holocene, however effusive activity is suspected. Further research is required to date lavas and better constrain the eruptive history.

Less than 1% of Malaysia's population live within 100 km of Bombalai, and indeed there is no population within 30 km. The Hazard Level is poorly constrained due to the sparse eruptive history.

The 100 km exposure radius of Malaysia's volcano extends beyond the border into Indonesia and exposes some infrastructure here.

No information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at Bombalai.

The Asian Disaster Reduction Center (ADRC) produced a report on the hazards in Malaysia in 2011, with a further six such reports dating back to 1998. In this they do not consider volcanic hazards, describing Malaysia as being 'generally free from...volcanic eruption'. They describe how disaster management in Malaysia operates on three levels – Federal, State and District. The Malaysian Meteorological Department (MMD) are responsible for monitoring disaster risk and strengthening disaster preparedness, specifically for meteorological, seismological and tsunami hazards. For full details of the disaster management and preparedness see the ADRC report.

See also:

Asian Disaster Reduction Center: Malaysia:
http://www.adrc.asia/nationinformation.php?NationCode=458&Lang=en&NationNum=16

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	-
Number of Holocene eruptions	-
Recorded Holocene VEI range	-
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
1	Small cone(s)	Basaltic (1)

Table 161: The number of volcanoes in Malaysia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	29,269,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	13,672
Gross National Income (GNI) per capita (2005 PPP $)	13,676
Human Development Index (HDI) (2012)	0.769 (High)

Population Exposure

Capital city	Kuala Lumpur
Distance from capital city to nearest Holocene volcano	325.6 km
Total population (2011)	28,728,607
Number (percentage) of people living within 10 km of a Holocene volcano	0 (0%)
Number (percentage) of people living within 30 km of a Holocene volcano	0 (0%)
Number (percentage) of people living within 100 km of a Holocene volcano	39,281 (<1%)

Ten largest cities, as measured by population, and populations:

Kuala Lumpur	1,453,975
Johor Baharu	802,489
Ipoh	673,318
Kuching	570,407
Shah Alam	481,654
Kota Kinabalu	457,326
Seremban	372,917
Kuantan New Port	366,229
Kuala Terengganu	285,065
Kota Baharu	279,316

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	4
Total length of roads within 100 km of a volcano (km)	205
Total length of railroads within 100 km of a volcano (km)	0

The Malaysian volcano Bombalai is located in the far east of the country, on the border with East Kalimantan, Indonesia. The 100 km radius around this volcano therefore affects Indonesia as well as Malaysia. Being located near the coast, four ports are proximal to this volcano. Only a small road network is within this radius, with the nearest airport being over 150 km away.

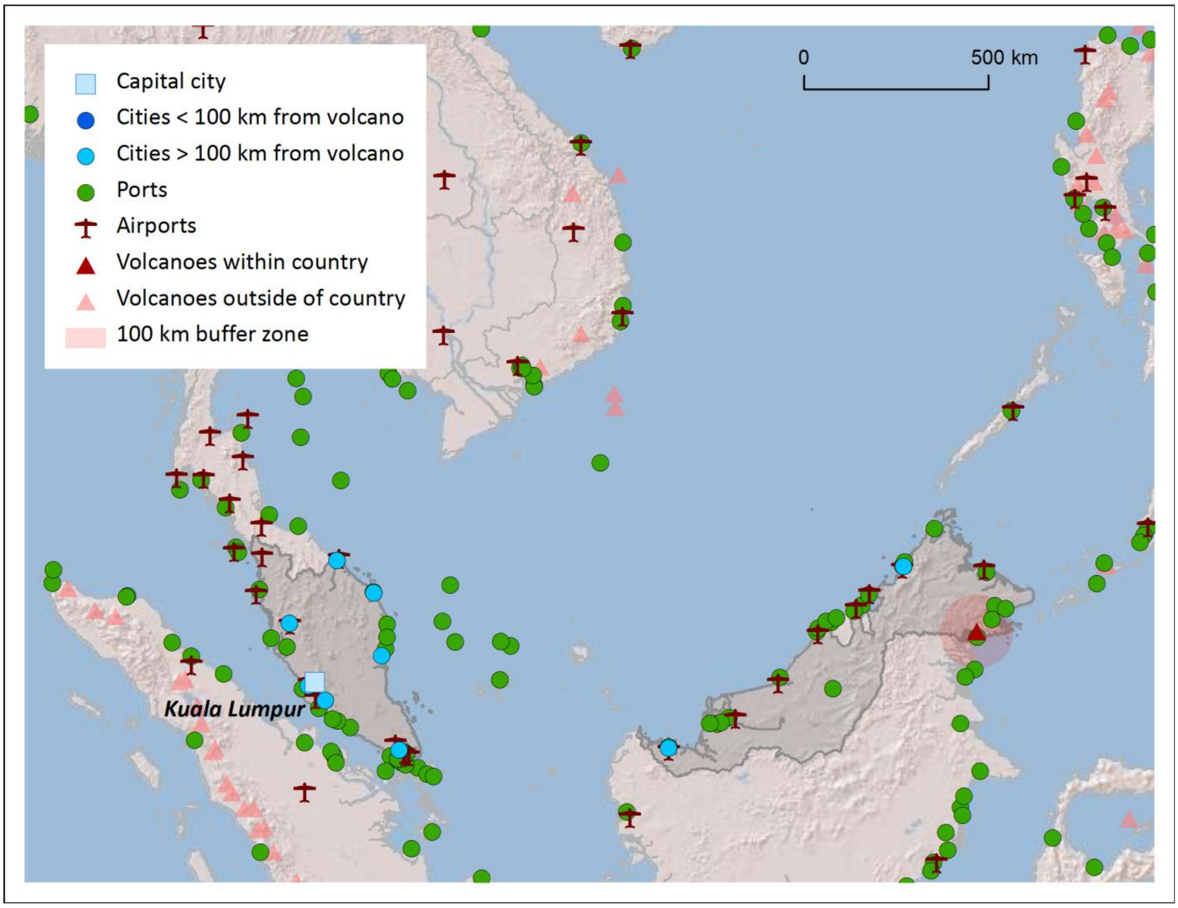


Figure 176: The location of Malaysia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The calculation of the hazard score cannot be undertaken for Bombalai due to the absence of an extensive eruption record, with no confirmed Holocene eruptions here. Bombalai has a moderate PEI of 4.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR							
	U- NHHR				Bombalai			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 162: Identity of Malaysia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Malaysia have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at Bombalai.

Region 7: Philippines and SE Asia

The Philippines and SE Asia region comprises volcanoes throughout Myanmar, the Philippines, Vietnam and southern China. Country profiles are provided for all, however see Region 10 (Kamchatka and Mainland Asia) for a country profile for China.

Country	Number of volcanoes
Myanmar (Burma)	3
China (See Region 10)	3
Philippines	47
Vietnam	6

Table 163: The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

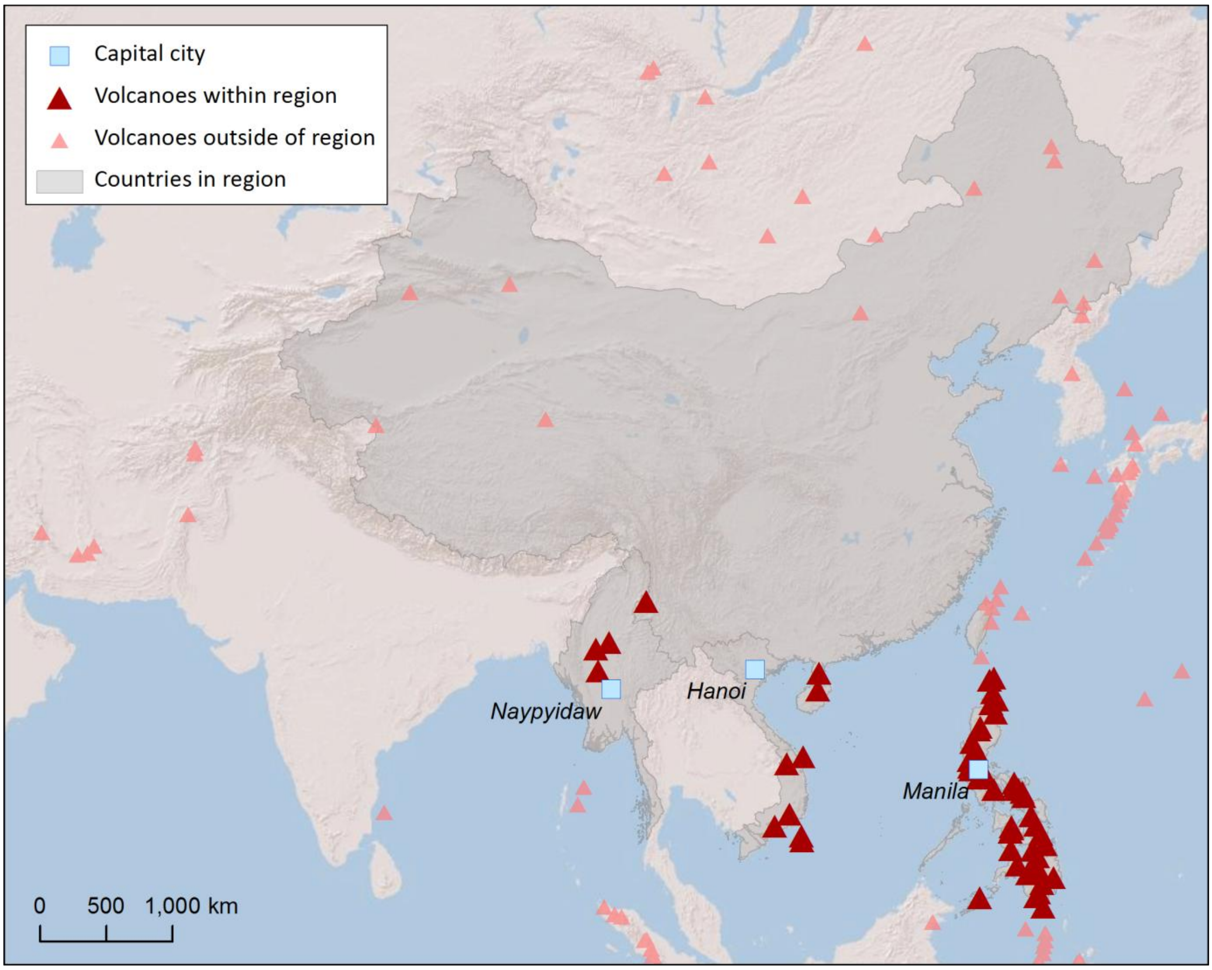


Figure 177: The distribution of Holocene volcanoes through the Philippines and SE Asia region. The capital cities of the constituent countries are shown.

Description

Fifty-nine Holocene volcanoes are located in Region 7: Philippines and SE Asia. Volcanism here is broadly due to the subduction of the Philippine Sea Plate beneath the Eurasian Plate. This has generated magmas of largely andesitic composition and dominantly (~75%) stratovolcanoes.

Of the 59 volcanoes, only 27 have confirmed Holocene eruptions recorded, with the remaining volcanoes having had activity of suspected Holocene age. This uncertainty in events complicates hazard assessment. Most (~88%) eruptions are recorded historically, post 1500-AD, and the Philippines dominates activity here.

Eruptions in this region have ranged from VEI 0 to 6 in size, indicating a range of activity styles, however about 9% of eruptions are classed at VEI ≥4. About 19% of historical eruptions have produced pyroclastic flows, and 20% have resulted in lahars. These mudflows remain a hazard for years after eruptions, with examples of secondary lahars at Pinatubo following the 1991 eruption burying thousands of homes years after the event. Tsunamis are associated with about 5% of historical eruptions here, making this region second only to the West Indies for proportion of tsunami-generating events.

The population density in this region is high, and about 2.9 million people throughout the region live within 10 km of one or more active volcanoes, rising to about 116 million within 100 km. Most volcanoes have a very high proximal population. The number of eruptions resulting in loss of life reflects the high local populations. About 17% of historical eruptions have resulted in fatalities; the largest proportion of any region. About a quarter of historical eruptions have resulted in property damage. This historical record extends to before the development of monitoring institutions and monitoring networks (PHIVOLCS, see Philippines). Monitoring is now dominantly focussed at Risk level II and III volcanoes, with about 36% of historically active volcanoes monitored by regular dedicated ground-based systems.

Volcano facts

Number of Holocene volcanoes	59
Number of Pleistocene volcanoes with M≥4 eruptions	4
Number of volcanoes generating pyroclastic flows	44
Number of volcanoes generating lahars	42
Number of volcanoes generating lava flows	35
Number of eruptions with fatalities	31
Number of fatalities attributed to eruptions	7,934
Largest recorded Pleistocene eruption	The 37.5 ka eruption of the Irosin Ignimbrites at Bulusan in the Philippines was the largest Quaternary explosive event in this region at M7.1.
Largest recorded Holocene eruption	Three eruptions of Pinatubo, including the 1991 eruption, are the largest recorded in the Holocene in LaMEVE at M6.1.
Number of Holocene eruptions	203 confirmed Holocene

	eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	20
Number of historical eruptions	178

Number of volcanoes	Primary volcano type	Dominant rock type
2	Caldera(s)	Andesitic (2)
42	Large cone(s)	Andesitic (32), Basaltic (8), Dacitic (2)
2	Lava dome(s)	Andesitic (2)
7	Small cone(s)	Andesitic (1), Basaltic (6)
3	Submarine	Basaltic (1), Unknown (2)

Table 164: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	60

Table 165: Average recurrence interval (years between eruptions) for small and large eruptions in the Philippines and SE Asia.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 60 years.

Eruption Size

Eruptions are recorded through the Philippines and SE Asia region of VEI 0 to 6, representing a range of eruption styles from gentle effusive events to large explosive eruptions. VEI 2 events dominate the record, with nearly 60% of all Holocene eruptions classed as such. 9% of eruptions here are explosive at VEI≥4.

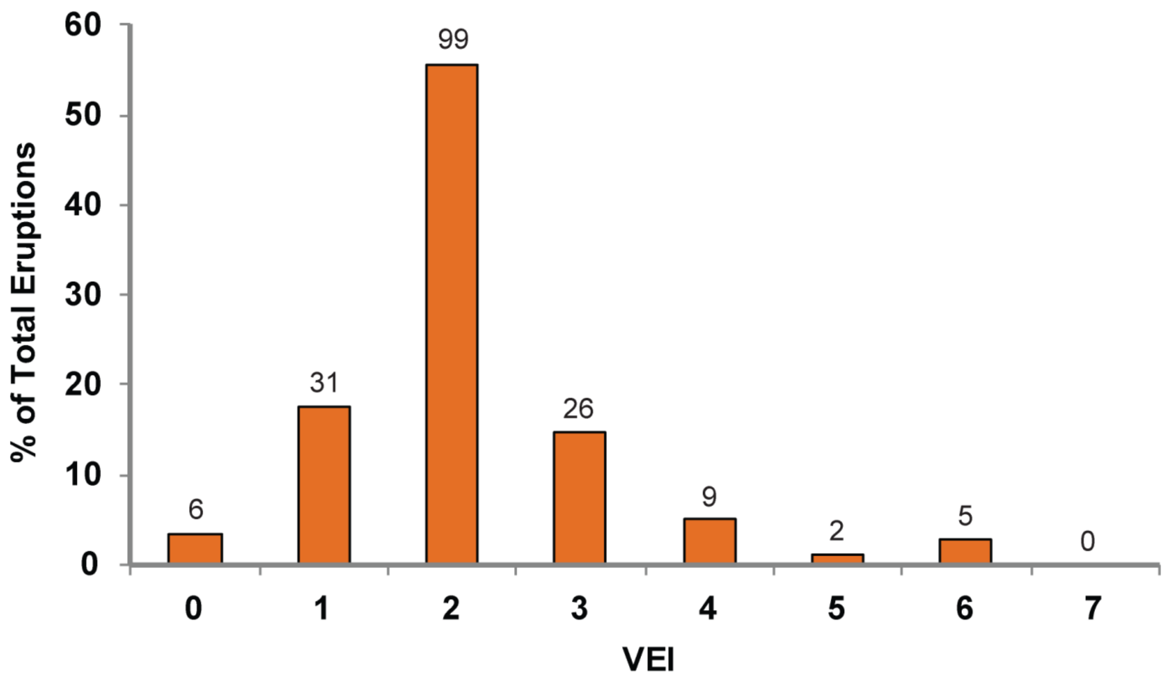


Figure 178: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 25 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	246,383,132
Gross Domestic Product (GDP) per capita (2005 PPP $)	3,013 – 3,631
	(Mean 3,322)
Gross National Income (GNI) per capita (2005 PPP $)	1,817 – 3,752
	(Mean 2,846)
Human Development Index (HDI) (2012)	0.498 – 0.654 (Low to Medium, Mean 0.590 Medium)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	2,976,701 (1.21 %)
Number (percentage) of people living within 30 km of a Holocene volcano	34,041,940 (13.82 %)
Number (percentage) of people living within 100 km of a Holocene volcano	116,383,251 (47.24 %)

CLASSIFIED	**Hazard III**					Camiguin	Mayon	Taal
	Hazard II		Babuyan Claro			Bulusan		
	Hazard I		Didicas		Ragang	Kanlaon		
UNCLASSIFIED	**U – HHR**		Camiguin de Babuyanes; Unnamed; **Cendres, Ile des**	**Cagua**	Parker	Makaturing; Cabalían; **Biliran**; **Pinatubo**	Jolo; **Musuan**	**Hainan Dao**
	U- HR			Iraya	Leonard Range	**Matutum**; Popa	Mariveles; **Tengchong**	San Pablo Volcanic Field
	U- NHHR		**Veteran**	Balut; Mahagnao; Cù-Lao Ré Group; Toroeng Prong	Latukan; Balatukan; **Ambalatungan Group**	Apo; Kalatungan; **Malindang**; Paco; Cuernos de Negros; Mandalagan; Silay; Isarog; Malindig; Natib; Patoc	Pocdol Mountains; Masaraga; Iriga; Banahaw; Amorong; Santo Tomas; Haut Dong Nai; Singu Plateau	Laguna Caldera; Arayat; Leizhou Bandao; Bas Dong Nai; Lower Chindwin
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 166: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
8	7
13	6
20	5
6	4
6	3
6	2
0	1

Table 167: The number of volcanoes in the Philippines and SE Asia classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
3	III
2	II
3	I
51	Unclassified

Table 168: The number of volcanoes in the Philippines and SE Asia region classified at each Risk Level.

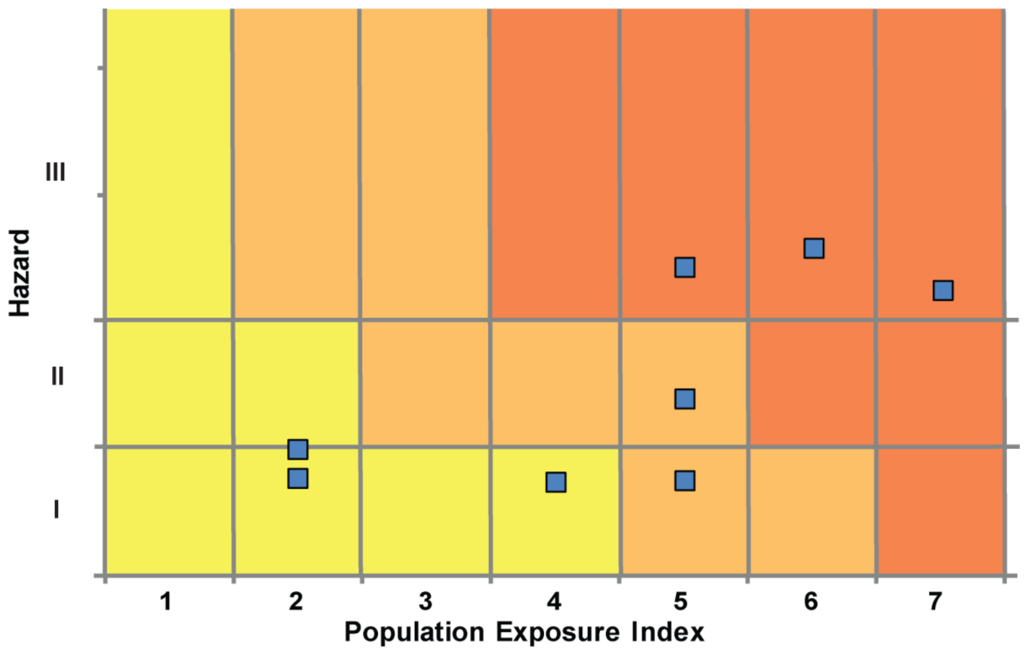


Figure 179: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional Monitoring Capacity

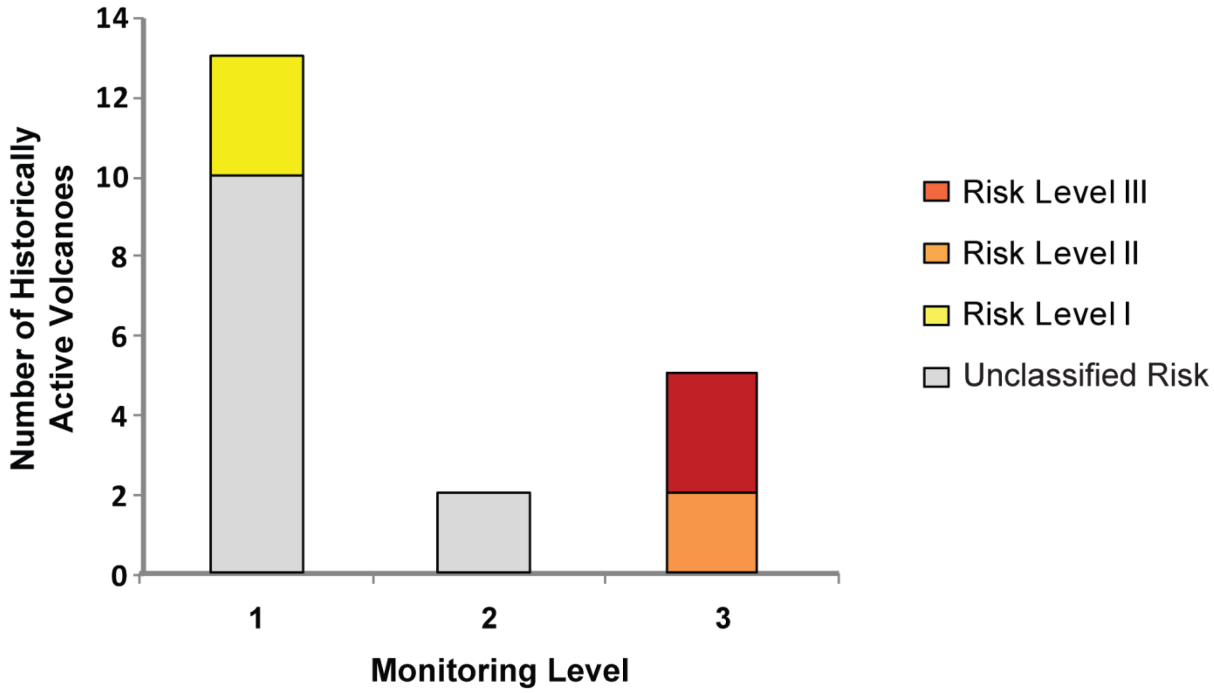


Figure 180: The monitoring and risk levels of the historically active volcanoes in the Philippines and SE Asia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Myanmar

Description

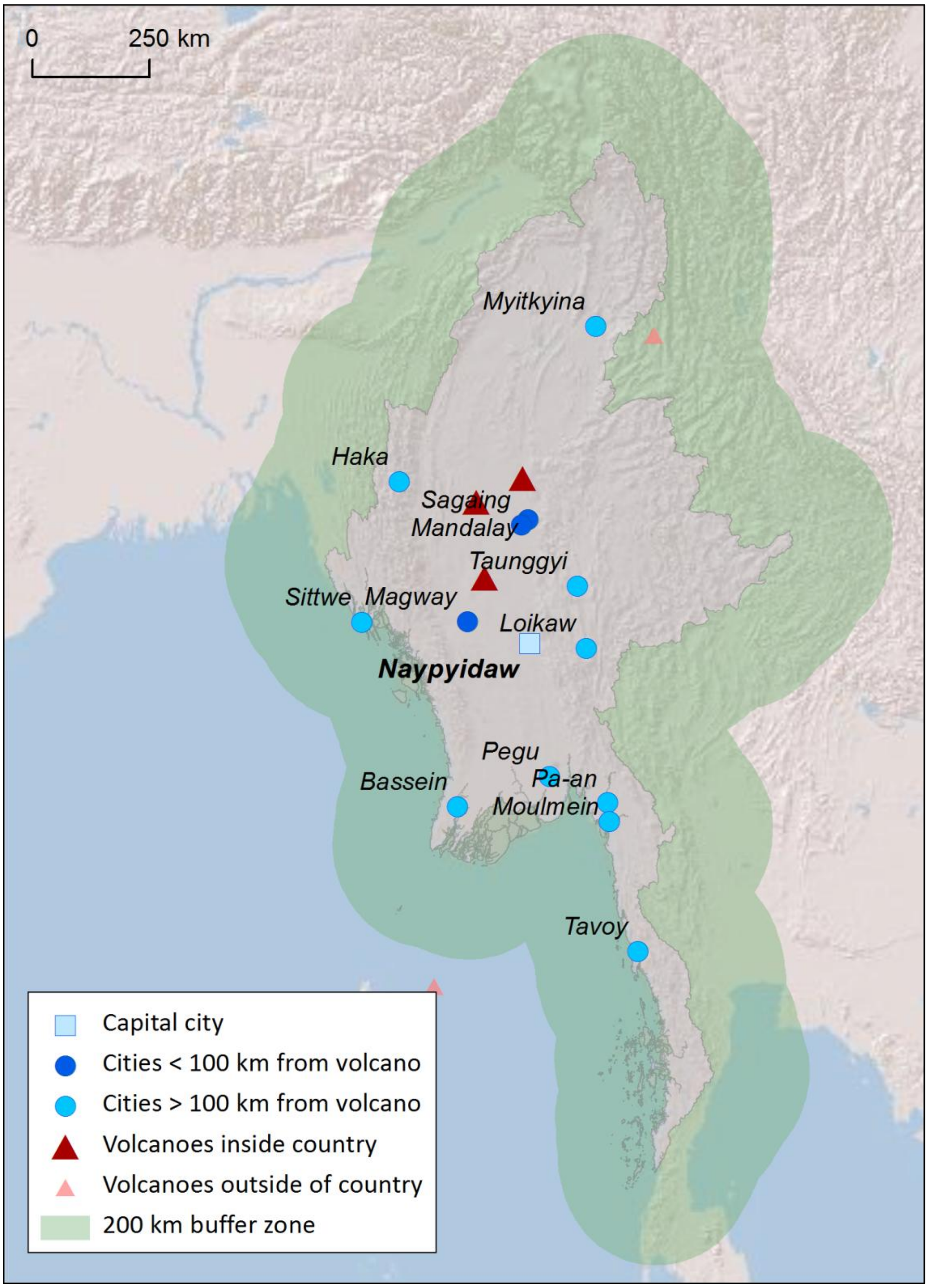


Figure 181: Location of Myanmar's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Myanmar.

Three Holocene volcanoes are located in central Myanmar. Of these, only Popa has a confirmed Holocene eruption. Lower Chindwin and Singu Plateau have suspected, but unconfirmed Holocene activity. These volcanoes are related to the subduction of the Indian plate under the Eurasian plate.

No volcanoes here have records of historical eruptions. The only recorded Holocene eruption occurred in 442 BC, and is of unknown VEI. The volcanoes here are basaltic to andesitic and comprise stratovolcanoes, small cones in a volcanic field and a fissure vent system. A range of activity could be expected from such features, from effusive to explosive, though the most recent activity appears to be largely effusive to Strombolian. The stratovolcano, Popa, has evidence of past flank collapse and debris avalanche, with a crater breached to the northwest.

The capital city, Naypyidaw, lies at about 160 km from Popa, however three of the largest cities in Myanmar lie within 100 km of the volcanoes and as such, all three volcanoes have large proximal populations of over 4 million within the individual 100 km radii. Nearly 23,000 people live within 10 km of Popa and a large proportion of this population live on the plain at the foot of the large channel from the crater. Hazardous flows of any kind originating at or around the summit vent here could be expected to be channelled through this topographic feature. The largest proximal population is found at Lower Chindwin volcanic field.

Tengchong volcano in southern China lies within 50 km of the border with Myanmar, and hence has the potential to affect the population and infrastructure here.

No regular ground-based monitoring is undertaken at the volcanoes in Myanmar.

The Asian Disaster Reduction Center (ADRC) produced a report on disaster risk reduction in Myanmar in 2013, in which they do not consider volcanic hazards. They describe how the Government of Myanmar established the National Disaster Preparedness Central Committees (NDPCC) and has Disaster Risk Management systems and plans on multiple levels including State, District and Local levels. Although volcanic hazards are not currently considered, it is likely these groups who would form the first response to activity. See the ADRC report for full details on DRR in Myanmar.

See also:

ADRC: Myanmar profile:
http://www.adrc.asia/nationinformation.php?NationCode=104&Lang=en&NationNum=17

Volcano Facts

Number of Holocene volcanoes	3
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-

Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Eruption was of unknown VEI.
Number of Holocene eruptions	1 confirmed eruption.
Recorded Holocene VEI range	Unknown
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Basaltic (1)
2	Small cone(s)	Andesitic (1), Basaltic (1)

Table 169: The number of volcanoes in Myanmar, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	52,865,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	
Gross National Income (GNI) per capita (2005 PPP $)	1,817
Human Development Index (HDI) (2012)	0.498 (Low)

Population Exposure

Capital city	Naypyidaw
Distance from capital city to nearest Holocene volcano	158.6 km
Total population (2011)	53,999,804
Number (percentage) of people living within 10 km of a Holocene volcano	124,041 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	1,583,171 (2.9%)
Number (percentage) of people living within 100 km of a Holocene volcano	12,950,553 (24%)

Ten largest cities, as measured by population, and populations:

Rangoon	4,477,638
Mandalay	1,208,099
Moulmein	438,861
Pegu	244,376
Bassein	237,089
Sittwe	177,743
Taunggyi	160,115
Tavoy	136,783
Magway	96,954
Myitkyina	90,894

Infrastructure Exposure

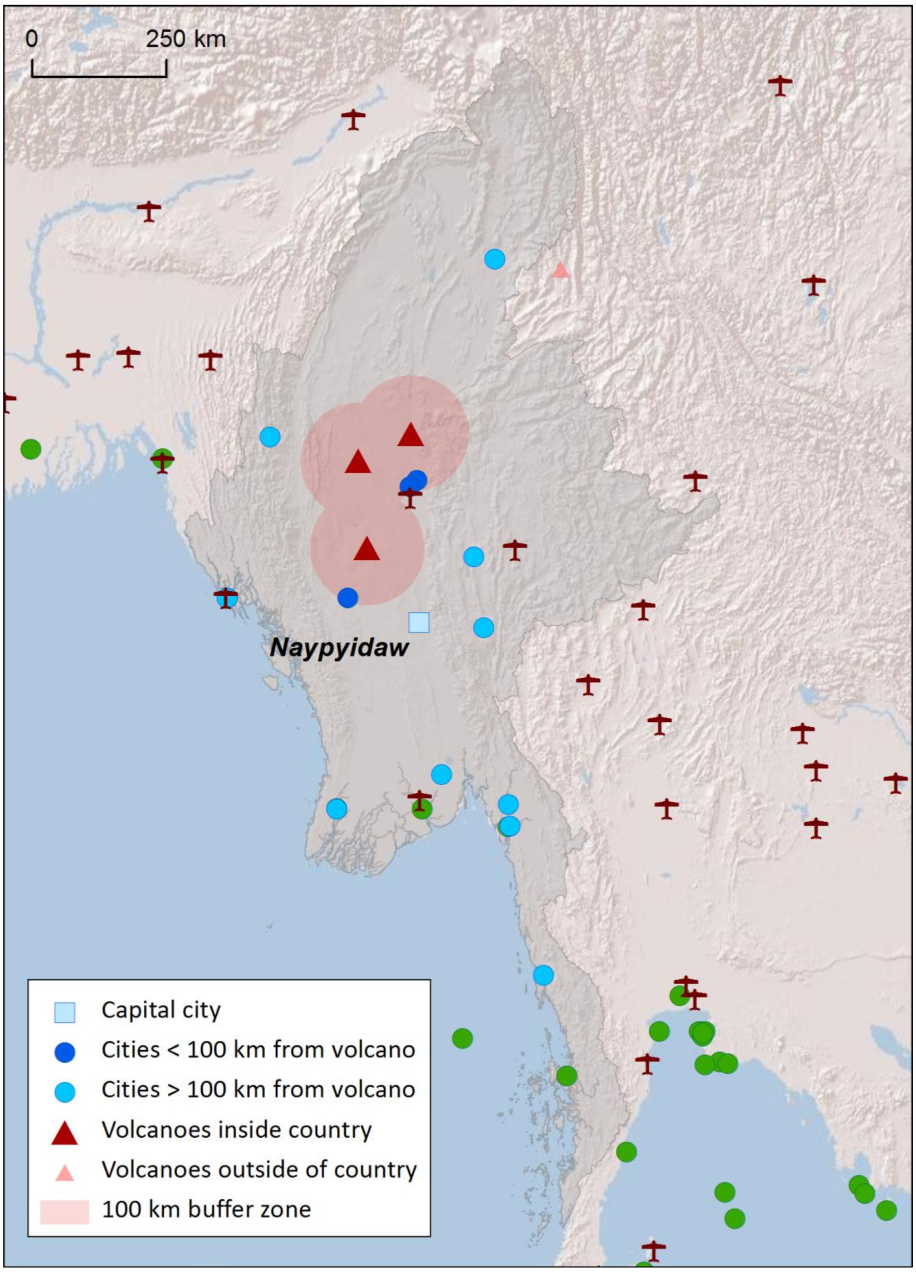


Figure 182: The location of Myanmar's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	2,905
Total length of railroads within 100 km of a volcano (km)	500

The volcanoes in Myanmar are situated in the centre of the country. Being inland volcanoes, no ports are located within 100 km. Whilst the capital, Naypyidaw, lies at nearly 160 km from Popa volcano, three of the largest cities in Myanmar lie within 100 km of the volcanoes placing significant infrastructure including an extensive road and rail network under threat.

Hazard, Uncertainty and Exposure Assessments

The eruptive record of the three volcanoes in Myanmar is insufficient for calculation of the hazard without large uncertainties. These volcanoes are therefore unclassified. Indeed, only Popa has a confirmed Holocene eruption record with just one eruption of unknown size in 442 BC.

At the Lower Chindwin volcano there is a high local population, represented by a PEI of 7. Although the hazard is unclassified here, the risk would classify at Risk Level III due to this population size. The risk level cannot be determined for Popa and Singu Plateau, although these also have high PEI levels of 5 and 6.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR					Popa		
	U- NHHR						Singu Plateau	Lower Chindwin
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 170: Identity of Myanmar's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Myanmar have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Myanmar.

Philippines

Description

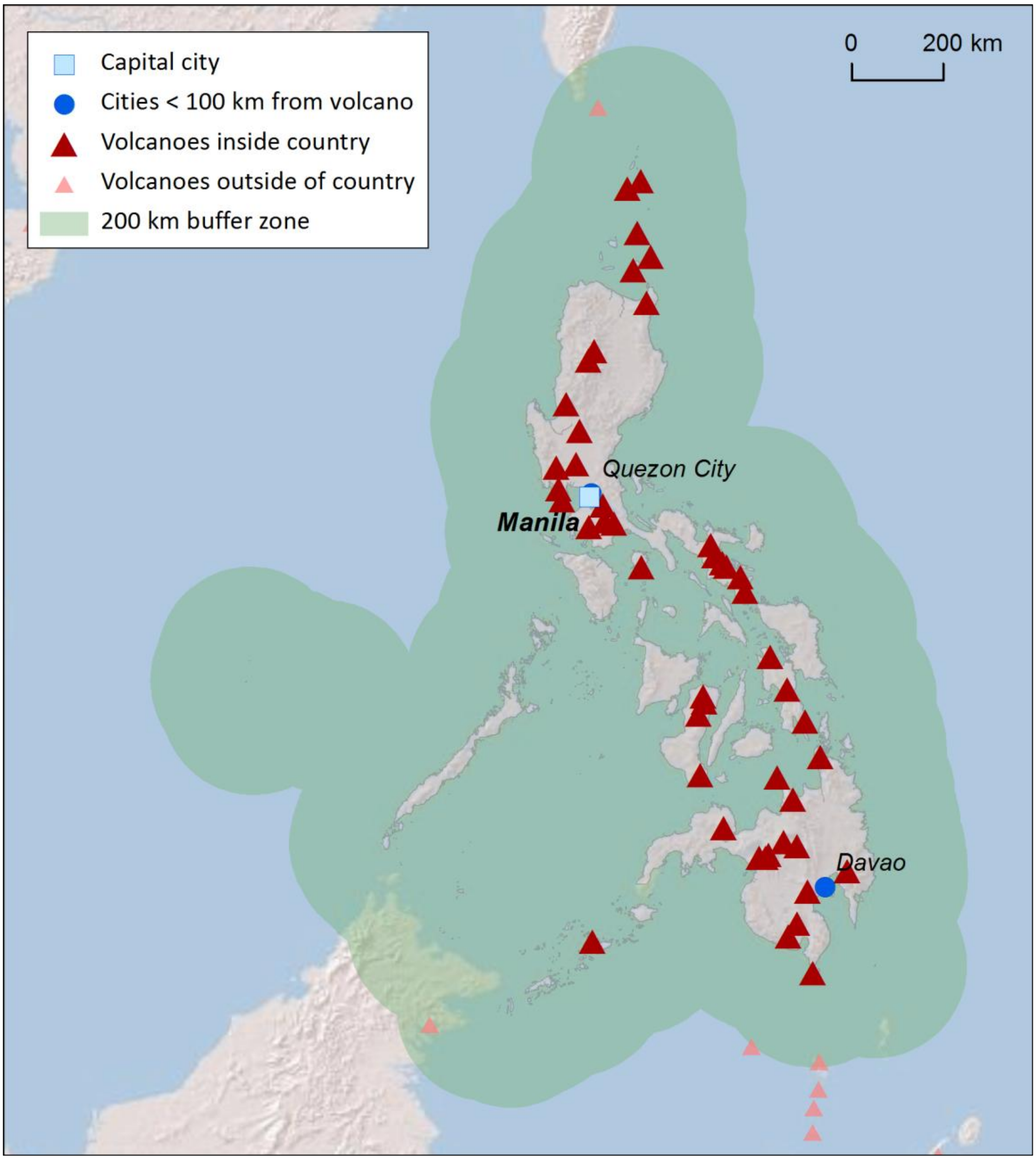


Figure 183: Location of the Philippines' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Philippines.

Forty-seven Holocene volcanoes are located throughout the Philippines. These volcanoes are located primarily across four of the largest Philippine islands and off the coast of Luzon in the north. Volcanism here is due to a complex interaction between multiple tectonic plates and micro-plates, with the Philippine and Eurasian Plates converging and undergoing subduction. There are two main volcanic arcs – the Luzon and Mindanao arcs, which roughly trend north-south.

The volcanoes in the Philippines are dominantly large cones, being principally stratovolcanoes and compound or complex volcanoes. Calderas and lava domes are also present. These volcano types along with the dominance of andesitic magmas illustrates that most of the volcanoes can be characterised by explosive activity. Indeed, the Holocene record includes 16 large explosive VEI ≥4 eruptions, including nine such historical eruptions. Five VEI 6 Holocene eruptions are recorded at Pinatubo and Taal, including the 1991 eruption of Pinatubo. The record of large explosive events in the Philippines continues into the Pleistocene with four recorded M≥4 eruptions, including the M7.1 eruption of Bulusan over 37,000 years ago. Such records of large explosive events indicate that similar sized eruptions could occur in the future.

175 historical eruptions are recorded in the Philippines from 18 volcanoes. Eight volcanoes have produced pyroclastic flows, and lahars have occurred at six. Heavy rainfall and typhoons frequently produces lahars and secondary lahars due to the remobilisation of tephra. This remobilisation can occur for years following eruptions. With a record of explosive eruptions, the historical record of the human impact of volcanism in the Philippines is quite extensive. 33 eruptions from Parker, Camiguin, Kanlaon, Bulusan, Mayon, Taal, Pinatubo, Didicas, Ragang and Ambalatungan Group resulted in fatalities between 1640 and 2013 AD. 18% of historical eruptions have resulted in fatalities. Multiple evacuations are recorded and property damage is recorded in 24% of historical eruptions.

The volcanoes in the Philippines can be expected to have considerable impacts on the population, as around 80% of the population live within 100 km of one or more Holocene volcanoes. The capital, Manila, and many other major cities lie within these radii and thus much of the critical infrastructure of the country is exposed to volcanic hazards. 37 volcanoes have a high local population, as demonstrated by the classification of these at PEI≥5. Taal and Mayon have some of the highest hazard scores in the country, both with an extensive historical record of moderate to large eruptions, and also have a very large population within 10 km.

Nearly 250,000 people live within 10 km of Mayon and pyroclastic flows and lahars are commonly produced in eruptions here, many of which have devastated areas at the base of the cone. 1,200 fatalities occurred during the 1814 VEI 4 eruption here.

The 1991 VEI 6 eruption of Pinatubo was one of the largest in the 20th century in the world. Though the damage caused by the eruption led to huge socio-economic impacts, the number of fatalities was low relative to the eruption size as a result of successful monitoring and evacuation. An estimated 800 lives were lost, though up to half of these are attributable to disease in evacuation camps. In general, the emergency response to the eruption was widely viewed as a major success with many tens of thousands of people having been evacuated in time.

Two Indonesian volcanoes and one volcano in Taiwan lie within 200 km of the Philippines, indicating that eruptions from these could impact on the Philippines.

The Philippine Institute of Volcanology and Seismology (PHIVOLCS) is the institute responsible for the country's volcanoes. PHIVOLCS continuously monitors about 40% of the historically active volcanoes, including five Risk Level III volcanoes. Multiple monitoring methods are utilised at these volcanoes. PHIVOLCS has responded to unrest at volcanoes in the past, increasing monitoring to better understand activity. PHIVOLCS assigns one of six alert levels for volcanic activity. 'No alert' is assigned to volcanoes in quiescence, and alert levels increase through '1. Abnormal', '2. Alarming', '3. Critical', '4. Eruption imminent' to '5. Eruption'. These levels are based on the level of unrest and trends in unrest. These alert levels are made available to the public as well as descriptors of activity and exclusion zones.

See also:

PHIVOLCS: http://www.phivolcs.dost.gov.ph/

Volcano Facts

Number of Holocene volcanoes	47
Number of Pleistocene volcanoes with M≥4 eruptions	4
Number of volcanoes generating pyroclastic flows	8
Number of volcanoes generating lahars	6
Number of volcanoes generating lava flows	6
Number of fatalities caused by volcanic eruptions	?>7,919
Tectonic setting	47 subduction zone
Largest recorded Pleistocene eruption	The M7.1 Irosin Ignimbrite eruption of Bulusan at 37.5 ka.
Largest recorded Holocene eruption	Three eruptions of Pinatubo are recorded at M6.1 – the Crow Valley eruptive period (5.5 ka), the Maraunot eruptive period (3 ka) and the 1991 AD eruption.
Number of Holocene eruptions	198 confirmed eruptions. 19 uncertain eruptions and 5 discredited eruptions.
Recorded Holocene VEI range	0 – 6 and unknown.
Number of historically active volcanoes	18
Number of historical eruptions	175

Number of volcanoes	Primary volcano type	Dominant rock type
2	Caldera(s)	Andesitic (2)
41	Large cone(s)	Andesitic (32), Basaltic (7), Dacitic (2)
2	Lava dome(s)	Andesitic (2)
1	Small cone(s)	Basaltic (1)
1	Submarine	Unknown (1)

Table 171: The number of volcanoes in the Philippines, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	96,899,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	3,631
Gross National Income (GNI) per capita (2005 PPP $)	3,752
Human Development Index (HDI) (2012)	0.654 (Medium)

Population Exposure

Capital city	Manila
Distance from capital city to nearest Holocene volcano	34.1 km
Total population (2011)	101,833,938
Number (percentage) of people living within 10 km of a Holocene volcano	2,708,394 (2.7%)
Number (percentage) of people living within 30 km of a Holocene volcano	30,511,866 (30%)
Number (percentage) of people living within 100 km of a Holocene volcano	80,918,982 (79.5%)

Largest cities, as measured by population, and populations:

Davao	1,212,504

Infrastructure Exposure

Number of airports within 100 km of a volcano	7
Number of ports within 100 km of a volcano	60
Total length of roads within 100 km of a volcano (km)	9,424
Total length of railroads within 100 km of a volcano (km)	768

The volcanoes of the Philippines are distributed throughout the country, across the many islands. With the number of volcanoes and the distribution of the islands, almost all of the Philippines are located within 100 km of a volcano. This places almost all critical infrastructure within the country under threat, including the capital, Manila, and other major cities. 60 ports and 7 airports are situated within 100 km of the volcanoes, as is an extensive road and rail network.

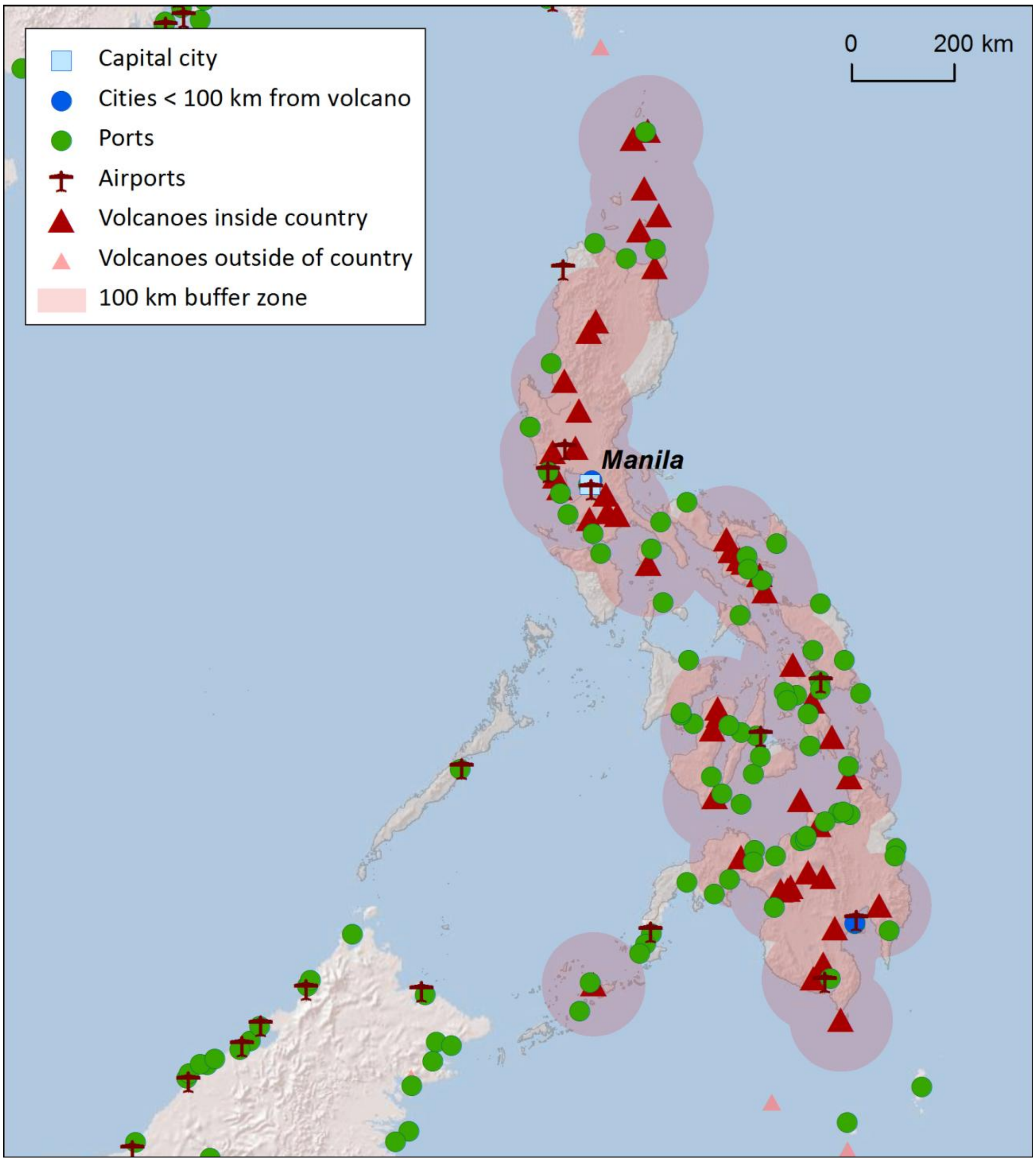


Figure 184: The location of the Philippines' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of data availability in the eruption records for the volcanoes of the Philippines. Less than 20% of volcanoes here have appropriate eruptive histories to define the hazard. These volcanoes are classified at Hazard Levels I, II and III, with just Camiguin, Mayon and Taal at Hazard Level III largely due to their history of explosive eruptions coupled with pyroclastic flow production.

Of the unclassified volcanoes, 24 have no confirmed Holocene eruptions. Though of these, Malindang and Ambalatungan Group have both shown unrest suspected to have been above background levels since 1900 AD. The remaining unclassified volcanoes have Holocene eruption records, including ten with historical eruptions. Biliran and Pinatubo both have erupted since 1900.

Pinatubo is unclassified, but has eight Holocene eruptions including five of VEI 5 and 6 indicating that this volcano is highly explosive and hazardous. Parker is also unclassified, though has a Holocene record of three eruptions of VEI 4 and 5.

PEI ranges from low to very high in the Philippines, with most volcanoes having high local populations - 35 volcanoes are classed at PEI ≥5. This tendency towards higher populations in combination with the Hazard Levels classes over 60% of the classified volcanoes of the Philippines at Risk Levels II and III. Taal and Mayon, two of the volcanoes classified with the highest Hazard in the Philippines, have very large populations within 10 km at >700,000 and nearly 250,000 respectively.

CLASSIFIED	**Hazard III**					Camiguin	Mayon	Taal
	Hazard II		Babuyan Claro			Bulusan		
	Hazard I		Didicas		Ragang	Kanlaon		
UNCLASSIFIED	**U – HHR**		Camiguin de Babuyanes; Unnamed	**Cagua**	Parker	Makaturing; Cabalían; **Biliran**; **Pinatubo**	Jolo; **Musuan**	
	U- HR			Iraya	Leonard Range	**Matutum**	Mariveles	San Pablo Volcanic Field
	U- NHHR			Balut; Mahagnao	Latukan; Balatukan; **Ambalatungan Group**	Apo; Kalatungan; **Malindang**; Paco; Cuernos de Negros; Mandalagan; Silay; Isarog; Malindig; Natib; Patoc	Pocdol Mountains; Masaraga; Iriga; Banahaw; Amorong; Santo Tomas	Laguna Caldera; Arayat
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 172: Identity of the Philippines' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Taal	7	III
Mayon	6	III
Camiguin	5	III
Bulusan	5	II
Kanlaon	5	II
Ragang	4	I
Babuyan Claro	2	I
Didicas	2	I

Table 173: Classified volcanoes of the Philippines ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 3 volcanoes; Risk Level II – 2 volcanoes; Risk Level III – 3 volcanoes.

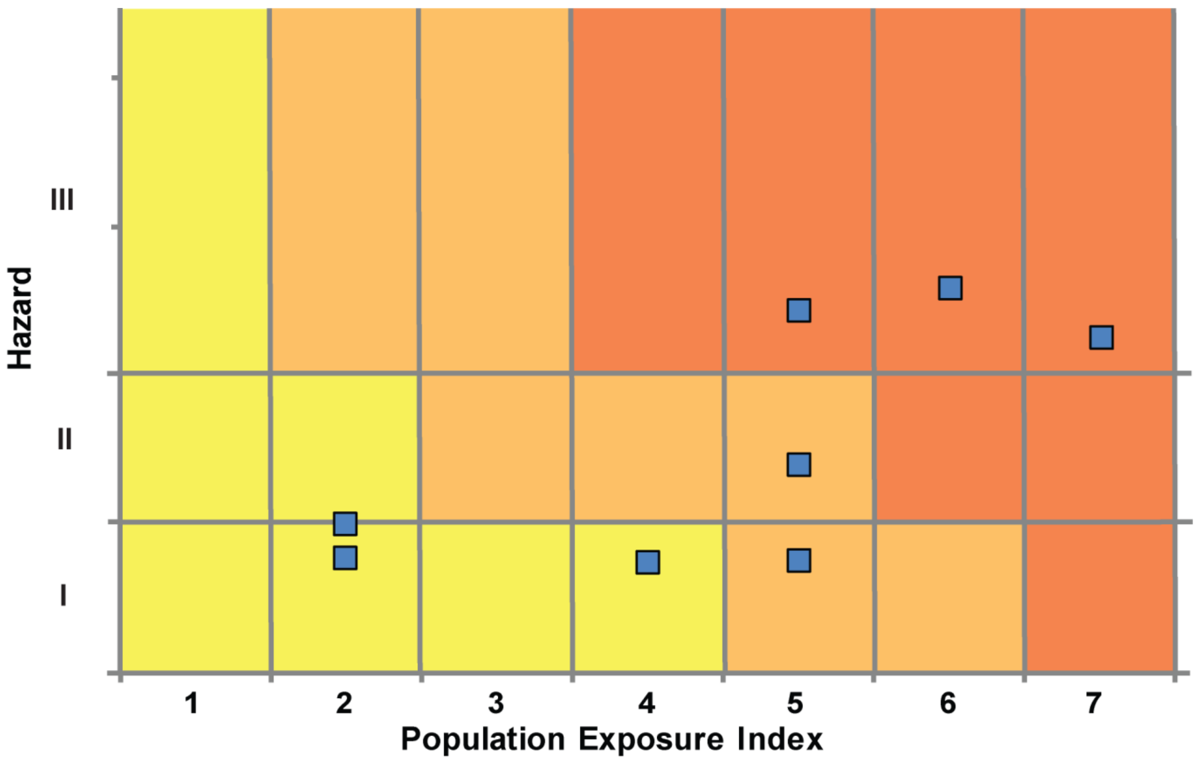


Figure 185: Distribution of the Philippines' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The Philippine Institute of Volcanology and Seismology (PHIVOLCS) is responsible for the volcanoes in the Philippines. 18 volcanoes have a historical eruption record. No information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at 11 of these volcanoes.

Seven volcanoes are continuously monitored. Parker and Pinatubo are classed at Monitoring Level 2, with seismic networks in place and additional gas monitoring at Pinatubo. Gen. Santos Seismic and Volcano Observatory and Pinatubo Volcano Observatory are responsible for monitoring these respectively. Multi-system monitoring, including seismic and deformation surveillance, is undertaken at Kanlaon, Camiguin, Bulusan, Mayon and Taal. Kanlaon Volcano Observatory, Quiboro Volcano Observatory, Bulusan Volcano Observatory, Lignon Hill Observatory and Taal Volcano Observatory conduct the monitoring. No Risk Level I volcanoes are of Monitoring Levels 2 and 3, suggesting prioritisation of resources.

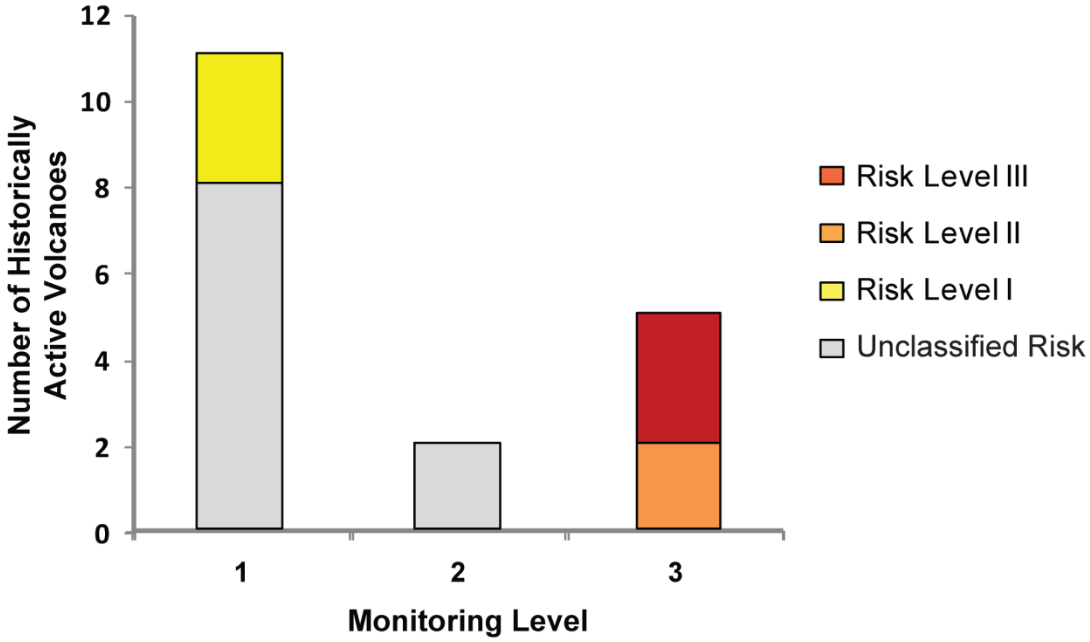


Figure 186: The monitoring and risk levels of the historically active volcanoes in the Philippines. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Vietnam

Description

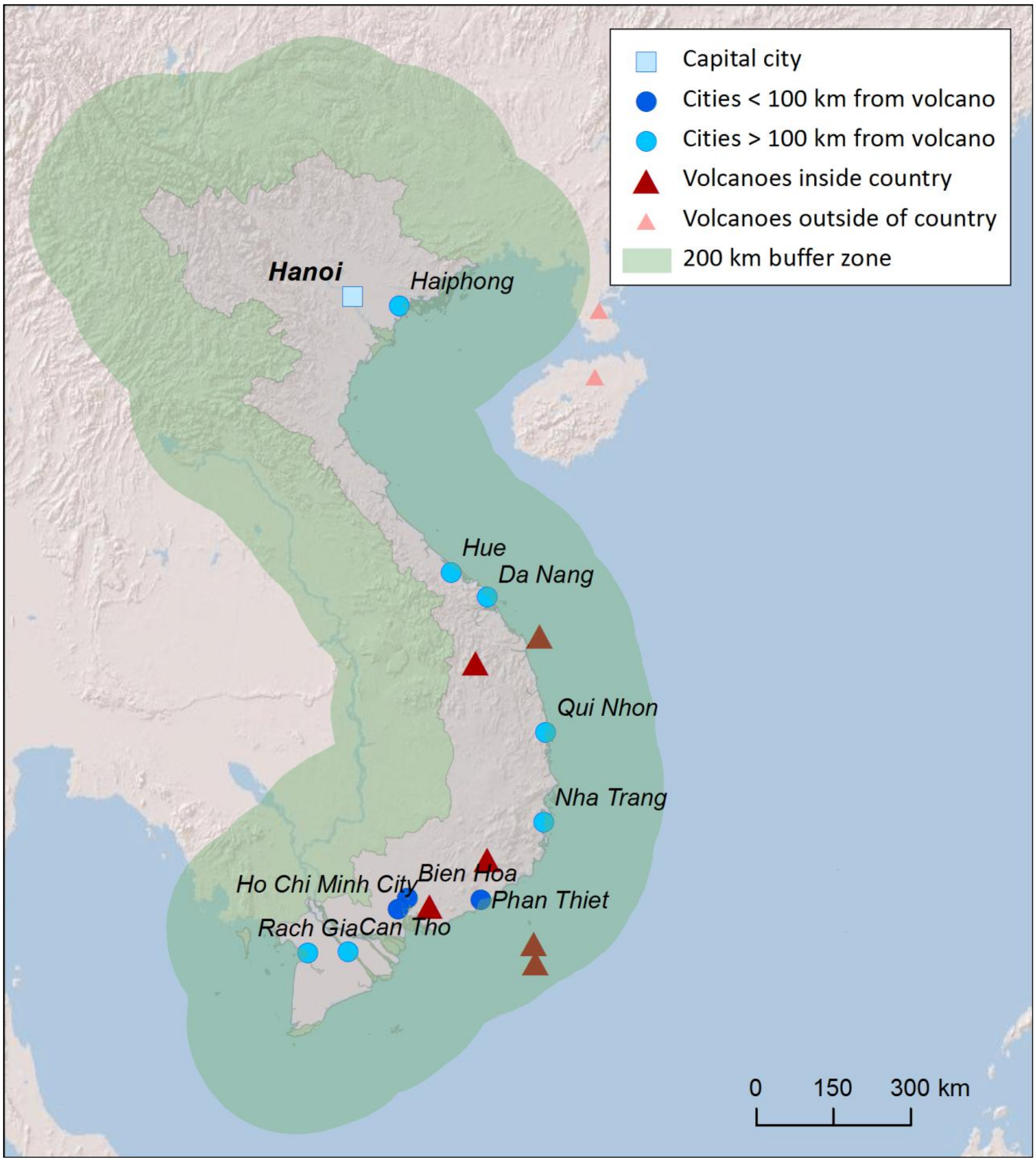


Figure 187: Location of Vietnam's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Vietnam.

Six Holocene volcanoes are distributed through the centre and south of Vietnam and within about 150 km of the coast. These volcanoes are located on the Sunda Plate, at the junction between the Eurasian and Philippine plates.

All volcanoes in Vietnam are dominantly basaltic, with the largest recorded eruption being a VEI 2. These volcanoes are dominantly effusive to moderately explosive forming cinder cones and volcanic fields.

Only one volcano in Vietnam has a record of historical activity. A confirmed VEI 2 eruption occurred at the submarine Ile des Cendres volcano in 1923, creating a new island. Two uncertain eruptions occurred at Veteran volcano in 1880 and 1928. Only the Ile des Cendres has a record of producing lava flows. No historic or Holocene records of explosive activity are present in Vietnam. Based on the volcano and rock types, effusive activity and the production of lavas can be expected to be the most frequent form of activity at these volcanoes, with potential for minor localised explosive activity.

No volcanoes lie within the 200 km buffer zone surrounding the country, though the capital of Vietnam, Hanoi, lies closer to Hainan Dao and Leizhou Bandao volcanoes in China than any Vietnamese volcano. Ho Chi Minh is the largest city in Vietnam, and Bas Dong Nai lies within 70 km of this city. This volcano thus has a very high local population. Most volcanoes here have a low to moderate PEI. Several of the largest cities in the south of Vietnam are located within 100 km of Haut Dong Nai and Bas Dong Nai and hence considerable infrastructure is exposed, and a very large population is located within 10 km of these volcanoes. The 100 km radius of Toroeng Prong extends beyond the Vietnam border and into Laos and Cambodia. No historical record of fatalities or property damage exists for eruptions in Vietnam.

No information is available at the time of the writing of this report to indicate that ground-based monitoring is undertaken at any of the volcanoes in Vietnam. The Institute of Geological Sciences and Geophysics at the Vietnam Academy of Science and Technology is responsible for undertaking research in geological hazards and for the prediction of geological hazards and mitigation of their effects. A network of seismometers is present through the country, with four broadband seismographs along the coast and two further inland in the north, which can be accessed through the Ocean Hemisphere Project Data Management Center at University of Tokyo.

See also:

Institute of Geological Sciences: http://www.vast.ac.vn/en/about-vast/organization-chart/institutes/institutes-established-by-the-government/1011-institute-of-geological-sciences

Volcano Facts

Number of Holocene volcanoes	6
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-

Largest recorded Holocene eruption	The VEI 2 eruption of the Ile des Cendres in 1923 AD.
Number of Holocene eruptions	1 confirmed eruption. 2 uncertain eruptions.
Recorded Holocene VEI range	2
Number of historically active volcanoes	1
Number of historical eruptions	1

Number of volcanoes	Primary volcano type	Dominant rock type
4	Small cone(s)	Basaltic (4)
2	Submarine	Basaltic (1), Unknown (1)

Table 174: The number of volcanoes in Vietnam, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	90,951,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	3,013
Gross National Income (GNI) per capita (2005 PPP $)	2,970
Human Development Index (HDI) (2012)	0.617 (Medium)

Population Exposure

Capital city	Hanoi
Distance from capital city to nearest Holocene volcano	448.4 km
Total population (2011)	90,549,390
Number (percentage) of people living within 10 km of a Holocene volcano	144,266 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	1,946,903 (2.2%)
Number (percentage) of people living within 100 km of a Holocene volcano	22,513,716 (24.9%)

Ten largest cities, as measured by population, and populations:

Ho Chi Minh City	3,467,331
Hanoi	1,431,270
Da Nang	752,493

Haiphong	602,695
Bien Hoa	407,208
Hue	287,217
Can Tho	259,598
Rach Gia	228,356
Phan Thiet	160,652
Long Xuyen	158,153

Infrastructure Exposure

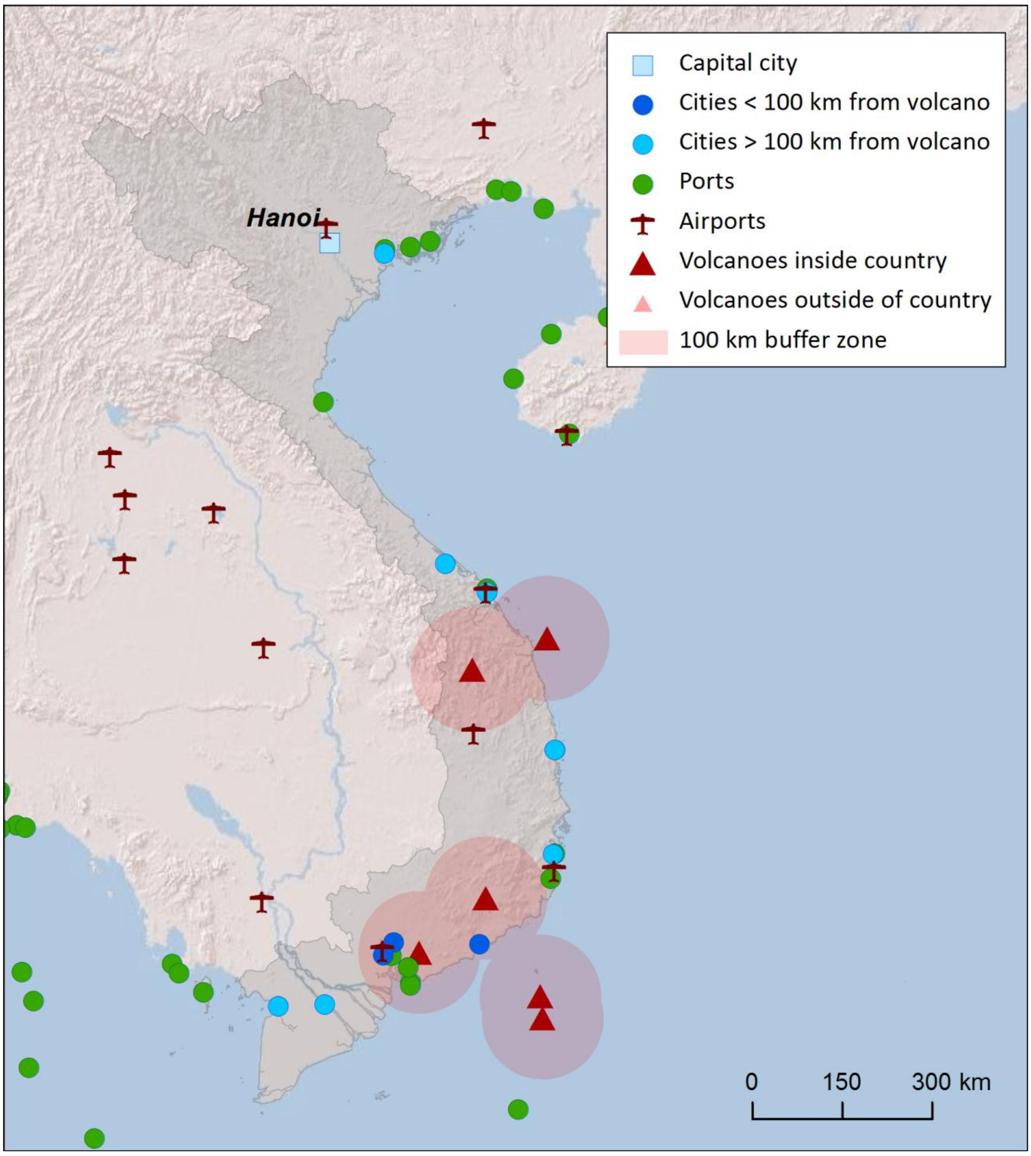


Figure 188: The location of Vietnam's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	6

Total length of roads within 100 km of a volcano (km) 2,271

Total length of railroads within 100 km of a volcano (km) 549

The Vietnamese volcanoes are situated in the south of the country and off the coast. Hanoi, the capital of Vietnam, is distal at over 400 km to the nearest volcano – Leizhou Bandao in China. Several of the largest cities in Vietnam are located within 100 km of Haut Dong Nai and Bas Dong Nai volcanoes, including Ho Chi Minh City, the largest city here. Significant infrastructure is located within 100 km of the volcanoes, including ports and airports, and an extensive road and rail network. The 100 km radius of Toroeng Prong extends beyond the Vietnam border and into Laos and Cambodia.

Hazard, Uncertainty and Exposure Assessments

The eruption record for Vietnam's volcanoes is too sparse to undertake calculation of the hazard without large associated uncertainties. Indeed, of the six volcanoes here, only Ile des Cendres has a confirmed Holocene record, with an eruption in 1923.

The PEI in Vietnam ranges from low to very high, with most volcanoes having a low to moderate PEI. Just one volcano, Bas Dong Nai located close to Ho Chi Minh, has a very high local population. Though the hazard level is unclassified here, the risk would be high due to this large population.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		**Ile des Cendres**					
	U- HR							
	U- NHHR		**Veteran**	Cù-Lao Ré Group; Toroeng Prong			Haut Dong Nai	Bas Dong Nai
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 175: Identity of Vietnam's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Only the submarine Ile des Cendres volcano has a record of historical activity. No information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at Ile des Cendres or any Holocene volcanoes in Vietnam. However, Vietnam has a network of broadband seismographs located along the coastline and in the north of the country.

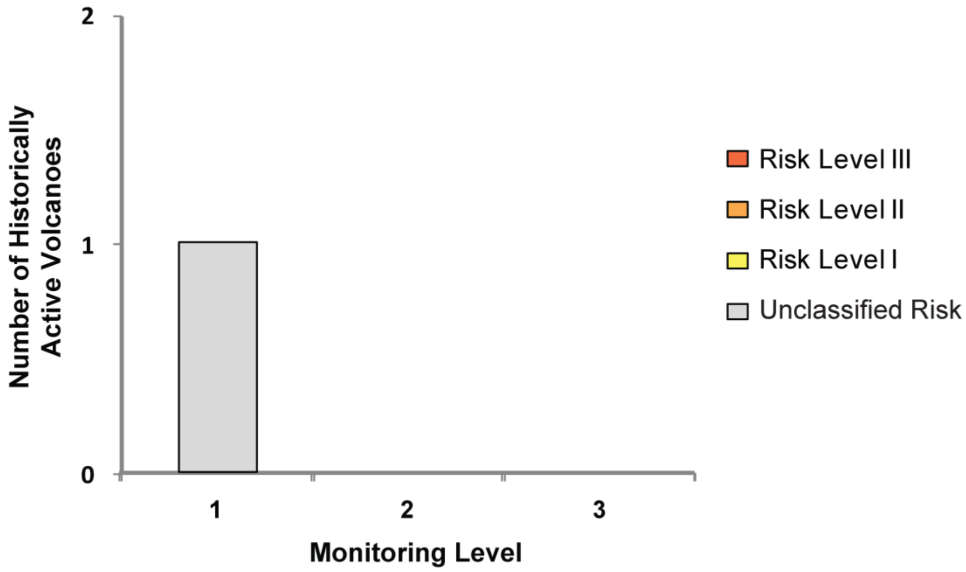


Figure 189: The monitoring and risk levels of the historically active volcanoes in Vietnam. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 8: Japan, Taiwan, Marianas

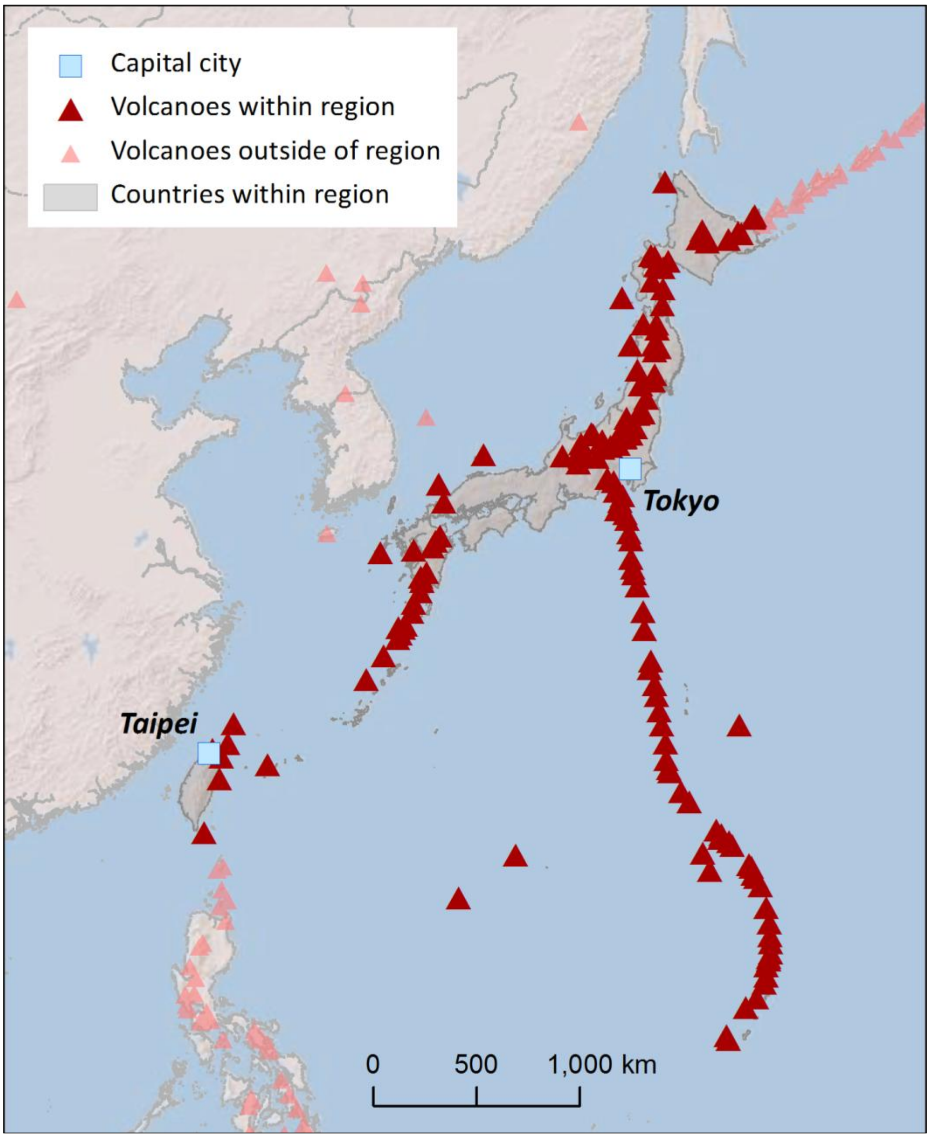


Figure 190: The distribution of Holocene volcanoes through the Melanesia and Australia region. The capital cities of the constituent countries are shown.

Description

Region 8: Japan, Taiwan and the Marianas comprises volcanoes through the main Japanese arc, the Izu Islands, Marianas Islands and the Ryuku Islands. Taiwan is considered here, separately to China. Three countries are represented here. All are included in this regional discussion and individual country profiles are provided.

Country	Number of volcanoes
Japan	114
Taiwan	8
USA – Marianas	21

Table 176: The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

143 volcanoes are located in Japan, Taiwan and the Marianas. Most of these volcanoes are in Japan. Although at the junction of a number of plates, volcanism in this region can broadly be described as related to the subduction of the Pacific Plate beneath the Eurasian Plate.

A large number (26) of submarine volcanoes are located in this region, along the Izu-Marianas arc. Subaerial volcanoes vary in form throughout the region, though most (64) are stratovolcanoes and complex volcanoes. The rock type through this region is dominantly andesitic, though ranges from basaltic to rhyolitic.

A range of activity styles and magnitudes are recorded through the Holocene, with eruptions of VEI 0 to 7. About 75% of eruptions here have been small, at VEI 0 to 2, however 117 eruptions (over 10%) have been large explosive VEI ≥4 events. These VEI ≥4 eruptions have largely been restricted to Japan, with just three in the Marianas Islands. The largest Holocene eruption in this region was the VEI 7 eruption of the Akahoya tephra from Kikai, in about 4350 BC. This eruption produced pyroclastic flows that travelled 100 km across the sea and produced widespread ash fall, devastating southern and central Kyushu.

Seventy-seven volcanoes have historical records of 874 eruptions, 97% of which were dated through direct observations. The large number of geological age (pre-1500 AD) eruptions reflects a relatively detailed Holocene record achieved through significant tephrochronological studies. 6% of historical events have produced pyroclastic flows and 8% have resulted in lahars. A further 8% have produced lava flows.

About 9% of historical eruptions (77) have resulted in loss of life. Most volcanoes have a small proximal population, largely reflecting the number of submarine volcanoes. About a quarter of volcanoes have a high local population. The Risk Levels reflect the varying population size and assigned hazard scores. Eleven volcanoes here are classed at Risk Level III (24% of classified volcanoes), reflecting large population sizes and frequent and/or large explosive eruptions. All Risk Level III volcanoes are in Japan.

Monitoring and research groups are active in Japan, Taiwan and the Marianas Islands, with monitoring focussed on the volcanoes of higher risk.

Volcano facts

Number of Holocene volcanoes	143
Number of Pleistocene volcanoes with M≥4 eruptions	91

Number of volcanoes generating pyroclastic flows	52 (160 eruptions)
Number of volcanoes generating lahars	39 (98 eruptions)
Number of volcanoes generating lava flows	47 (188 eruptions)
Number of eruptions with fatalities	85
Number of fatalities attributed to eruptions	22,770
Largest recorded Pleistocene eruption	The largest recorded Quaternary explosive eruption occurred at 87 ka with the eruption of Unit 4 from Aso in Japan.
Largest recorded Holocene eruption	The M8.1 Akahoya tephra eruption of Kikai in 7330 BP is the largest recorded Holocene eruption in LaMEVE in this region. Even at M7.2 which the volume indicates, this would still be the largest eruption in the region.
Number of Holocene eruptions	1,481 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 7 and unknown
Number of historically active volcanoes	77
Number of historical eruptions	874

Number of volcanoes	Primary volcano type	Dominant rock type
12	Caldera(s)	Andesitic (8), Dacitic (2), Rhyolitic (2)
64	Large cone(s)	Andesitic (48), Basaltic (15), Dacitic (1)
8	Lava dome(s)	Andesitic (5), Dacitic (1), Rhyolitic (2)
8	Shield(s)	Andesitic (5), Basaltic (2), Dacitic (1)
4	Small cone(s)	Andesitic (1), Basaltic (2)
26	Submarine	Andesitic (8), Basaltic (5), Dacitic (3), Rhyolitic (2), Unknown (8)

Table 177: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	40

Table 178: Average recurrence interval (years between eruptions) for small and large eruptions in Japan, Taiwan and the Marianas.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 40 years.

Eruption Size

Eruptions are recorded through the Japan, Taiwan and Marianas region of VEI 0 to 7, representing a range of eruption styles from gentle effusive events to very large explosive eruptions. VEI 2 events dominate the record, with about 50% of all Holocene eruptions classed as such. Just over 10% of eruptions here are explosive at VEI≥4.

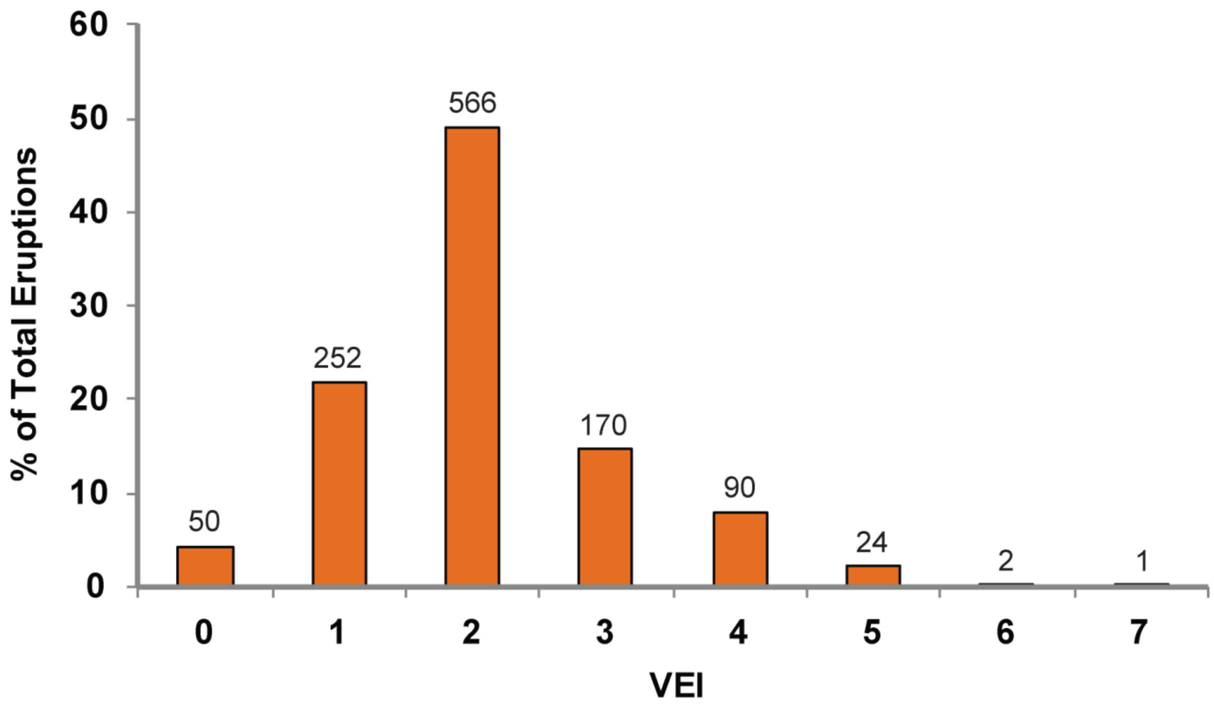


Figure 191: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 326 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	150,587,372
Gross Domestic Product (GDP) per capita (2005 PPP $)	30,660 (Japan)
Gross National Income (GNI) per capita (2005 PPP $)	32,545 (Japan)

Human Development Index (HDI) (2012)	0.912 (Very High, Japan)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	1,234,976 (0.82 %)
Number (percentage) of people living within 30 km of a Holocene volcano	17,144,484 (11.39 %)
Number (percentage) of people living within 100 km of a Holocene volcano	72,295,057 (48.01 %)

Infrastructure Exposure

Number of airports within 100 km of a volcano	35
Number of ports within 100 km of a volcano	107
Total length of roads within 100 km of a volcano (km)	44,523
Total length of railroads within 100 km of a volcano (km)	7,645

CLASSIFIED	**Hazard III**	Pagan; Anatahan	Aogashima	Tokachidake; Rausudake	Hakusan; Niigata-Yakeyama; Towada; Hachijojima; Mashu	Fujisan; Hokkaido-Komagatake; Toya (Usu)	Aira; Unzendake; Shikotsu	
	Hazard II		Suwanosejima; Kuchinoerabujima; Kikai		Kirishimayama; Yakedake; Kurikomayama; Chokaisan; Akita-Komagatake; Akita-Yakeyama; Iwakisan	Ibusuki Volcanic Field; Asamayama; Kusatsu-Shiranesan; Bandaisan; Zaozan		
	Hazard I	Farallon de Pajaros	Io-Torishima; Myojinsho; Izu-Torishima; Ioto; Fukutoku-Oka-no-Ba; Shiretoko-Iozan	Miyakejima; Akan	Nikko-Shiranesan; Nasudake; Azumayama; Hakkodasan	Asosan; Izu-Oshima		
UNCLASSIFIED	**U – HHR**	**Sumisujima**; **Nishinoshima**; **Kaitoku Seamount; Minami-Hiyoshi; Fukujin; Kasuga; Ahyi; Supply Reef; Asuncion; Agrigan**; Guguan; **South Sarigan Seamount**	**Submarine Volcano NNE of Iriomotejima**; Yokoate-jima; **Nakanoshima**; **Kita-Ioto; Kita-Fukutokutai; Oshima-Oshima; Ruby; NW Rota-1**	**Esan**; Taisetsuzan; Maruyama; Unnamed (281030)	**Ontakesan**; **Midagahara**; Hiuchigatake	**Kujusan**; **Adatarayama**; **Iwatesan**; **Osorezan**; Kuttara; Kueishantao	**Izu-Tobu**	
	U- HR	Alamagan	Kuchinoshima; Mikurajima	Megata; **Niijima**; **Kozushima**; Rishirizan	Abu; Sanbesan; Norikuradake; Numazawa; Hachimantai; Toshima; Niseko; Yoteizan; Kussharo	Fukue; Yokodake; Myokosan; Nantai; Omanago Group; Takaharayama; Naruko	Yonemaru-Sumiyoshiike; Yufu-Tsurumi; **Hakoneyama;** Harunasan	Tatun Group
	U-NHHR	**Sofugan; Suiyo Seamount; Mokuyo Seamount; Sarigan; Doyo Seamount; Kaikata Seamount;** Unnamed; **Nikko**; Minami Kasuga; NW Eifuku; Daikoku; Tenchozan; Unnamed (281010); Unnamed (281011); Zengyu; Unnamed (284138); Unnamed (284139); Maug Islands; **Zealandia Bank**	Akuseki-jima; Kogaja-jima; Kurose Hole; Kita-Bayonnaise; Unnamed (281020); East Diamante; **Esmeralda Bank**; Forecast Seamount; Seamount X	Shikaribetsu Group	Oki-Dogo; Washiba-Kumonotaira; Unnamed (281040)	Shiga; Akagisan; Hijiori		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 179: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
1	7
8	6
26	5
31	4
13	3
29	2
35	1

Table 180: The number of volcanoes in Japan, Taiwan and the Marianas classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
11	III
17	II
18	I
97	Unclassified

Table 181: The number of volcanoes in the Japan, Taiwan and Marianas region classified at each Risk Level.

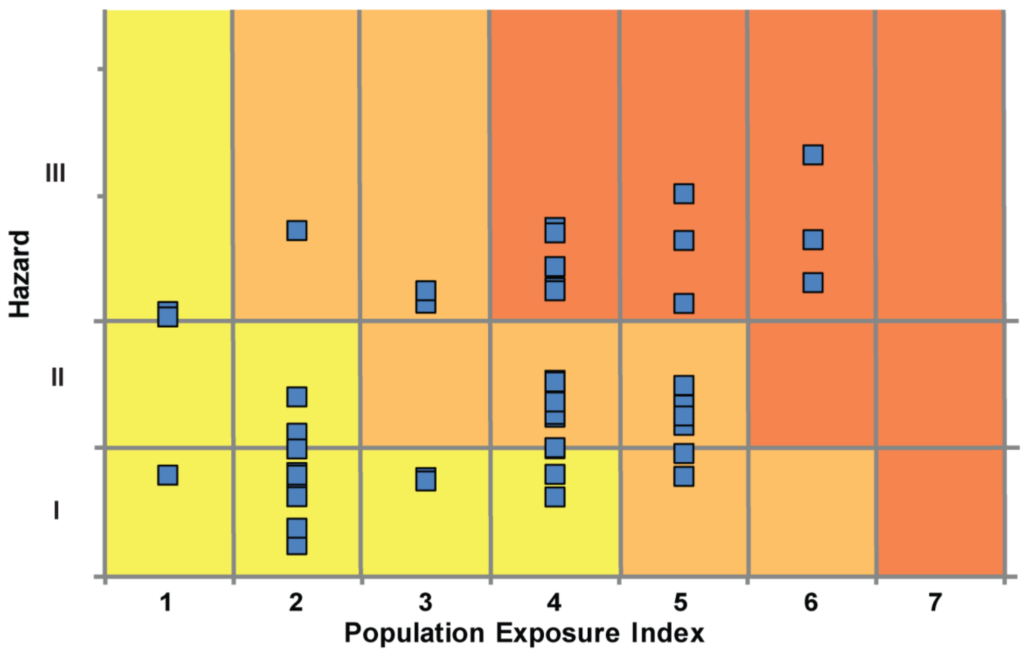


Figure 192: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

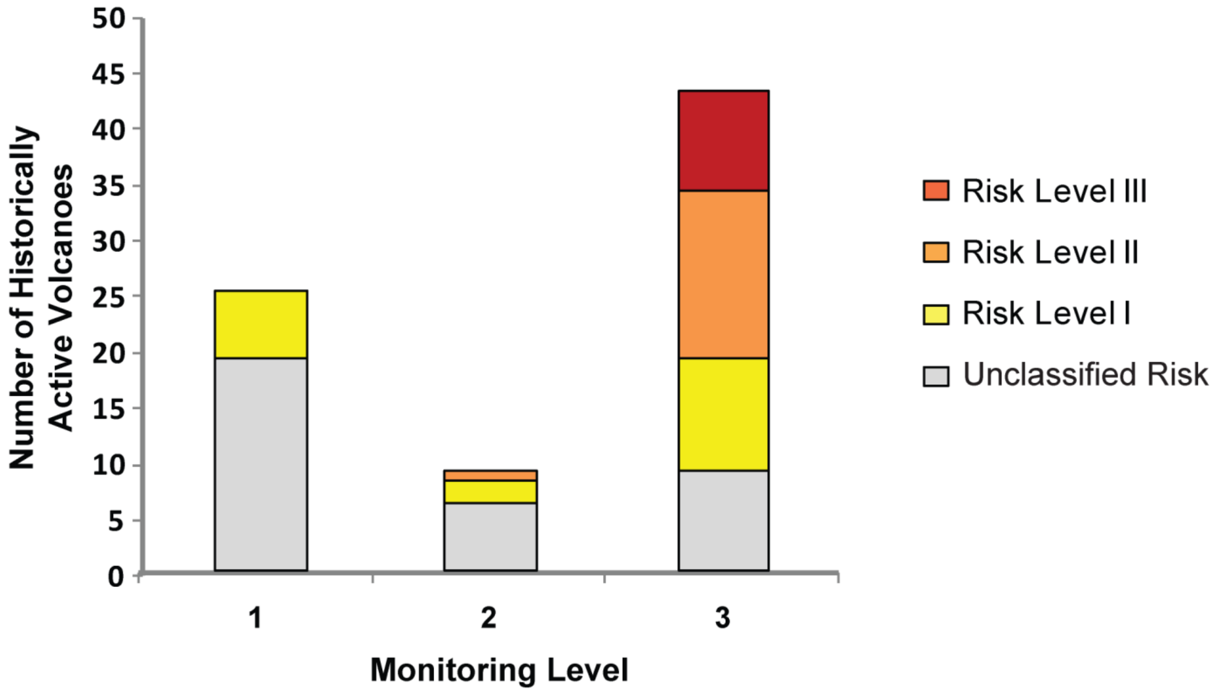


Figure 193: The monitoring and risk levels of the historically active volcanoes in Taiwan. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Japan

Description

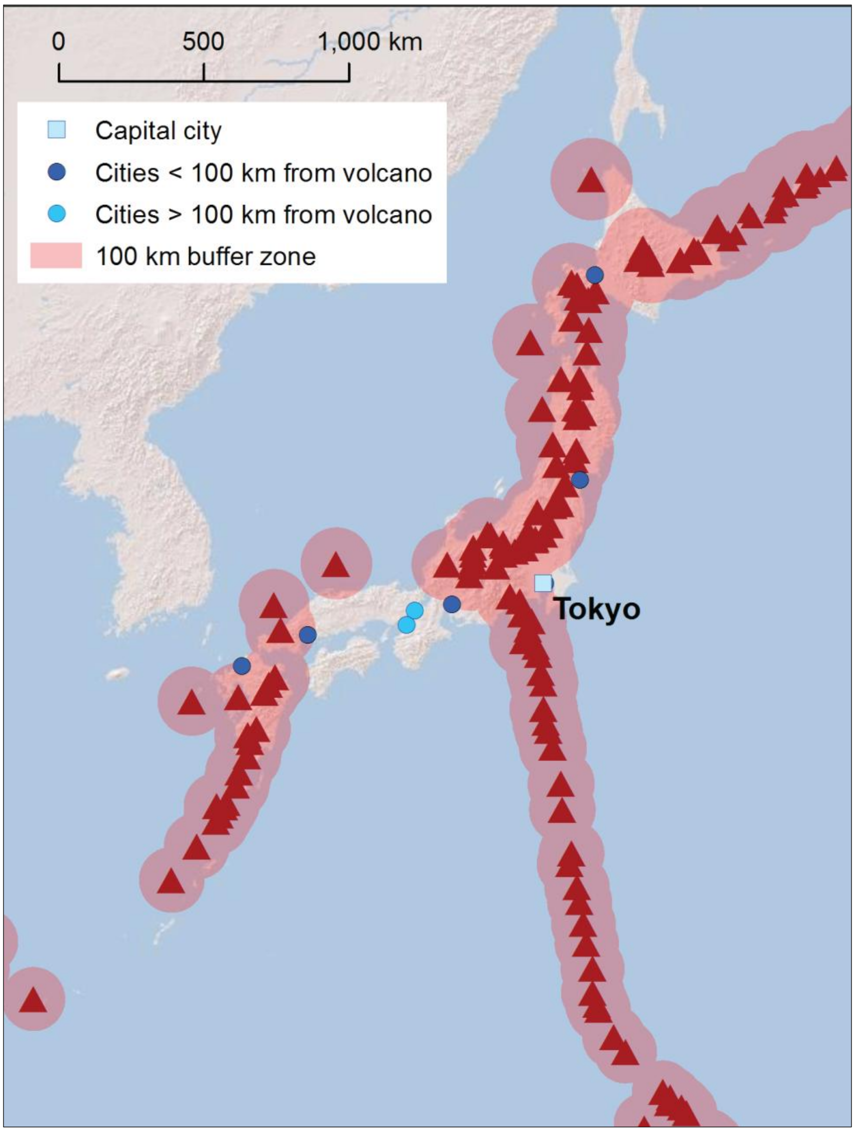


Figure 194: Distribution of volcanoes. The capital and largest cities in Japan are shown.

130 Holocene volcanoes are listed in Volcanoes of the World 4.0 as located throughout the islands of Japan. The subduction of the Pacific Plate beneath the Eurasian and Philippine Plates has given rise to extensive volcanism, with a range of volcano types. Subaerial volcanism is dominated by andesitic stratovolcanoes, complexes and calderas, and extensive submarine volcanism occurs throughout the Izu-Ogasawara and Ryuku Islands.

The current listing of volcanoes in VOTW4.0 differs from that of the Geological Survey of Japan and Japan Meteorological Agency (JMA), who consider 110 volcanoes to have had Holocene activity. The most recent activity at the remaining volcanoes is considered to have been Pleistocene in age. Some discrepancies are present in the classification and naming of the volcanoes between the two datasets. Here, for consistency and reproducibility we continue to use the VOTW4.0 dataset.

Japan has an extensive Pleistocene record of large explosive eruptions, with 91 volcanoes recorded in LaMEVE with eruptions of VEI/M≥4. The largest recorded Pleistocene eruption was the M8.4 Aso 4 eruption of about 90,000 years ago, which produced extensive air fall and pyroclastic flows which covered much of Kyushu.

102 volcanoes have records of Holocene activity in VOTW4.0, with the remaining volcanoes having activity of suspected though unconfirmed Holocene age. 1,455 Holocene eruptions are recorded here, from VEI 0 to 7. This size range demonstrates the range in activity in Japan, from small events to very large explosive eruptions. About 8% of eruptions here are recorded at VEI ≥4. About 11% of eruptions have records of producing pyroclastic flows. However, most commonly, small eruptions of VEI 0 – 2 are recorded. The largest Holocene eruption occurred about 7,000 years ago with the eruption of the Akahoya tephra from Kikai caldera, located south of Kyushu. This eruption produced pyroclastic flows which travelled 100 km across the sea to Kyushu.

Of the Holocene record, about 60% of the eruptions have been recorded post-1500 AD, with 846 historic eruptions of VEI 0 to 5 from 72 volcanoes. A smaller percentage of these eruptions are VEI ≥4, with about 3% being classed as such. This reflects both the longer recurrence intervals for eruptions of this size and the preservation of large deposits preferentially to small. Five VEI 5 eruptions have occurred historically, including one at Fuji in 1707, which deposited ash in nearby Tokyo.

In total, throughout Japan about 50% of the population live within 100 km of one or more Holocene volcano. The size of the local population varies at each volcano, with about equal numbers of volcanoes having small, moderate and high PEI values. The hazards are also variable. Fatalities are recorded in about 9% of historical eruptions, although none have been recorded since the 1990s.

The Japan Meteorological Agency (JMA) is the primary volcano monitoring institute in Japan. The JMA has worked with local governments to consider volcano disaster prevention measures and has implemented alert levels. The Coordinating Committee for Prediction of Volcanic Eruption (CCPVE) selected 47 volcanoes which required improvements to the monitoring and observation systems and is undertaking these improvements. Continuous monitoring is now in place at all 47 volcanoes using dedicated seismic and deformation networks, in addition to other techniques. Individual observatories of Usu Volcano Observatory, Shimabara Volcano Observatory, Asama Volcano Observatory, Kirishima Volcano Observatory, Aso Volcano Observatory, Sakurajima Volcano Observatory and Izu-Oshima Volcano Observatory have been set up by Universities. Multiple research and monitoring institutions work on the volcanoes of Japan, including the JMA, Volcanological Society of Japan, Universities (Tohoku University, Hokkaido University, Earthquake Research Institute in University of Tokyo, Kyoto University, Kyushu University etc), National Organisations (National Research Institute for Earth Science and Disaster Prevention, Japan Coast Guard, Geological Survey of Japan, etc) and other local institutes.

Monitoring data from each volcano is sent to the Volcanic Observations and Information Center in the JMA, where Volcanic Warnings are issued. Warnings are given for residential areas, non-residential areas near the crater and around the crater. These warnings include descriptions of the observed monitoring data and activity. Warnings are provided to the Japan Coast Guard, the Ministry of Land, Infrastructure, Transport and Tourism, the media, emergency services, the NTT

(Nippon Telegraph and Telephone Corporation), prefectural offices and the public. Volcanic Alert Levels of 1 to 5 are given with clear descriptions of appropriate action to take. These Levels and the warnings given depend on the level of activity and the area affected. The regional VAAC is also notified when appropriate.

See also:

Japan Meteorological Agency Volcanic Warnings:
http://www.data.jma.go.jp/svd/vois/data/tokyo/STOCK/kaisetsu/English/level.html

National Research Institute for Earth Science and Disaster Prevention: http://www.bosai.go.jp/e/

National Catalogue of the Active Volcanoes in Japan, 4th Edition (JMA):
http://www.data.jma.go.jp/svd/vois/data/tokyo/STOCK/souran_eng/menu.htm

GSJ Quaternary volcano database: https://gbank.gsj.jp/volcano/Quat_Vol/volcano_list.html

Volcano Facts

Number of Holocene volcanoes	130
Number of Pleistocene volcanoes with M≥4 eruptions	95
Number of volcanoes generating pyroclastic flows	51
Number of volcanoes generating lahars	39
Number of volcanoes generating lava flows	42
Number of fatalities caused by volcanic eruptions	?>22,770
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M8.4 eruption 4 of Aso, which occurred about 90,000 years ago.
Largest recorded Holocene eruption	The eruption of the Akahoya tephra from Kikai volcano at 7330 BP is recorded as M8.1. The volume of this event indicates that the magnitude should be recalculated at M7.2, however this still would be classed as the largest eruption in Japan in the Holocene.
Number of Holocene eruptions	1,455 confirmed eruptions.
Recorded Holocene VEI range	0 -7 and unknown.
Number of historically active volcanoes	72

Number of historical eruptions	846

Number of volcanoes	Primary volcano type	Dominant rock type
13	Caldera(s)	Andesitic (9), Dacitic (2), Rhyolitic (2)
77	Large cone(s)	Andesitic (57), Basaltic (17), Dacitic (1), Unknown (2)
7	Lava dome(s)	Andesitic (4), Dacitic (1), Rhyolitic (2)
8	Shield(s)	Andesitic (5), Basaltic (2), Dacitic (1)
4	Small cone(s)	Andesitic (1), Basaltic (2)
21	Submarine	Andesitic (8), Basaltic (5), Dacitic (3), Rhyolitic (2), Unknown (3)

Table 182: The number of volcanoes in Japan, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	127,157,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	30,660
Gross National Income (GNI) per capita (2005 PPP $)	32,545
Human Development Index (HDI) (2012)	0.912 (Very High)

Population Exposure

Capital city	Tokyo
Distance from capital city to nearest Holocene volcano	83.3 km
Total population (2011)	127,469,543
Number (percentage) of people living within 10 km of a Holocene volcano	622,818 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	9,381,463 (7.4%)
Number (percentage) of people living within 100 km of a Holocene volcano	61,363,766 (48.1%)

Ten largest cities, as measured by population, and populations (2010, from UNdata data.un.org):

Tokyo	8,945,695
Yokohama	3,688,773
Osaka	2,665,314

Nagoya	2,263,894
Sapporo	1,913,545
Kobe	1,544,200
Kyoto	1,474,015
Fukuoka	1,463,743
Kawasaki	1,425,512
Saitama	1,222,434

Infrastructure Exposure

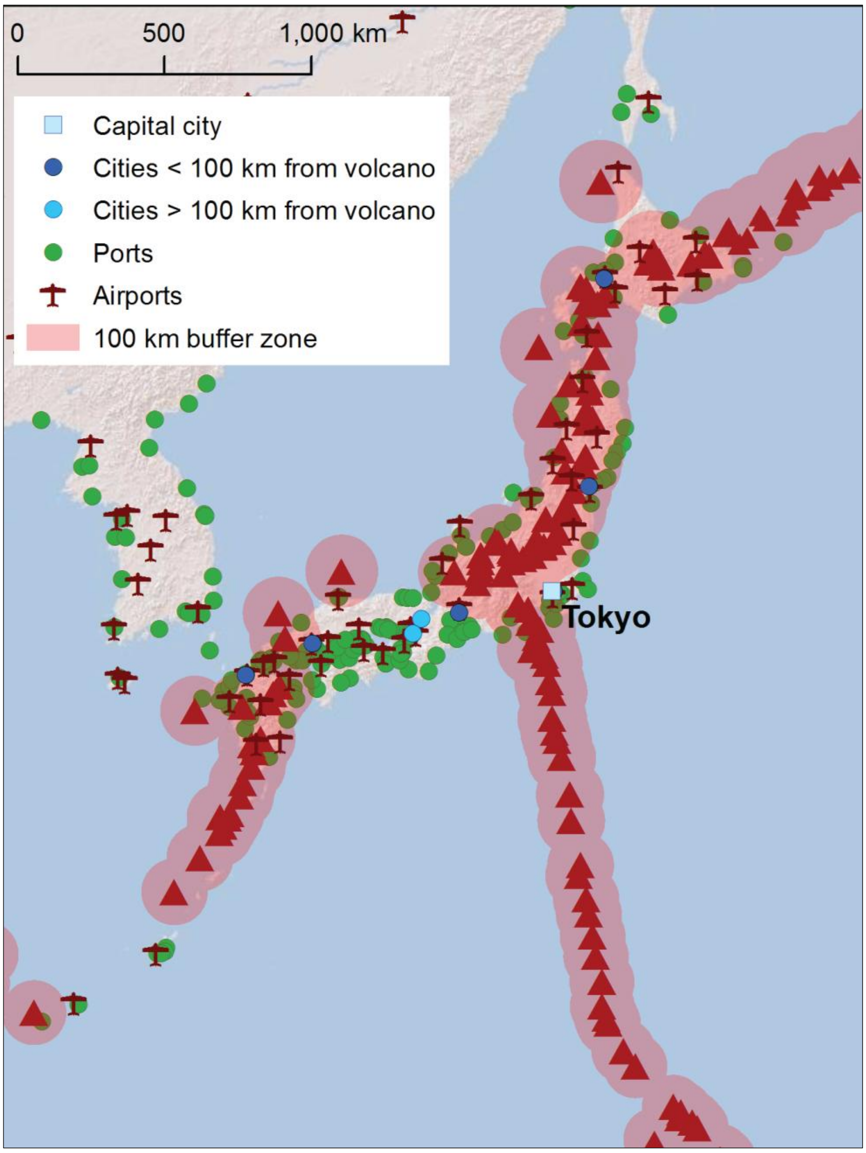


Figure 195: The location of the volcanoes in Japan and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Number of airports within 100 km of a volcano	30
Number of ports within 100 km of a volcano	99

Total length of roads within 100 km of a volcano (km)	41,982
Total length of railroads within 100 km of a volcano (km)	7,097

Holocene volcanoes are distributed throughout Japan, placing large parts of the country within 100 km of these volcanoes. Many of the largest cities in Japan, including the capital, Tokyo, lie within 100 km of one or more volcanoes. This means that most of the critical infrastructure is exposed, including nearly 100 ports, 30 airports including international airports, and a very extensive road and rail network linking the islands.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of data available in the eruption records of Japan's volcanoes. About 40% of the volcanoes here have enough data in their records to permit the calculation of the hazard, and these volcanoes are classified across all three hazard levels, with approximately equal numbers of volcanoes in each level.

Over 60% of the volcanoes have large uncertainties associated with the classification of the Hazard level due to incomplete or sparse eruption records, and these are therefore unclassified. Indeed, about a third of the unclassified volcanoes have no records of confirmed eruptions during the Holocene, though of these, six have had episodes of apparent unrest since 1900 AD suggestive of active systems. A further third of the unclassified volcanoes have Holocene records of eruptions before 1500 AD, and the remaining third have had historical activity, including 15 volcanoes with eruptions since 1900 AD. Twelve of the unclassified volcanoes have Holocene records of large magnitude, VEI ≥4 eruptions.

The PEI ranges from low to high, with approximately equal numbers of low PEI, moderate PEI and high PEI volcanoes. Some of the volcanoes with the highest hazard also have the highest PEI. The classified volcanoes categorise in all three risk levels, with 11 classed at Risk Level III. Sakurajima (Aira), with the highest Hazard level in Japan also has a very high local population, with over 110,000 living within 10 km, making this a Risk Level III volcano.

*Table 183 (next page): Identity of Japan's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

CLASSIFIED	**Hazard III**		Aogashima	Tokachidake; Rausudake	Hakusan; Niigata-Yakeyama; Towada; Hachijojima; Mashu	Fujisan; Hokkaido-Komagatake; Toya (Usu)	Aira; Unzendake; Shikotsu	
	Hazard II		Suwanosejima; Kuchinoerabujima; Kikai; Chachadake [Tiatia]; Etorofu-Yakeyama [Grozny Group]		Kirishimayama; Yakedake; Kurikomayama; Chokaisan; Akita-Komagatake; Akita-Yakeyama; Iwakisan	Ibusuki Volcanic Field; Asamayama; Kusatsu-Shiranesan; Bandaisan; Zaozan		
	Hazard I		Io-Torishima; Myojinsho; Izu-Torishima; Ioto; Fukutoku-Oka-no-Ba; Shiretoko-Iozan; Moyorodake [Medvezhia]	Miyakejima; Akan	Nikko-Shiranesan; Nasudake; Azumayama; Hakkodasan	Asosan; Izu-Oshima		
UNCLASSIFIED	**U – HHR**	**Sumisujima**; **Nishinoshima**; **Kaitoku Seamount; Minami-Hiyoshi**; **Fukujin**; **Kasuga**	**Submarine Volcano NNE of Iriomotejima**; Yokoate-jima; **Nakanoshima**; **Kita-Ioto**; **Kita-Fukutokutai; Oshima-Oshima;** Tomariyama [Golovnin]; **Raususan [Mendeleev];** Etorofu-Atosanupuri [Atosanupuri]; Sashiusudake [Baransky]; Chirippusan [Chirip]	**Esan**; Taisetsuzan; Maruyama	**Ontakesan**; **Midagahara**; Hiuchigatake	**Kujusan**; **Adatarayama**; **Iwatesan**; **Osorezan**; Kuttara	**Izu-Tobu**	
	U- HR		Kuchinoshima; Mikurajima; Moekeshiwan [Lvinaya Past]	Megata; **Niijima**; **Kozushima**; Rishirizan	Abu; Sanbesan; Norikuradake; Numazawa; Hachimantai; Toshima; Niseko; Yoteizan; Kussharo	Fukue; Yokodake; Myokosan; Nantai; Omanago Group; Takaharayama; Naruko	Yonemaru-Sumiyoshiike; Yufu-Tsurumi; **Hakoneyama;** Harunasan	
	U- NHHR	**Sofugan; Suiyo Seamount; Mokuyo Seamount; Doyo Seamount; Kaikata Seamount;** Unnamed; **Nikko**; Minami Kasuga; NW Eifuku; Daikoku; Tenchozan; Odamoisan [Tebenkov]	Akuseki-jima; Kogaja-jima; Kurose Hole; Kita-Bayonnaise; Ruruidake [Smirnov]; Unnamed (290061); Berutarubesan [Berutarube]; Rucharuyama [Golets-Tornyi Group]; Nishihitokappuyama [Bogatyr Ridge]; Rakkibetsudake [Demon]	Shikaribetsu Group	Oki-Dogo; Washiba-Kumonotaira	Shiga; Akagisan; Hijiori		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Volcano	Population Exposure Index	Risk Level
Aira	6	III
Unzendake	6	III
Shikotsu	6	III
Fujisan	5	III
Hokkaido-Komagatake	5	III
Toya	5	III
Ibusuki Volcanic Field	5	II
Asosan	5	II
Asamayama	5	II
Kusatsu-Shiranesan	5	II
Bandaisan	5	II
Zaozan	5	II
Izu-Oshima	5	II
Hakusan	4	III
Niigata-Yakeyama	4	III
Towada	4	III
Hachijojima	4	III
Mashu	4	III
Kirishimayama	4	II
Yakedake	4	II
Kurikomayama	4	II
Chokaisan	4	II
Akita-Komagatake	4	II
Akita-Yakeyama	4	II
Iwakisan	4	II
Nikko-Shiranesan	4	I
Nasudake	4	I
Azumayama	4	I
Hakkodasan	4	I
Tokachidake	3	II
Rausudake	3	II
Miyakejima	3	I
Akan	3	I
Aogashima	2	II
Chachadake [Tiatia]	2	I
Etorofu-Yakeyama [Grozny Group]	2	I
Fukutoku-Oka-no-Ba	2	I
Io-Torishima	2	I
Ioto	2	I
Izu-Torishima	2	I
Kuchinoerabujima	2	I
Kikai	2	I
Moyorodake [Medvezhia]	2	I
Myojinsho	2	I
Shiretoko-Iozan	2	I
Suwanosejima	2	I

Table 184: Classified volcanoes ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 15 volcanoes; Risk Level II – 17 volcanoes; Risk Level III – 11 volcanoes.

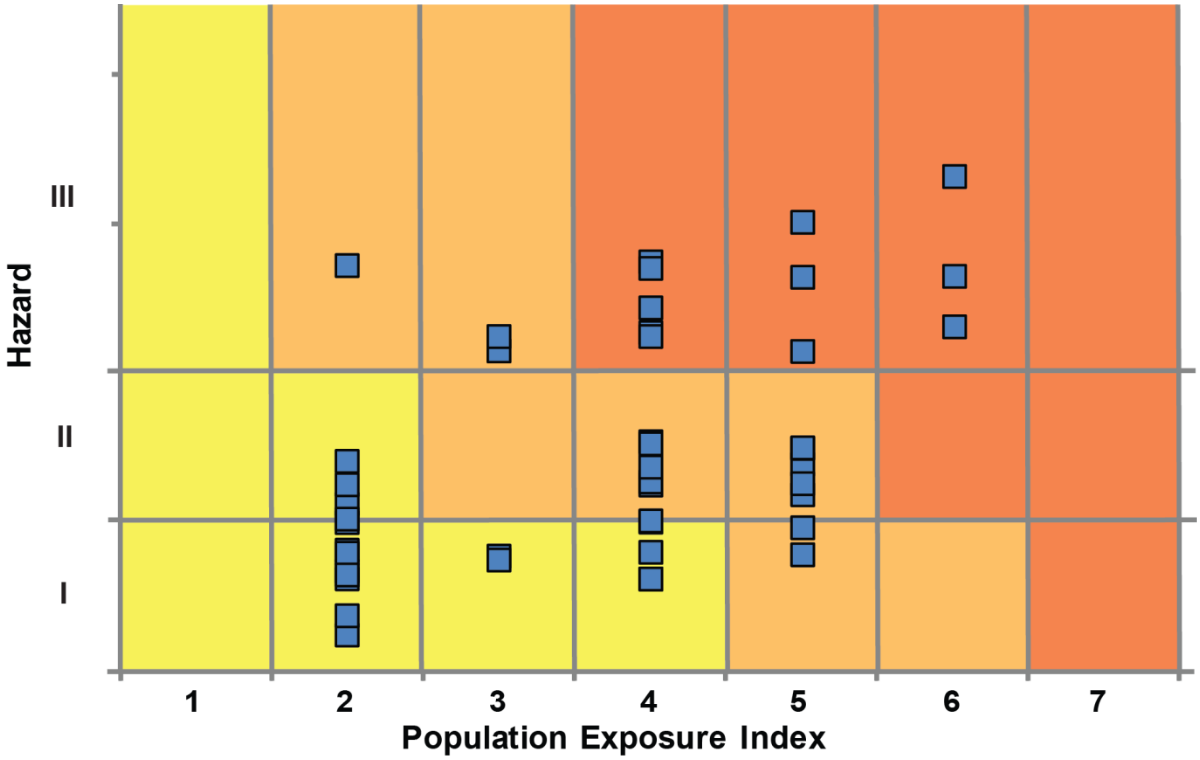


Figure 196: Distribution of volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Seventy-two volcanoes have historical records of activity. These volcanoes range across the risk spectrum, with most classed as Risk Level II. Several research and monitoring institutions are active in Japan, though the JMA is the principal monitoring body. The level of monitoring varies volcano to volcano, however there is an overall trend in increased monitoring at the higher risk volcanoes. Forty-one of these volcanoes are continuously monitored by the JMA using dedicated seismic and deformation networks. A further seven volcanoes have monitoring networks located within 20 km or networks with discontinuous monitoring. JMA also continuously monitor a number of volcanoes which have a Holocene record of activity prior to 1500 AD.

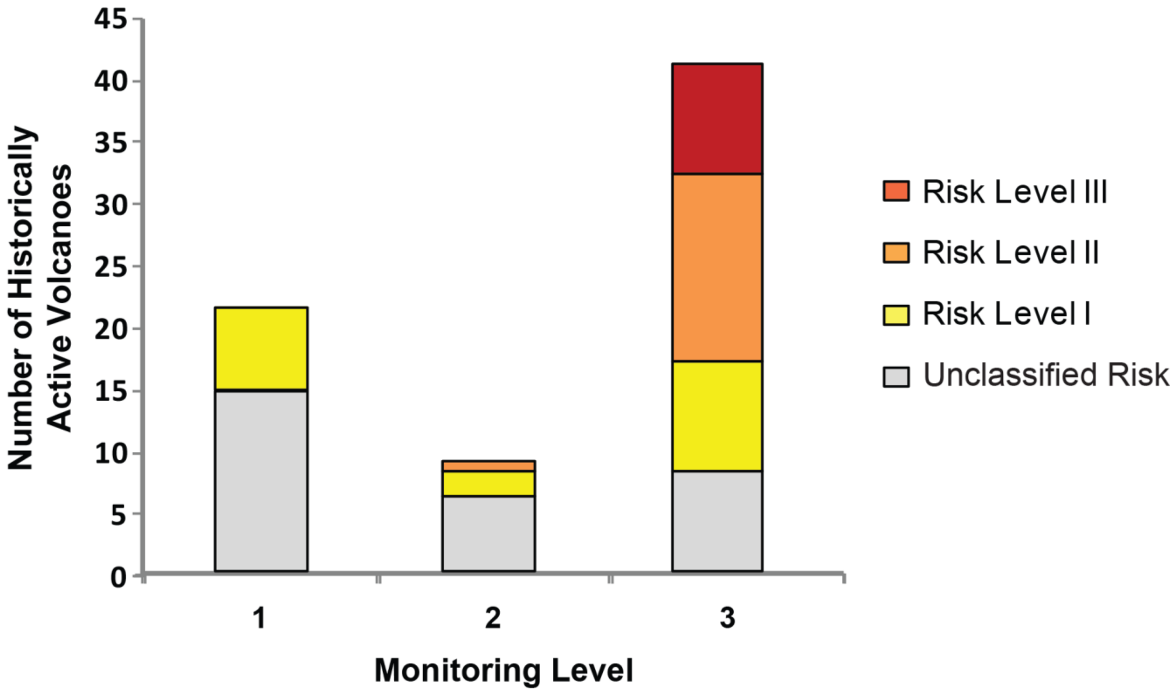


Figure 1971: The monitoring and risk levels of the historically active volcanoes in Japan. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

N.B. The volcanoes on the Kunashir and Iturup Islands are also discussed in the separate Region 9: Kuril Islands profile.

Taiwan

Description

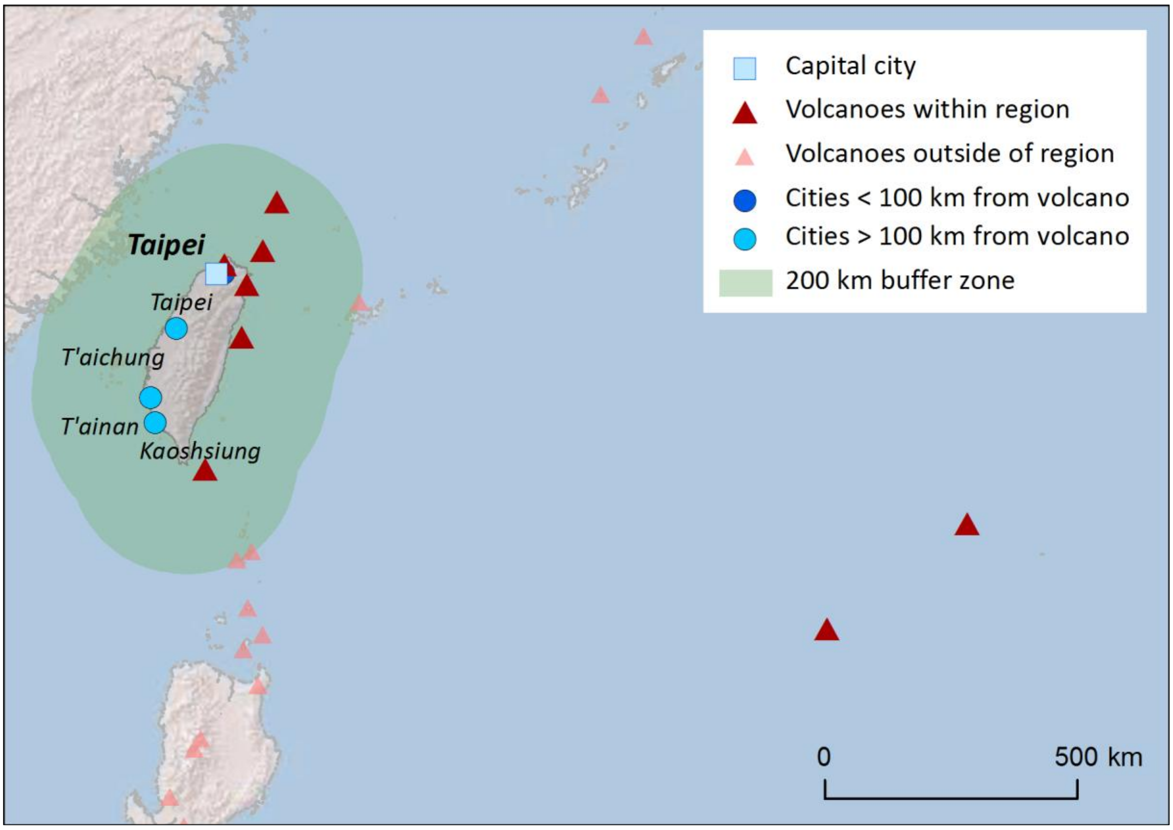


Figure 198: Location of Taiwan's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Taiwan.

Eight Holocene volcanoes are located in Taiwan: the Tatun Group volcano on mainland Taiwan; Kueishantao and another three volcanoes near the north-east coast; and one volcano off the south-east coast. Volcanism here is due to the subduction of the Philippine Plate under the Eurasian Plate.

The Tatun Group is a complex of dominantly andesitic lava domes. Kueishantao is also dominantly andesitic, and is the only stratovolcano in Taiwan. The other six Holocene volcanoes are submarine of unknown composition.

Of the eight Holocene volcanoes, only three have confirmed Holocene records of eruptions, the remaining are suspected of having Holocene age activity. Tatun Group has a dated VEI 1 eruption of 4100 BC, whilst Kueishantao and an unnamed submarine volcano have historical records of eruptions in 1785 and 1853 respectively. The largest recorded eruption was the VEI 2 eruption in 1853.

Although most of Taiwan's volcanoes are located offshore, a considerable percentage of the population resides in areas proximal to Taiwan's Holocene volcanoes. This is due to the location of the Tatun Group, situated within 10 km of the capital, Taipei.

The sparse Holocene eruption record in Taiwan means that assessment of hazard here is associated with large uncertainties, and focussed research is required to more fully understand the eruptive histories, particularly of the subaerial features. Indeed, in response to this need the Taiwan Volcano Observatory (TVO) was founded and became operational in October 2011. The TVO has primary responsibility for the Tatun Group volcano, where the observatory is situated, and Kueishantao. Monitoring is undertaken at both these volcanoes, with an extensive multi-system network of dedicated instrumentation and research at Tatun Group.

The TVO is supported by the Ministry of Science and Technology and is funded by the Taiwan government. At present risk assessments are being developed and the TVO participate in managing and mitigating the risks.

See also:

Taiwan Volcano Observatory – Tatun,
http://tec.earth.sinica.edu.tw/TVO/free.php?link=sciedu/knowvol

Volcano Facts

Number of Holocene volcanoes	6 with 2 unconfirmed
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone (6), Rift zone (1)
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The VEI 2 eruption of an unnamed volcano in 1853.
Number of Holocene eruptions	3 confirmed eruptions. 5 uncertain eruptions, 1 discredited.
Recorded Holocene VEI range	0 – 2
Number of historically active volcanoes	2
Number of historical eruptions	2

Number of volcanoes	**Primary volcano type**	**Dominant rock type**

1	Large cone(s)	Andesitic (1)
1	Lava dome(s)	Andesitic (1)
6	Submarine	Unknown (6)

Table 185: The number of volcanoes in Taiwan, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2014) (National Statistics, Republic of China[i])	23,379,594
Gross Domestic Product (GDP) per capita (2013, CIA[ii])	39,600
Gross National Income (GNI) per capita (2005 PPP $)	
Human Development Index (HDI) (2011[iii])	0.882

Population Exposure

Capital city	Taipei
Distance from capital city to nearest Holocene volcano	<10 km
Total population (2011)	23,071,779
Number (percentage) of people living within 10 km of a Holocene volcano	612,157 (2.7%)
Number (percentage) of people living within 30 km of a Holocene volcano	7,763,020 (33.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	10,878,326 (47.2%)

Infrastructure Exposure

Number of airports within 100 km of a volcano	3
Number of ports within 100 km of a volcano	4
Total length of roads within 100 km of a volcano (km)	2,415
Total length of railroads within 100 km of a volcano (km)	548

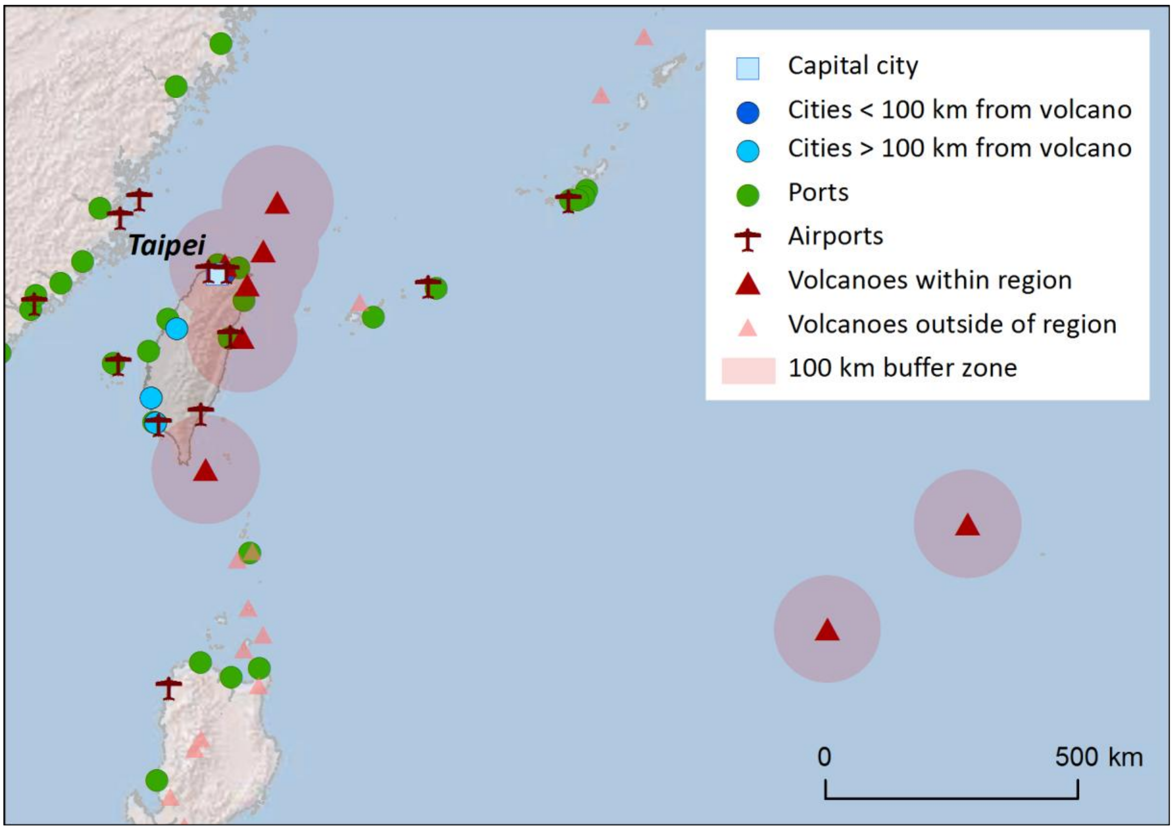


Figure 199: The location of Taiwan's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The volcanoes in Taiwan are concentrated in the north, where the capital Taipei lies within 100 km. Indeed it is less than 10 km from Taipei to the Tatun Group volcano. Other large cities and considerable infrastructure are exposed in the north, including airports and ports. Large cities in the south are also within 100 km of an unnamed volcano off the coast of Taiwan. An extensive road and rail network is exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The eruption records for the volcanoes in Taiwan are sparse and this prevents hazard assessment without significant associated uncertainties. The volcanoes here are therefore unclassified. Indeed, of the eight volcanoes, just three have a Holocene eruption record each with just one eruption. Both an unnamed volcano and Kueishantao have erupted historically, whilst the last recorded eruption of Tatun Group was in 4100 BC.

The PEI ranges from low to very high in Taiwan. No volcanoes are classified by risk level due to the absence of a hazard classification, however the high local population around the Tatun Group makes this a PEI 7 volcano, which indicates high risk.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR			Unnamed (281030)		Kueishantao		
	U- HR							Tatun Group
	U- NHHR	Unnamed (281010); Unnamed (281011); Zengyu	Unnamed (281020)		Unnamed (281040)			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 186: Identity of Taiwan's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Two volcanoes have historical activity: an unnamed submarine volcano and Kueishantao. The Taiwan Volcano Observatory principally monitors Tatun Group (active in the Holocene) and Kueishantao. The location of the Tatun Group volcano with a large proximal population and the dominance of monitoring activities here indicates that monitoring resources are focussed on volcanoes of highest risk.

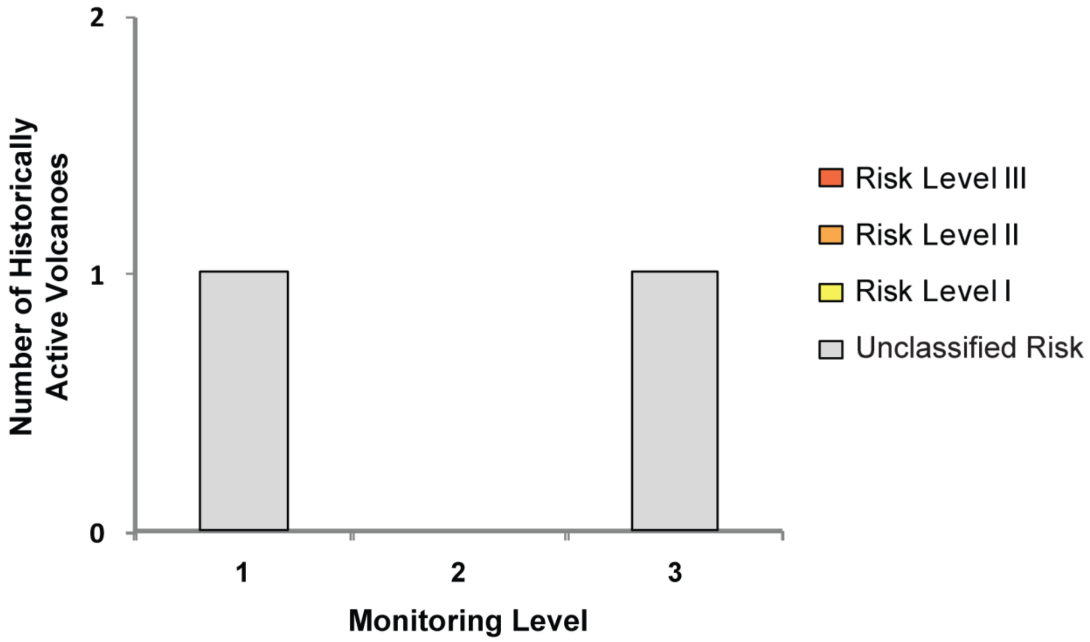


Figure 200: The monitoring and risk levels of the historically active volcanoes in Taiwan. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

USA – Mariana Islands

For further USA profiles see Region 4 for American Samoa, Region 11 for Alaska, Region 12 for the contiguous states, Region 13 for Hawaii.

Description

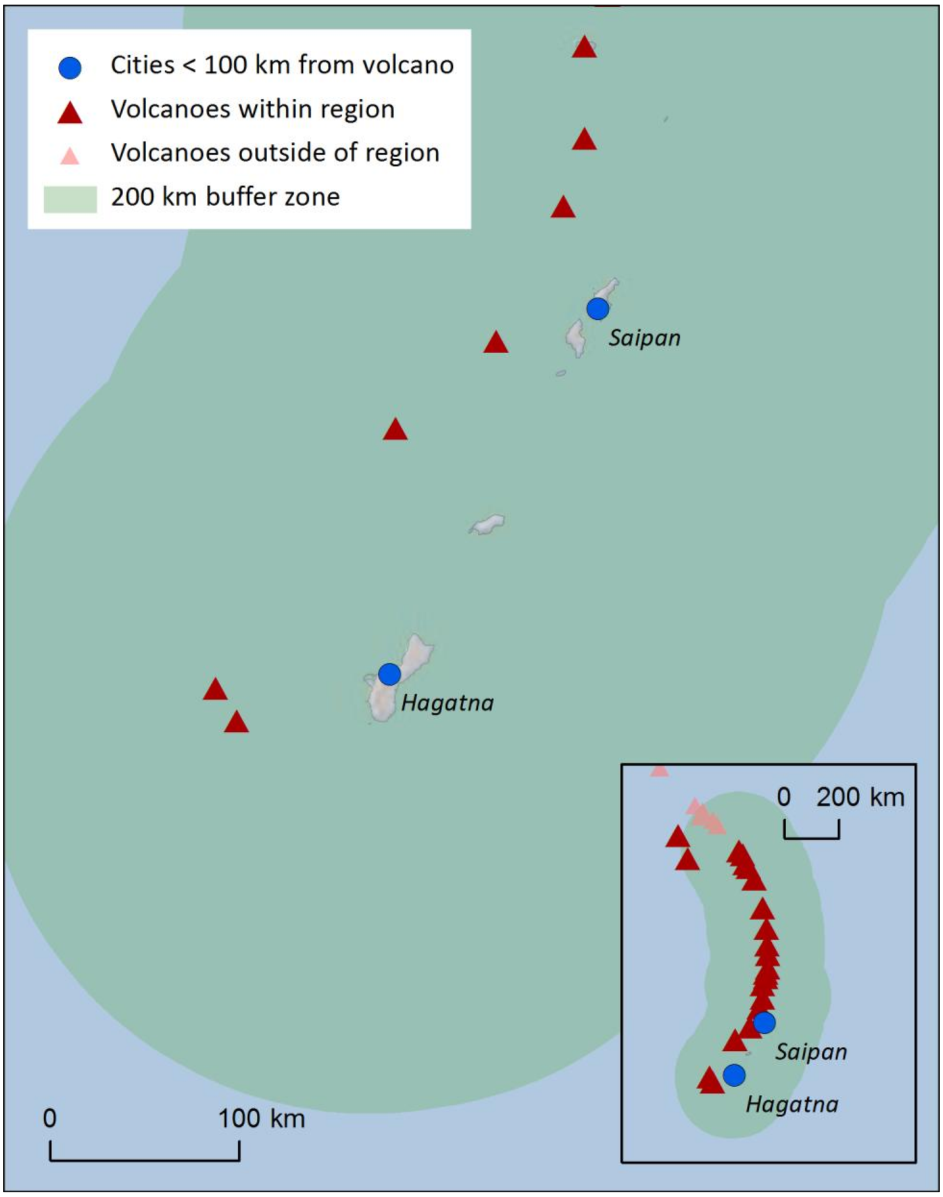


Figure 201: Location of the Marianas Island volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Marianas Islands.

Twenty-one Holocene volcanoes are located in the Marianas Islands, located at the southern end of the Izu-Marianas arc. Volcanism here is due to the subduction of the Pacific Plate beneath the Philippine plate, producing the ocean island arc. Eleven volcanoes are submarine, while all subaerial volcanoes are stratovolcanoes. Basaltic to dacitic rock types are present, with basalts and andesites being most common.

Fifty-two confirmed Holocene eruptions are recorded in the Marianas, of VEI 0 to 4, indicating a range of activity from mild to large explosive events. Of these, forty-nine are recorded historically, all but one since 1800, demonstrating that the geological record is sparse and that activity here prior to this time is poorly understood. Pyroclastic flows are recorded in four historical eruptions (8% of events).

The population of the Marianas is sparse, with the biggest settlements being restricted to the largest islands to the east of the volcanic chain. The population within 30 km of the Holocene volcanoes is therefore just 1, however extending the radii to 100 km encompasses the whole population of the Marianas. Evacuations have been called during eruptions of Agrigan, Pagan and South Sarigan Seamount as recently as 2010. The 2010 eruption of South Sarigan Seamount produced an eruption column to 12km above the surface.

The CNMI (Commonwealth of the Northern Mariana Islands) Emergency Management Office, the Southern Methodist University and the Alaska and Hawaii Volcano observatories of the U.S. Geological Survey have been collaborating to establish monitoring networks in the Mariana Islands and to assess the volcanic hazards. Telemetered seismic stations are located on the historically active Anatahan and Pagan volcanoes and the Holocene Sarigan volcano, and infrasound arrays are used to detect explosive activity at the other Mariana Island volcanoes. Satellite monitoring is also undertaken.

See also:

Hawaii Volcano Observatory:
http://hvo.wr.usgs.gov/volcanowatch/archive/2003/03_09_18.html

USGS Volcano Hazards Program: http://volcanoes.usgs.gov/vhp/observatories.php

USGS Northern Mariana Islands: http://volcanoes.usgs.gov/nmi/activity/

Volcano Facts

Number of Holocene volcanoes	21
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	3
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	6
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The M4.5 870 AD eruption of

	Alamagan.
Number of Holocene eruptions	52 confirmed eruptions.
Recorded Holocene VEI range	0 – 4 and unknown.
Number of historically active volcanoes	11
Number of historical eruptions	49

Number of volcanoes	Primary volcano type	Dominant rock type
10	Large cone(s)	Andesitic (6), Basaltic (4)
11	Submarine	Andesitic (2), Basaltic (4), Dacitic (1) Unknown (4)

Table 187: The number of volcanoes in the Marianas Islands, their volcano type classification and dominant rock type according to VOTW4.0.

Population Exposure

Capital city	Saipan
Distance from capital city to nearest Holocene volcano	25.3 km
Total population (2011)	46,050
Number (percentage) of people living within 10 km of a Holocene volcano	1 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	1 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	52,965 (>100%)

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	4
Total length of roads within 100 km of a volcano (km)	127
Total length of railroads within 100 km of a volcano (km)	0

The Northern Marianas Islands include many small settlements, with the biggest cities on the largest islands of Guam, Rota Island, Tinian and Saipan. Much of the infrastructure is also located on these islands, including four ports and two airports. These largest islands lie within 100 km of the volcanoes which are displaced to the west.

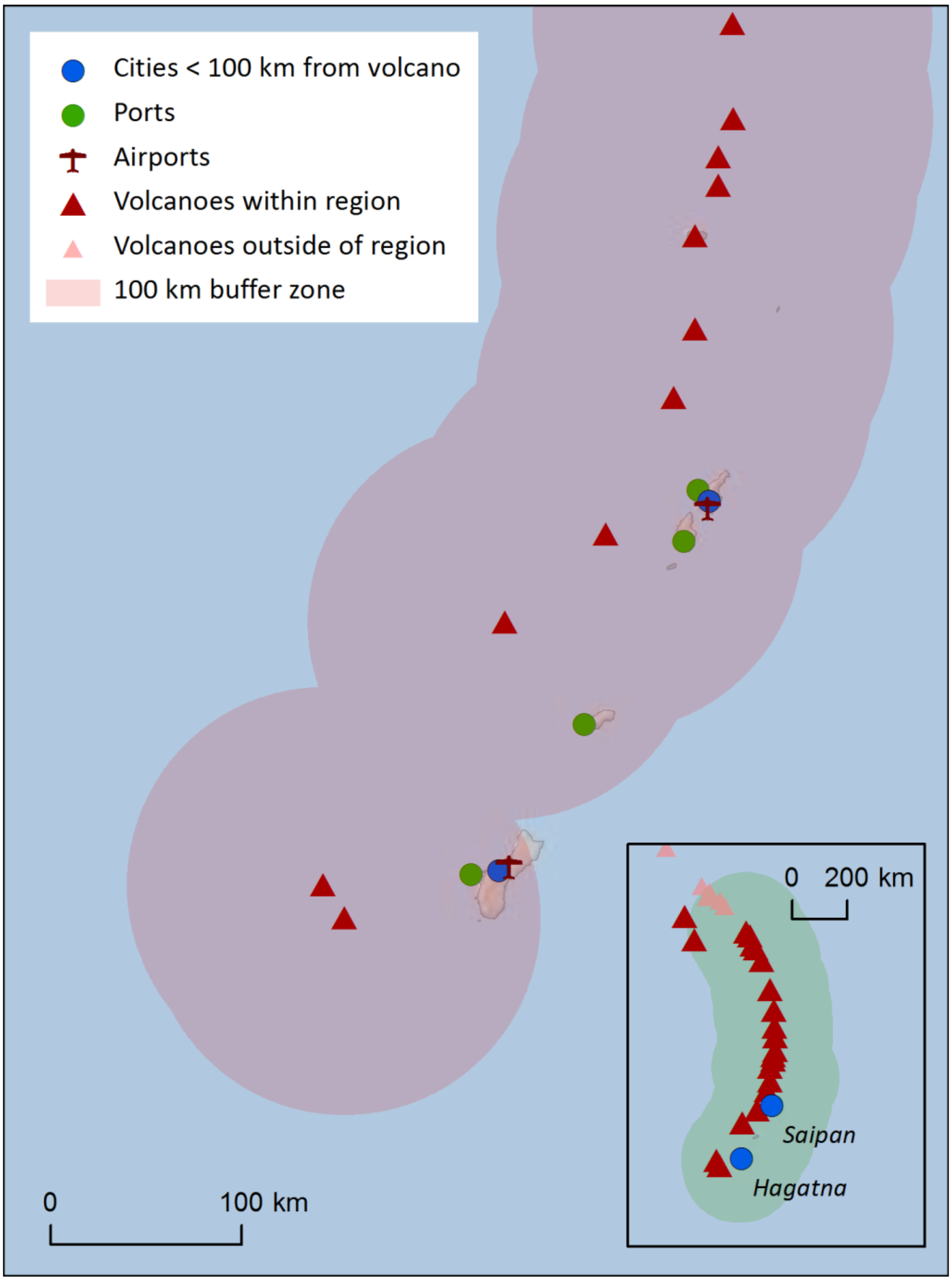


Figure 202: The location of CNMI's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of data available in the eruption records of the volcanoes of the Marianas Islands. Indeed, out of 21 volcanoes, just three have sufficiently extensive and detailed records to have their hazard levels classified. These volcanoes, Pagan, Anatahan and Farallon de Pajaros, have records of 40 confirmed Holocene eruptions, most of which also have an attributed size. All but one of these eruptions occurred since the 1600s. With no eruptions over VEI 2, Farallon de Pajaros is classified at Hazard Level I, whilst Anatahan and Pagan, with records of VEI 3 and 4 eruptions respectively, are ranked at Hazard Level III. These three volcanoes are classified at Risk Level I, with no local populations.

With the exception of these three volcanoes, all others are unclassified. Nine volcanoes have no Holocene eruption record, though three, Zealandia Bank, Sarigan and Esmeralda Bank, have experienced unrest since 1900 AD. Eight unclassified volcanoes have records of historical eruptions, including eruptions since 1900 at seven volcanoes.

With low proximal populations in the Marianas, including no population within 30 km at any of the volcanoes, the PEI is low at 1 and 2.

CLASSIFIED	**Hazard III**	Pagan; Anatahan						
	Hazard II							
	Hazard I	Farallon de Pajaros						
UNCLASSIFIED	**U – HHR**	**Ahyi; Supply Reef; Asuncion; Agrigan;** Guguan; **South Sarigan Seamount**	**Ruby; NW Rota-1**					
	U- HR	Alamagan						
	U- NHHR	Unnamed (284138); Unnamed (284139); Maug Islands; **Zealandia Bank; Sarigan**	East Diamante; **Esmeralda Bank**; Forecast Seamount; Seamount X					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 188: Identity of the Marianas Islands' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Anatahan	1	I
Farallon de Pajaros	1	I
Pagan	1	I

Table 189: Classified volcanoes of Mariana Islands ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 3 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

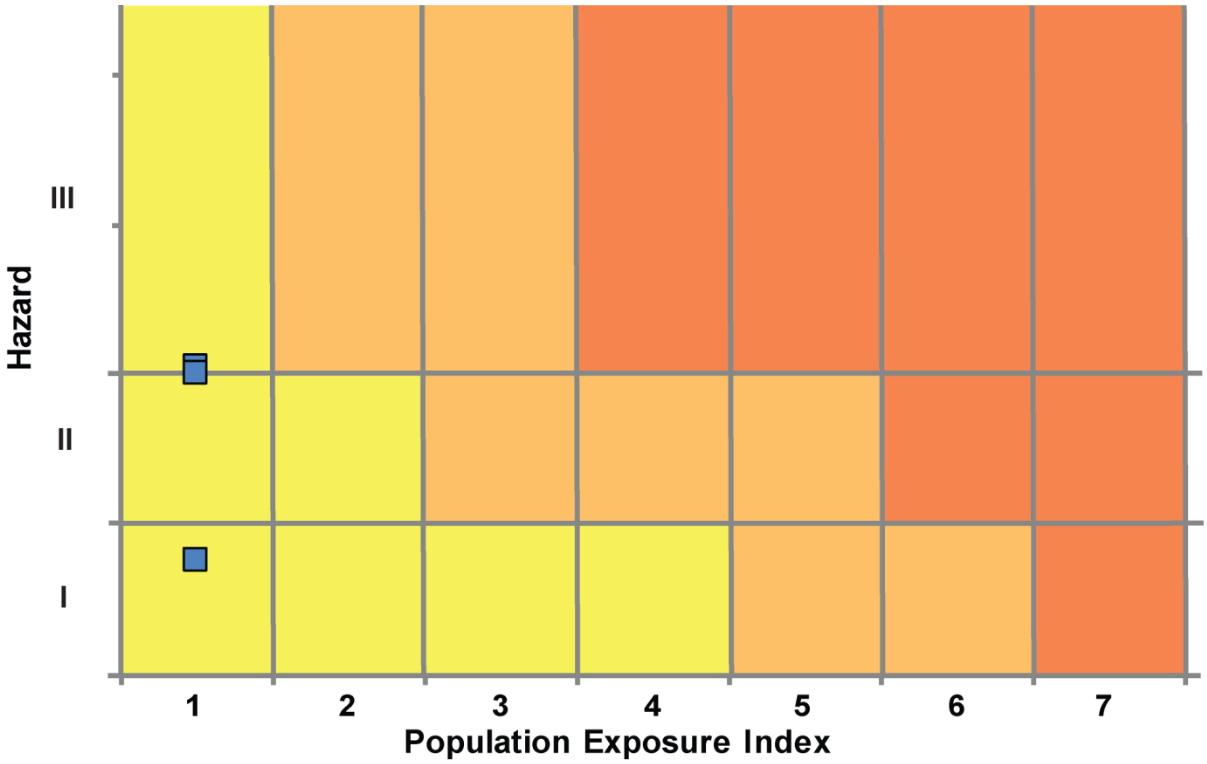


Figure 203: Distribution of the Marianas Islands' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The monitoring of the Marianas Island volcanoes is the responsibility of the Alaska Volcano Observatory. The USGS Northern Marianas Duty Scientist is a position that rotates between the Alaska and Hawaii Volcano Observatories. The Risk Level I Anatahan and Pagan volcanoes have dedicated seismic monitoring in place, as does the Holocene age Sarigan. Infrasound arrays are used for detection of activity at other volcanoes here.

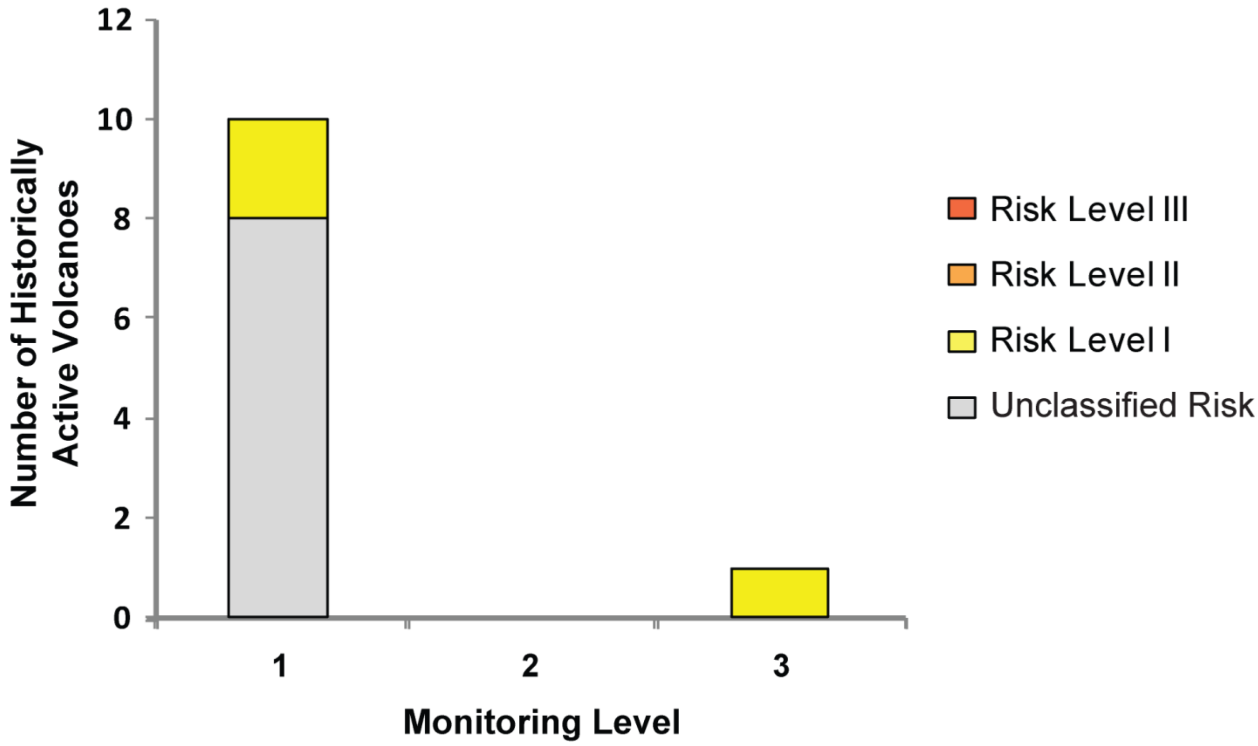


Figure 204: The monitoring and risk levels of the historically active volcanoes in the Marianas Islands. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 9: Kuril Islands

Description

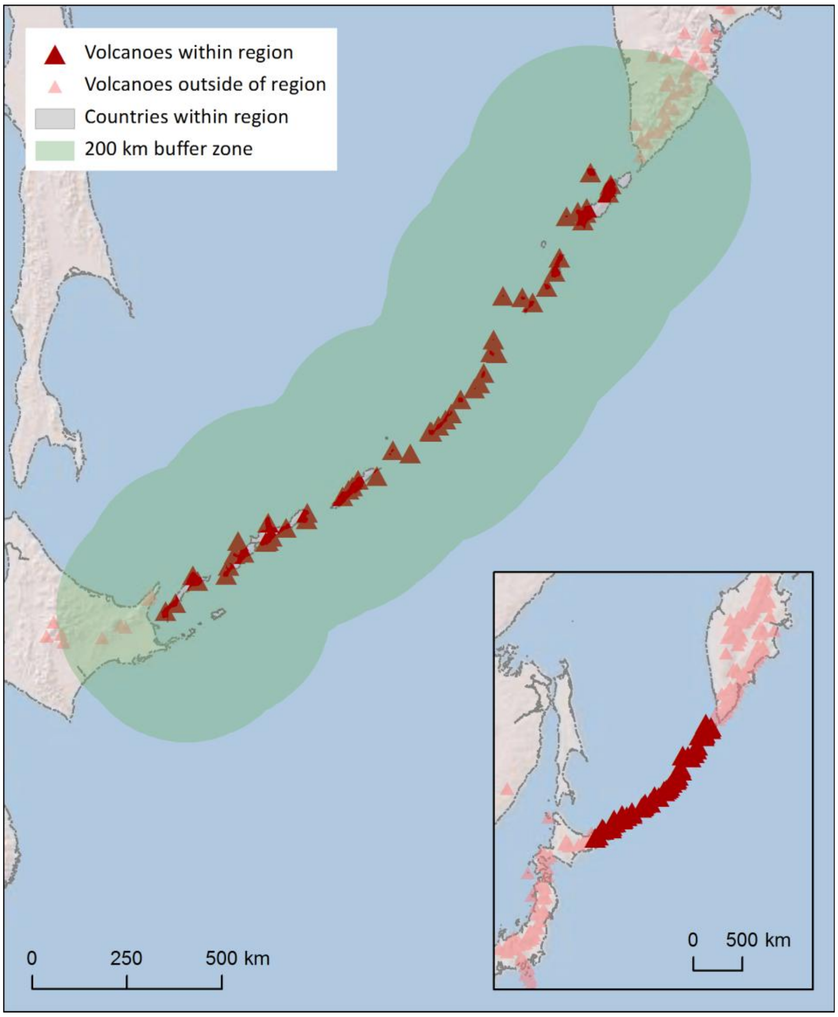


Figure 205: The distribution of Holocene volcanoes through the Kuril Islands region.

Forty-eight Holocene volcanoes are located in the Kuril Islands, stretching from Hokkaido, Japan in the south, to Kamchatka, Russia in the north. Volcanism in this arc is due to the subduction of the Pacific Plate beneath the Eurasian Plate. Most volcanoes here are of dominantly andesitic composition, and most are volcano types typically associated with explosive activity including stratovolcanoes and calderas.

Thirty-one of these volcanoes have Holocene records of 165 eruptions, of these, 148 of the eruptions are recorded post 1500 AD at thirty volcanoes, indicating the geological eruption record is sparse. Historical eruptions have ranged in size from VEI 0 to 5, indicating a range of eruption styles from mild events to large explosive eruptions. Two VEI 6 eruptions are recorded in the Holocene record and there are Pleistocene records of larger events, with the largest Quaternary eruption recorded in the Kuril Islands being the M7.3 eruption of Nemo Peak at 45 ka. Moderate eruptions dominate the record, however twelve large explosive historical eruptions of VEI ≥4 are recorded.

The size of a large number of eruptions in the Kuril Islands is unknown, and the dominance of the historical record indicates that further research is required to more fully understand the eruptive histories in this region and to better understand the hazard. However, the Kuril Islands are sparsely populated with only four volcanoes having over 10,000 people located within 100 km radii, reducing the risk substantially.

Both Japan and Russia are very familiar with responding to and monitoring eruptions and unrest (see Japan, region 8; and Russia, region 10). The northernmost volcanoes in the Kuril Islands are monitored by the Kamchatka Volcanic Eruption Response Team (KVERT) who primarily monitor these volcanoes by satellite observations with a few seismometers located on two historically active volcanoes.

Volcano facts

Number of Holocene volcanoes	48
Number of Pleistocene volcanoes with M≥4 eruptions	6
Number of volcanoes generating pyroclastic flows	8
Number of volcanoes generating lahars	6
Number of volcanoes generating lava flows	13
Number of eruptions with fatalities	3
Number of fatalities attributed to eruptions	32
Largest recorded Pleistocene eruption	The largest recorded Quaternary eruption occurred at Nemo Peak with the M7.3 K3 (Nemo 1) eruption at 45 ka.
Largest recorded Holocene eruption	The 8290 BP M7 caldera formation at Tao-Rusyr Caldera is the largest recorded Holocene eruption in LaMEVE in this region.
Number of Holocene eruptions	165 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	30
Number of historical eruptions	148

Number of volcanoes	Primary volcano type	Dominant rock type
5	Caldera(s)	Andesitic (5)
34	Large Cone(s)	Andesitic (26), Basaltic (6), Unknown (2)
4	Small Cone(s)	Andesitic (3), Unknown (1)
5	Submarine	Unknown (5)

Table 190: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Note that the stratovolcano Chikurachki comprises the sub-features of the Lomonosov Group and stratovolcano Tatarinov.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	2
Large (> VEI 3)	30

Table 191: Average recurrence interval (years between eruptions) for small and large eruptions in the Kuril Islands.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about 2 years, whilst the ARI for large eruptions is longer, at about 30 years.

Eruption Size

Eruptions are recorded through the Kuril Islands of VEI 0 to 6, representing a range of eruption styles from gentle effusive events to large explosive eruptions. VEI 2 events dominate the record, with over 50% of all Holocene eruptions classed as such.

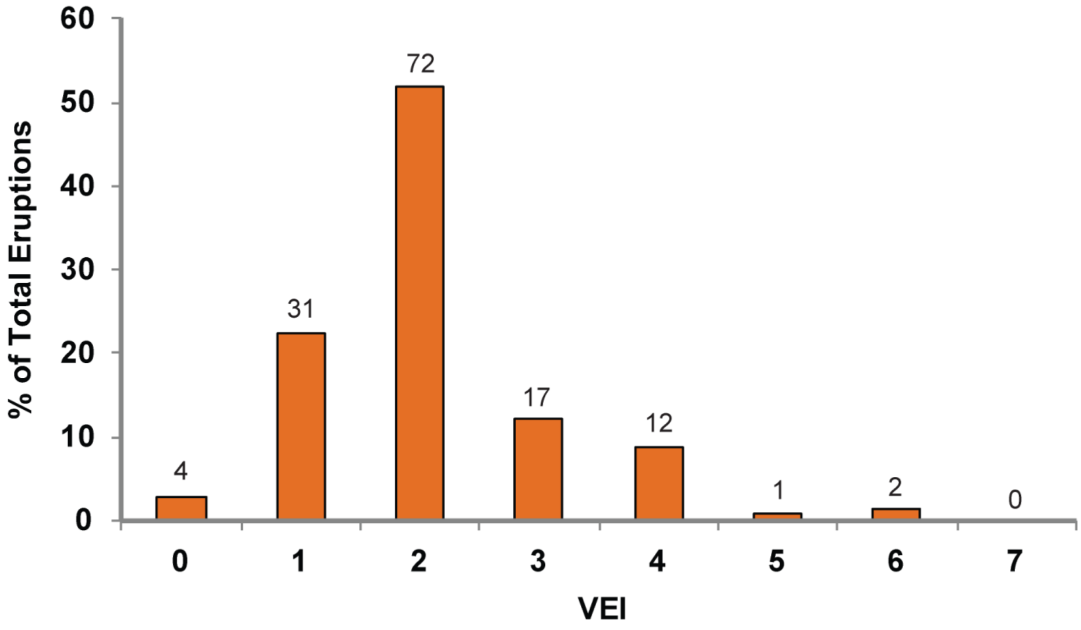


Figure 206: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 26 eruptions were recorded with unknown VEI.

Infrastructure Exposure

The volcanoes of the Kuril Islands are distributed between Hokkaido, Japan in the south and Kamchatka in the north. The entirety of the Kuril Island chain is volcanic and thus lies within 100 km of volcanoes, and the 100 km radii extend into Hokkaido and Kamchatka, exposing infrastructure here, including ports and airports. Whilst no infrastructure is described in the Kurile Islands here, there are settlements on some of the islands and all critical infrastructure is exposed.

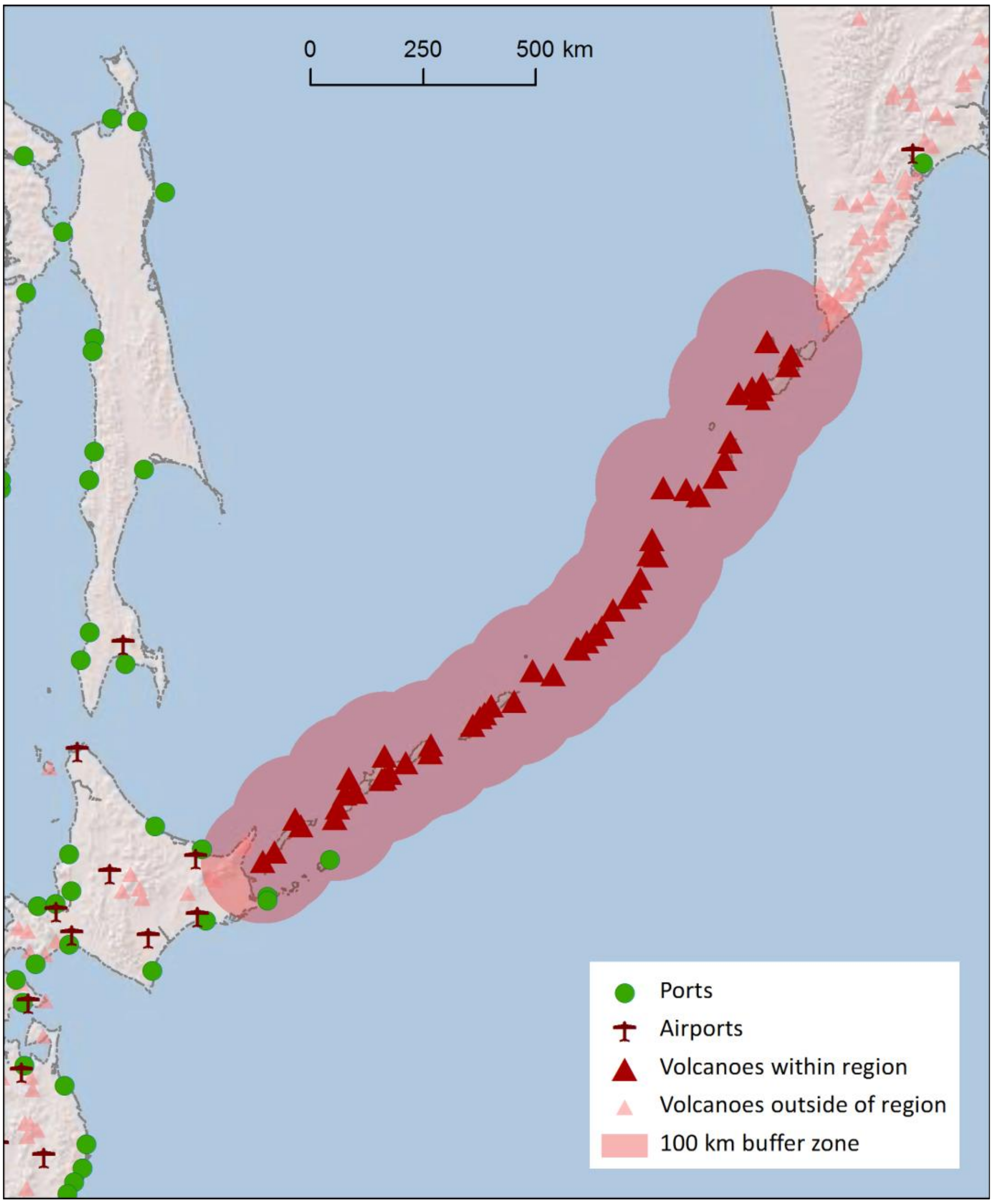


Figure 207: The location of the volcanoes in the Kuril Islands and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Of the 48 volcanoes in the Kuril Islands just 13 have a sufficient eruption record for hazard assessment. These volcanoes are classified into all three hazard levels, with Sarychev Peak, Sinarka and Kharimkotan being classed at the highest hazard here, Level III all with Holocene records of large explosive eruptions and pyroclastic flows recorded in more than 10% of their eruptions.

The 35 unclassified volcanoes have varying degrees of information in their records. 16 of these have no confirmed Holocene eruptions. One, Moekeshiwan [Lvinaya Past], has a Holocene record but no historical eruptions, and 18 have confirmed historical events including 12 with eruptions since 1900. Three volcanoes, Fuss Peak, Raususan [Mendeleev] and Ushishur, have records of increased fumarolic emissions in the 1980s suggesting unrest above background levels.

The population in the Kuril Islands is low, and all volcanoes are classed with a low PEI of 1 and 2, with all but four volcanoes having fewer than 10,000 inhabitants located within 100 km (Tomariyama [Golovnin], Raususan [Mendeleev], Ruruidake [Smirnov], and Chachadake [Tiatia]). This low PEI coupled with the dominant distribution of the volcanoes across Hazard Levels I and II makes the majority of the classified volcanoes of the Kuril Islands Risk Level I volcanoes. Just three volcanoes, Kharimkotan, Sarychev Peak and Sinarka, are classed at Risk Level II.

CLASSIFIED	**Hazard III**		Sarychev Peak; Sinarka; Kharimkotan					
	Hazard II		Chachadake [Tiatia]; Etorofu-Yakeyama [Grozny Group]; Chirpoi; Chikurachki; Ebeko; Alaid					
	Hazard I	Chirinkotan	Moyorodake [Medvezhia]; Kolokol Group; Goriaschaia Sopka					
UNCLASSIFIED	**U – HHR**	**Ekarma**	Tomariyama [Golovnin]; **Rausuan [Mendeleev]; Etorofu-Atosanupuri [Atosanupuri]; Sashiusudake [Baransky];** Chirippusan [Chirip]; **Unnamed (290160); Zavaritzki Caldera**; Prevo Peak; **Ketoi**; **Ushishur**; **Rasshua**; **Unnamed (290230)**; **Raikoke**; **Tao-Rusyr Caldera**; **Nemo Peak; Fuss Peak**; **Karpinsky Group**					
	U- HR		Moekeshiwan [Lvinaya Past]					
	U- NHHR	Odamoisan [Tebenkov]	Ruruidake [Smirnov]; Berutarubesan [Berutarube]; Nishihitokappuyama [Bogatyr Ridge]; Unnamed; Rucharuyama [Golets-Tornyi Group]; Rakkibetsudake [Demon]; Ivao Group; Rudakov; Tri Sestry; Unnamed; Milne; Urataman; Srednii; Shirinki; Vernadskii Ridge					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 192: Identity of the Kuril Islands' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
0	5
0	4
0	3
45	2
3	1

Table 193: The number of volcanoes in the Kuril Islands classed in each PEI category.

Volcano	Population Exposure Index	Risk Level
Sarychev Peak	2	II
Sinarka	2	II
Kharimkotan	2	II
Chachadake [Tiatia]	2	I
Etorofu-Yakeyama[Grozny Group]	2	I
Moyorodake [Medvezhia]	2	I
Kolokol Group	2	I
Chirpoi	2	I
Goriaschaia Sopka	2	I
Chikurachki	2	I
Ebeko	2	I
Alaid	2	I
Chirinkotan	1	I

Table 194: Classified volcanoes of the Kuril Islands ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given.

Risk Levels

Number of Volcanoes	Risk Level
0	III
3	II
10	I
35	Unclassified

Table 195: The number of volcanoes in the Kuril Islands classified at each Risk Level.

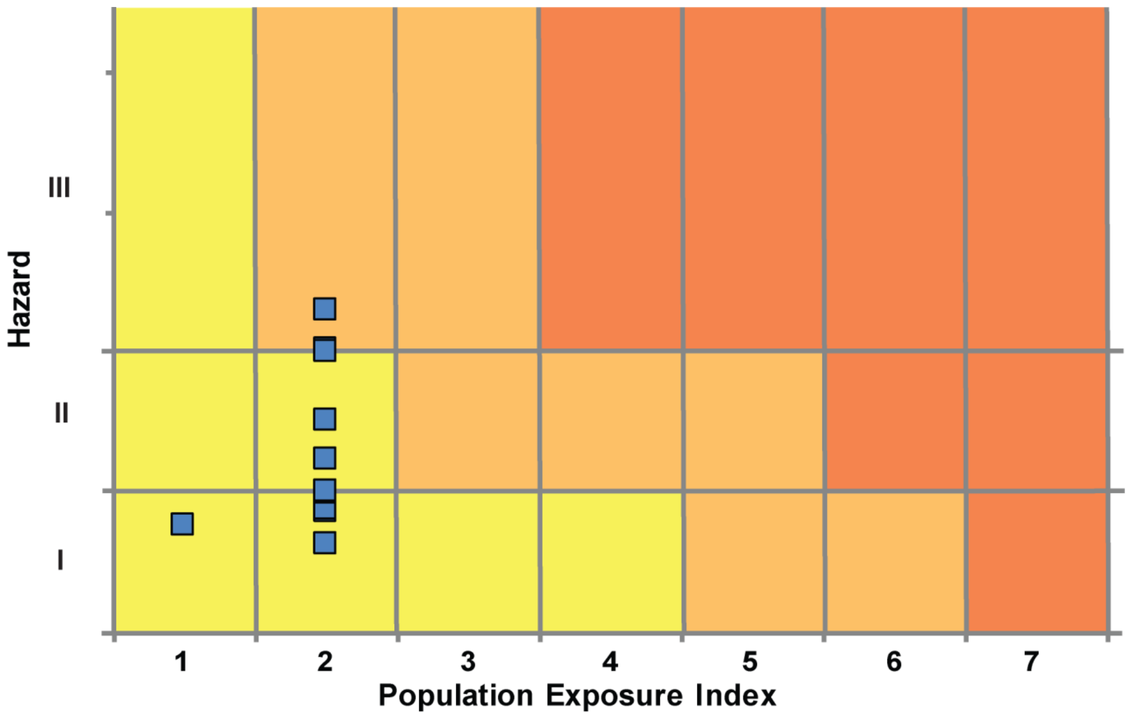


Figure 208: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Thirty-one volcanoes in the Kuril Islands have records of historical activity. The Kamchatka Volcanic Eruption Response Team (KVERT) monitors six volcanoes in the northern Kuriles, five of which have had historical activity. Of these, seismic stations are located at two volcanoes. At the time of the writing of this report, no information is available to suggest that there is dedicated ground-based monitoring throughout the remaining Kuril Island volcanoes.

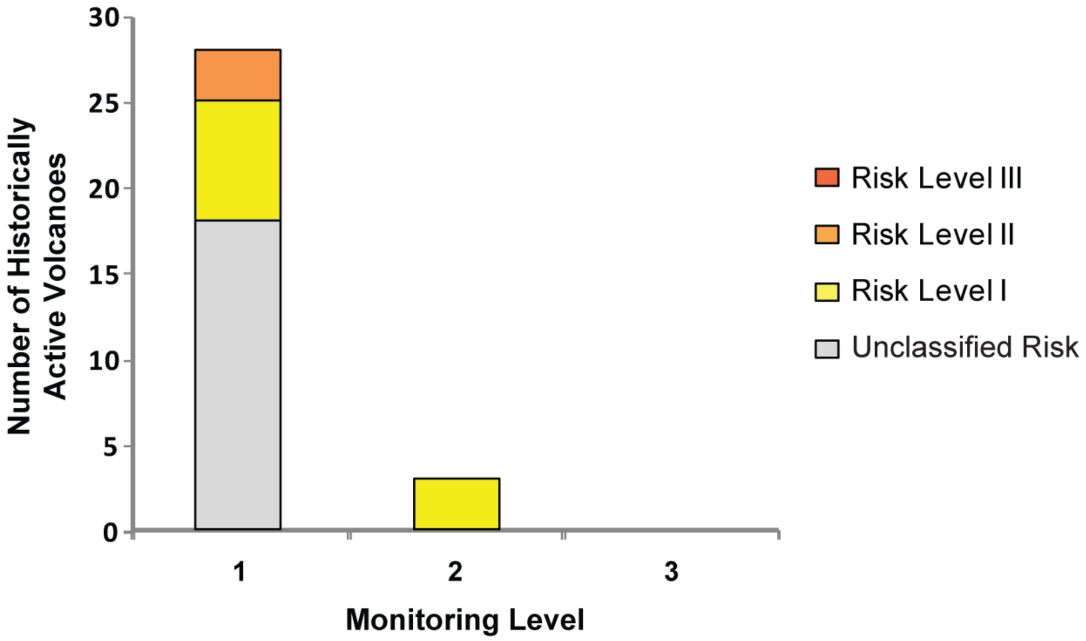


Figure 209: The monitoring and risk levels of the historically active volcanoes in the Kuril Islands. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

[i] http://eng.stat.gov.tw/mp.asp?mp=5
[ii] https://www.cia.gov/library/publications/the-world-factbook/geos/tw.html
[iii] 16124371.pdf

Region 10: Kamchatka and Mainland Asia

Region 10: Kamchatka and Mainland Asia comprises volcanoes from the China-Pakistan border in the west to Kamchatka in the east. Five countries are represented here. The country profiles for China and Russia include additional volcanoes from outside of this region.

Country	Number of volcanoes
China	11 + 3 from Region 7
DPRK	3
Mongolia	5
Republic of Korea	3
Russia	120 + 1 from Region 1

Table 196: The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

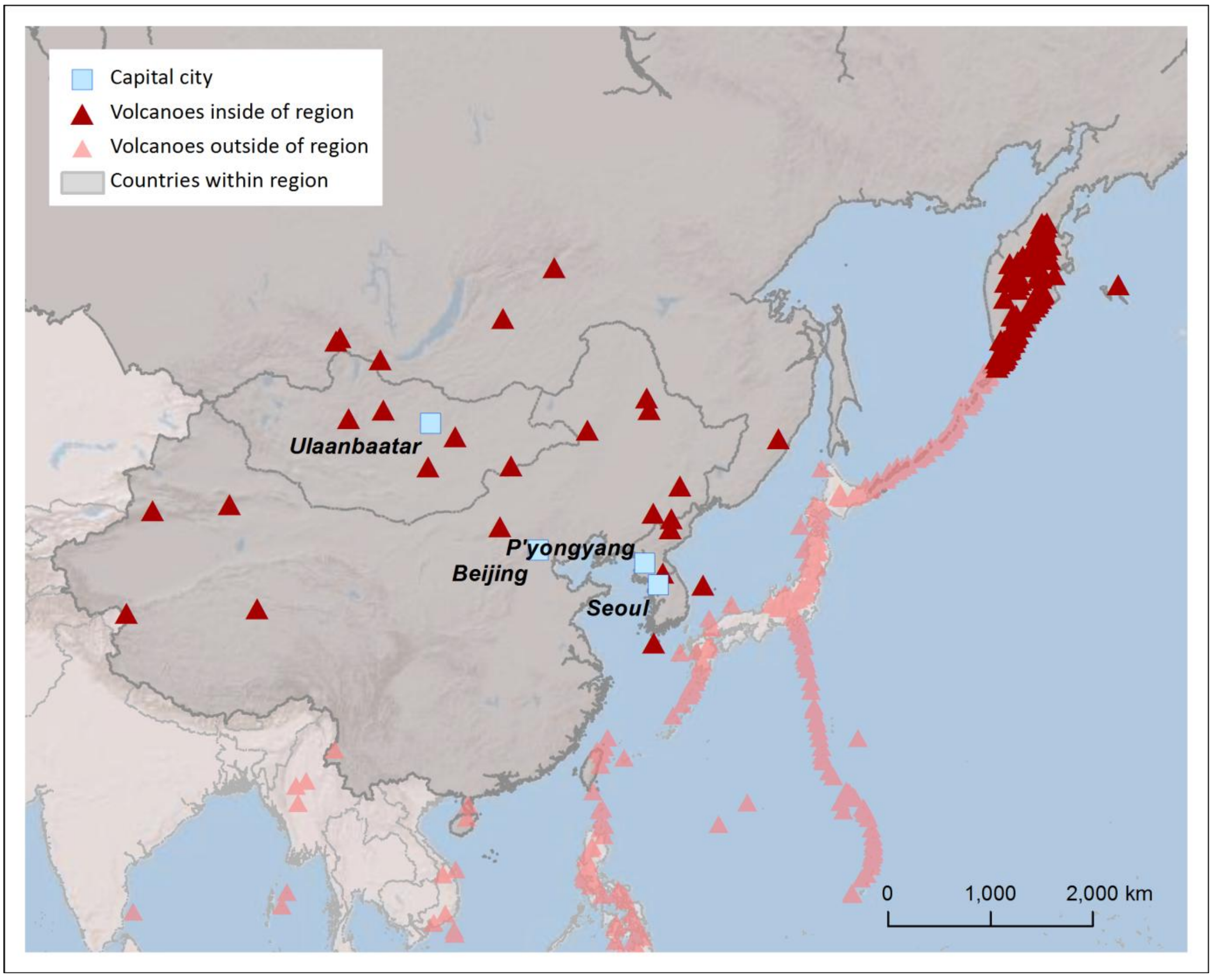


Figure 210: The distribution of Holocene volcanoes through the Kamchatka and Mainland Asia region. The capital cities of the constituent countries are shown.

Description

140 Holocene volcanoes are located in Kamchatka (Russia) and Mainland Asia. Most of these volcanoes (120) are in Russia, dominantly on the Kamchatka Peninsula. Volcanism here is largely due to the subduction of the Pacific Plate beneath the Eurasian Plate, with volcanoes of the mainland being chiefly controlled through tensional processes.

A range of volcano morphologies are present in this region, though stratovolcanoes and other large cones dominate (74). Shield volcanoes, volcanic fields and cinder cones are also common features. Although a range of rock types are present, the composition is mostly mafic to intermediate with basaltic and andesitic compositions most common.

Along with volcano form and composition, a range of activity styles and eruption sizes are recorded throughout the Holocene, with eruptions of VEI 0 to 7. The most common eruption sizes are VEI 2 to 4, with about 80% of eruptions being designated as such, indicating that moderately explosive volcanism is a common feature of activity here. About 20% (107) of recorded sized eruptions have been large explosive VEI ≥4 events. These eruptions have been restricted to 22 volcanoes in Russia, Changbaishan on the China-DPRK border and Ulreung, Republic of Korea. The largest Holocene eruption in this region was the VEI 7 eruption of Changbaishan about 950 years ago. Large explosive eruptions are recorded from 22 volcanoes back into the Pleistocene.

Twenty-eight volcanoes have historical records of 337 eruptions, 95% of which were recorded through direct observations. 16% of historical events have involved the production of pyroclastic flows and 12% have resulted in lahars. 26% of historical eruptions have records of lava flows.

Just 1% of historical eruptions in this region have resulted in loss of life, largely due to the low population in this region. Most volcanoes (85%) have low proximal population, and as such are considered relatively low risk. However, the hazard (VHI) is not classified at 90% of the volcanoes here.

Of the historically active volcanoes, half have dedicated monitoring systems in place, with monitoring undertaken by the Institute of Volcanology and Seismology – KVERT in Russia, the China Seismological Bureau and Volcano Research Centre in China, and scientists in North Korea in collaboration with overseas research groups.

Volcano facts

Number of Holocene volcanoes	140
Number of Pleistocene volcanoes with M≥4 eruptions	22
Number of volcanoes generating pyroclastic flows	26 (136 eruptions)
Number of volcanoes generating lahars	13 (47 eruptions)
Number of volcanoes generating lava flows	46 (227 eruptions)
Number of eruptions with fatalities	5
Number of fatalities attributed to eruptions	20

Largest recorded Pleistocene eruption	The largest recorded Quaternary eruption occurred at Diky Greben in Kamchatka at 443 ka with the M7.6 eruption of the Golygin Ignimbrite.
Largest recorded Holocene eruption	The 950 BP M7.4 eruption of Changbaishan is the largest recorded Holocene eruption in this region in LaMEVE.
Number of Holocene eruptions	781 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 7 and unknown.
Number of historically active volcanoes	28
Number of historical eruptions	337

Number of volcanoes	Primary volcano type	Dominant rock type
10	Caldera(s)	Andesitic (5), Basaltic (4), Dacitic (1)
74	Large cone(s)	Andesitic (37), Basaltic (31), Dacitic (3), Trachytic/Andesitic (2), Unknown (1)
4	Lava dome(s)	Andesitic (1), Basaltic (2), Dacitic (1)
47	Shield(s)	Andesitic (2), Basaltic (45)
38	Small cone(s)	Andesitic (5), Basaltic (26), Phonolitic (1), Trachytic/Andesitic (1), Unknown (5)
5	Submarine	Dacitic (1), Unknown (4)
1	Unknown	Unknown (1)

Table 197: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	20

Table 198: Average recurrence interval (years between eruptions) for small and large eruptions in Kamchatka and West Asia.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 20 years.

Eruption Size

Eruptions are recorded through the Kamchatka and Western Asia region of VEI 0 to 7, representing a range of eruption styles from gentle effusive events to very large explosive eruptions. VEI 2 events dominate the record, with nearly 50% of all Holocene eruptions classed as such, and about 80% of eruptions are VEI 2 to 4. 19% of eruptions here are explosive at VEI≥4.

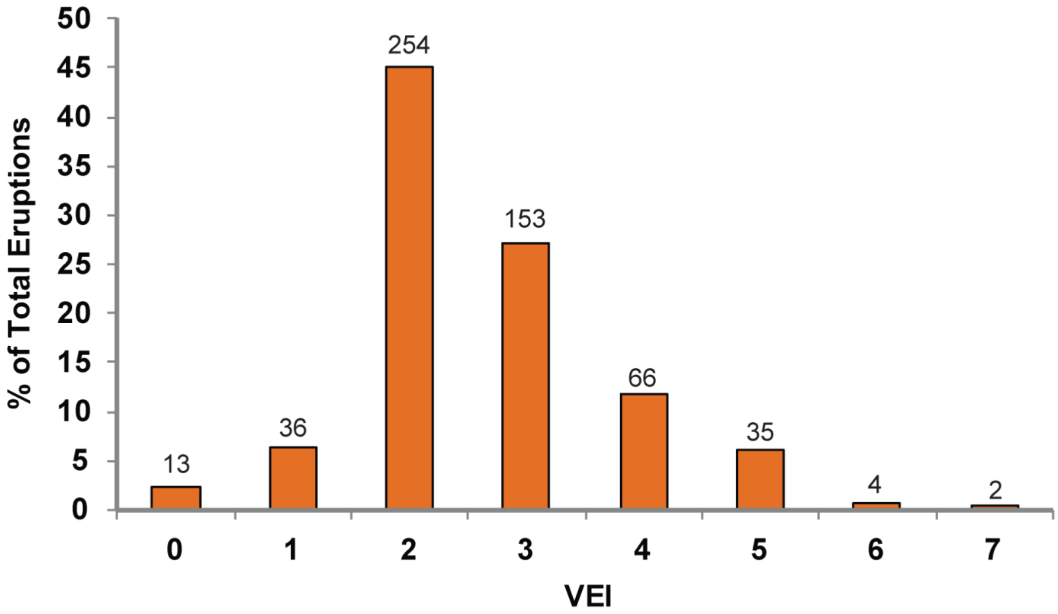


Figure 211: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 218 eruptions were recorded with unknown VEI.

Socio-Economic Facts (excluding North Korea)

Total population (2011)	1,551,803,374
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,178 – 27,541 (Mean 13,486)
Gross National Income (GNI) per capita (2005 PPP $)	4,245 – 28,231 (Mean 13,271)
Human Development Index (HDI) (2012)	0.675 – 0.909 (Medium to Very High, Mean 0.768 High)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	415,094 (0.03 %)
Number (percentage) of people living within 30 km of a Holocene volcano	3,787,660 (0.24 %)
Number (percentage) of people living within 100 km of a Holocene volcano	32,410,044 (2.09 %)

CLASSIFIED	**Hazard III**		Bezymianny; Shiveluch	Koryaksky; Avachinsky				
	Hazard II		Karymsky; Maly Semiachik; Kikhpinych; Krasheninnikov; Tolbachik; Kliuchevskoi					
	Hazard I		Mutnovsky; Gorely; Zhupanovsky; Kostakan					
UNCLASSIFIED	**U – HHR**		Koshelev; **Ilyinsky**; **Zheltovsky**; **Ksudach**; Opala; **Akademia Nauk**; **Kronotsky**; **Kizimen**; Ushkovsky; Khangar; **Ichinsky**; Alney-Chashakondzha; **Kunlun Volcanic Group**	**Changbaishan**		Wudalianchi		
	U- HR		Kambalny; Yavinsky; Diky Greben; Kurile Lake; Khodutka; Tolmachev Dol; Vilyuchik; Barkhatnaya Sopka; Veer; Bakening; Zavaritsky; Bolshoi Semiachik; Taunshits; **Uzon**; Gamchen; Komarov; Vysoky; Piip; Cherpuk Group; Bolshoi-Kekuknaysky; Shisheika; Terpuk; Sedankinsky; Gorny Institute; Kinenin; Bliznetsy; Titila; Elovsky; Nylgimelkin; Spokoiny; Ostry; Severny; Udokan Plateau; Tianshan Volcanic Group	Arshan; Taryatu-Chulutu; Ulreung	Halla	Turfan; Jingbo; Longgang Group		
	U- NHHR		Mashkovtsev; Kell; Belenkaya; Ozernoy; Olkoviy Volcanic Group; Plosky; Piratkovsky; Ostanets; Otdelniy; Golaya; **Asacha**; Visokiy; Unnamed; Bely; Bolshe-Bannaya; Dzenzursky; Schmidt; Unnamed; Udina; Zimina; Kamen; Maly Payalpan; Bolshoi Payalpan; Akhtang; Kozyrevsky; Romanovka; Uksichan; Kulkev; Geodesistoy; Anaun; Krainy; Kekurny; Eggella; Cherny; Unnamed; Verkhovoy; Pogranychny; Zaozerny; Bliznets; Kebeney; Uka; Fedotych; Leutongey; Tuzovsky; Mezhdusopochny; Shishel; Alngey; Kaileney; Plosky; Snezhniy; Iktunup; Snegovoy; Iettunup; Voyampolsky; Vitim Plateau; Tunkin Depression; Oka Plateau; Azas Plateau; Unnamed; Bus-Obo	Khanuy Gol; Middle Gobi	Keluo Group; Xianjindao; Dariganga Volcanic Field	Unnamed; Unnamed; Sikhote-Alin; Honggeertu; Ch'uga-ryong		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 199: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
9	5
4	4
8	3
119	2
0	1

Table 200: The number of volcanoes in Kamchatka and Mainland Asia classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
0	III
4	II
10	I
126	Unclassified

Table 201: The number of volcanoes in the Kamchatka and Mainland Asia region classified at each Risk Level.

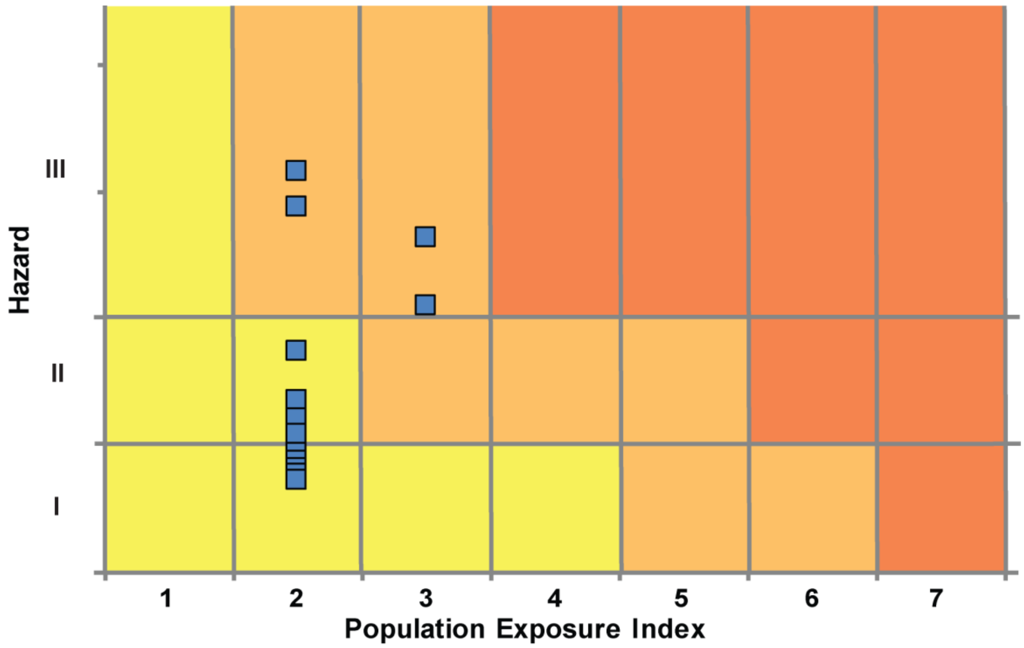


Figure 212: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

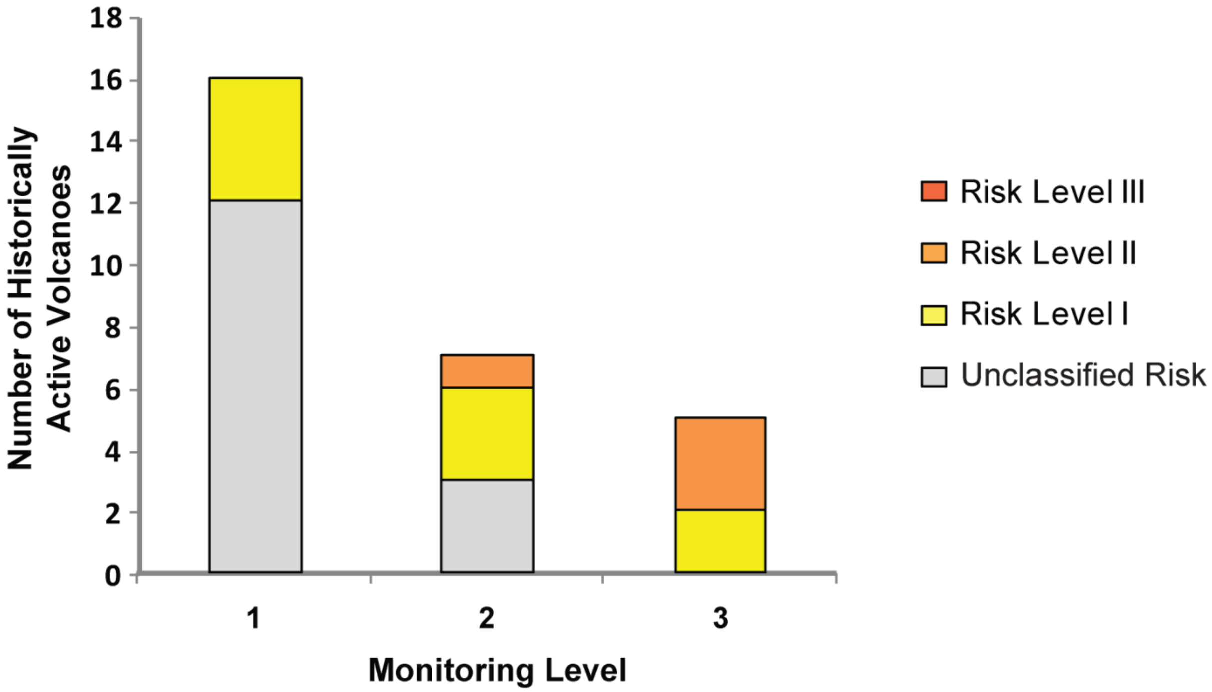


Figure 213: The monitoring and risk levels of the historically active volcanoes in the Kamchatka and Mainland Asia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

China

Note that we include Hainan Dao, Leizhou Dao and Tengchong from Region 7 in this profile.

Description

Figure 214: Location of China's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect China.

Fourteen Holocene volcanoes are located in China, in three broad groups – one in the south, one in the west and one in the north-east. These volcanoes are related to intra-plate processes. All but the stratovolcano Changbaishan, on the border with the Democratic People's Republic of Korea (DPRK), are volcanic fields, and small pyroclastic and cinder cones. Changbaishan is Trachytic/andesitic, whilst the small cones are largely much more mafic, with basaltic compositions.

Twenty-two confirmed eruptions are recorded in China during the Holocene, from ten volcanoes. These measured VEI 2 to 7, indicating a range of activity from mild to very large explosive events. The largest Holocene eruption was that of Changbaishan in 1000 AD, which deposited tephra as far as Japan. This volcano also has a Pleistocene record of VEI 7 activity.

Four volcanoes have records of nine historical eruptions, measuring VEI 2 to 3 with over half of these being of unknown size. No historical eruptions are reported to have caused property damage or fatalities.

Throughout China about 380,000 people live within 10 km of a Holocene volcano, with over 23.4 million within 100 km of one or more volcanoes. As such, many of the volcanoes individually have very large local populations increasing the risk. Changbaishan has a moderate PEI, with about 30,000 within 30 km and over 1.6 million living within 100 km.

The China Seismological Bureau in the Institute of Geology monitor Changbaishan, Tenchong and Wudalianchi, the former two having experienced recent unrest. Due to the history of large explosive eruptions, monitoring is dominantly focussed at Changbaishan, where seismic, deformation and geochemical monitoring is undertaken. As this volcano borders the DPRK monitoring is undertaken separately across the border. The China Seismological Bureau is undertaking risk assessments, and currently grades Changbaishan at Risk Levels 3-4 (Potential risk to Conceivable threat), Tengchong as Risk level 3 (Potential risk) and Wudalianchi as Risk level 2 (no risk in the near future).

The Asian Disaster Reduction Center (ADRC) produced a report on Disaster Risk Reduction in China in 2012 however they do not consider volcanic hazards in this report. They describe the disaster management system in China, comprising a number of laws and the China National Committee for Disaster Reduction (NCDR) and the efforts of China to address the Hyogo Framework for Action. For full details of the disaster management system in China, see the ADRC report.

See also:

Hong, H. Et al., (2003) Volcano monitoring and risk assessing in China. IUGG 2013 abstract. http://www.jamstec.go.jp/jamstec-e/iugg/htm/abstract/abst/v11/016211-1.html

Institute of Geology, China Earthquake Administration: http://www.eq-igl.ac.cn/en/index.htm

ADRC China profile:
http://www.adrc.asia/nationinformation.php?NationCode=156&Lang=en&NationNum=22

Volcano Facts

Number of Holocene volcanoes	14, inclusive of one on the border with the DPRK
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	2
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	3
Number of fatalities caused by volcanic eruptions	?15
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	The M7 Oga eruption of Changbaishan at 448 ka.

Largest recorded Holocene eruption	The 950 BP Baegdusan-Tomakomai tephra eruption from Changbaishan on the border with the DPRK at M7.4.
Number of Holocene eruptions	22 confirmed eruptions. 4 uncertain eruptions and 1 discredited eruption.
Recorded Holocene VEI range	2 – 7 and Unknown
Number of historically active volcanoes	4
Number of historical eruptions	9

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Trachytic / Andesitic (1)
13	Small cone(s)	Basaltic (9), Phonolitic (1), Trachytic / Andesitic (1), Unknown (2)

Table 202: The number of volcanoes in China, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	1,376,569,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	7,418
Gross National Income (GNI) per capita (2005 PPP $)	7,945
Human Development Index (HDI) (2012)	0.699 (Medium)

Population Exposure

Capital city	Beijing
Distance from capital city to nearest Holocene volcano	336.6 km
Total population (2011)	1,336,718,015
Number (percentage) of people living within 10 km of a Holocene volcano	381,848 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	2,745,202 (<1%)
Number (percentage) of people living within 100 km of a	23,492,100 (1.8%)

Holocene volcano

Ten largest cities, as measured by population, and populations:

Shanghai	14,608,512
Taipei	7,871,900
Beijing	7,480,601
Hong Kong	7,012,738
Wuhan	4,184,206
Chongqing	3,967,028
Chengdu	3,950,437
Tianjin	3,766,207
Shenyang	3,512,192
Harbin	3,229,883

Infrastructure Exposure

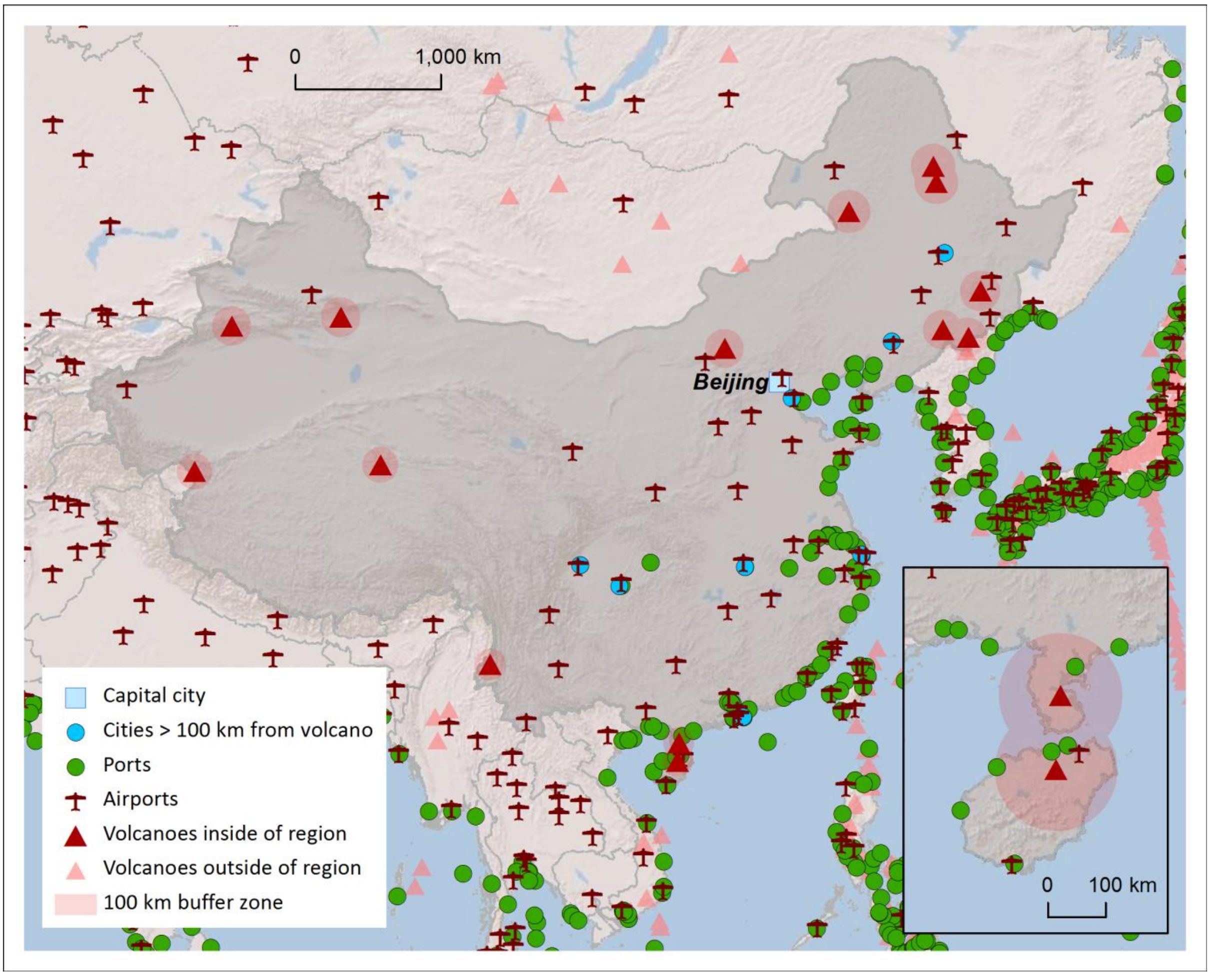


Figure 215: The location of China's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	4
Total length of roads within 100 km of a volcano (km)	12,059
Total length of railroads within 100 km of a volcano (km)	2,645

The volcanoes of China are widespread throughout the country. Those volcanoes in the west of the country are inland, away from the coast and ports, and distal to the largest cities in China which are concentrated in the east of the country. The Hainan Dao and Leizhou Bandao volcanoes in the south have ports and an airport within 100 km radius. Further airports are located in the radii of the northern volcanoes, though none of the ten largest cities are exposed. An extensive road and rail network falls within the radii. Some of the volcanoes here are located on the border with surrounding countries, with their 100 km radii extending into these countries including Myanmar, the DPRK, Mongolia and the Tibet Autonomous Region.

Hazard, Uncertainty and Exposure Assessments

The eruption record for the volcanoes in China are not sufficiently extensive or detailed to enable assessment of the hazard through the calculation of the VHI without large uncertainties, and these volcanoes are therefore unclassified. Out of the 22 confirmed Holocene eruptions here, only seven have a known VEI. Four volcanoes have a historical eruption record, two of which have erupted since 1900AD – Kunlun Volcanic Group and Changbaishan. Changbaishan has a record of three Holocene eruptions of VEI ≥4, including a VEI 7 eruption in 1000 AD.

The PEI in China ranges from low to very high, with over half the volcanoes having PEI 5 – 7. The risk levels are unclassified as hazard is not known.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		**Kunlun Volcanic Group**	**Changbaishan**		Wudalianchi		Hainan Dao
	U- HR		Tianshan Volcanic Group	Arshan		Turfan; Jingbo; Longgang Group	Tengchong	
	U- NHHR		Unnamed		Keluo Group	Honggeertu		Leizhou Bandao
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 203: Identity of China's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Four Chinese volcanoes have historical records of eruptions. At the time of the writing of this report no information is available to indicate the presence of dedicated ground-based monitoring at Hainan Dao or Kunlun Volcanic Field. However, the Institute of Geology, China Seismological Bureau monitor three: Changbaishan using at least one permanent seismic station, deformation and gas measurements; Wudalianchi using seismic stations; and the Holocene age Tenchong using an integrated monitoring network.

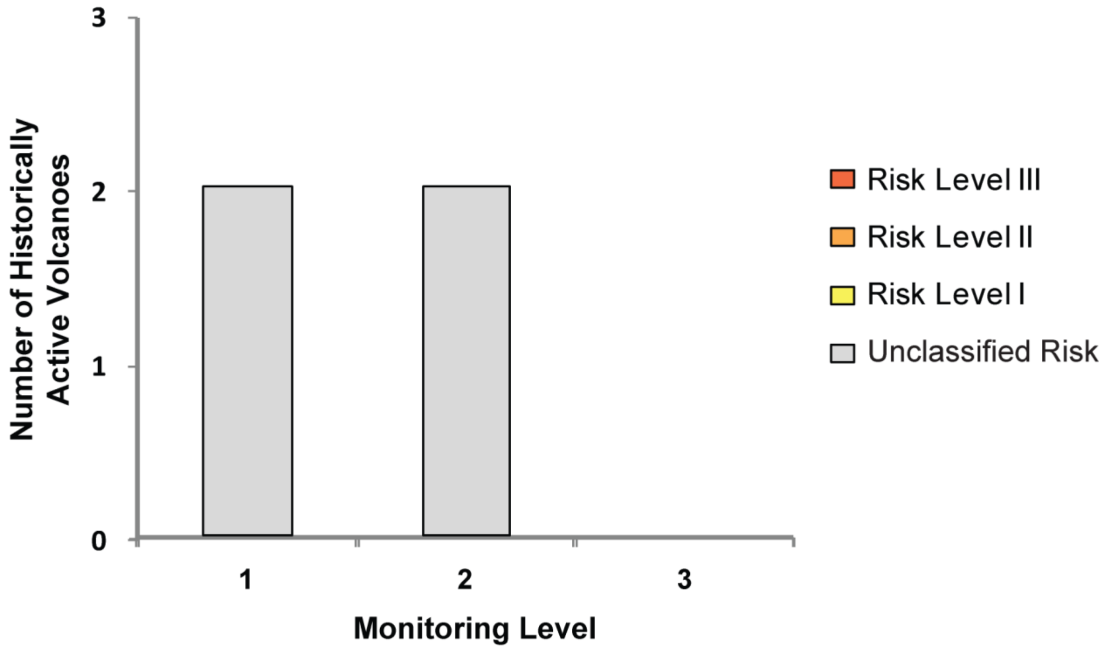


Figure 216: The monitoring and risk levels of the historically active volcanoes in China. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Democratic People’s Republic of Korea (DPRK)

Description

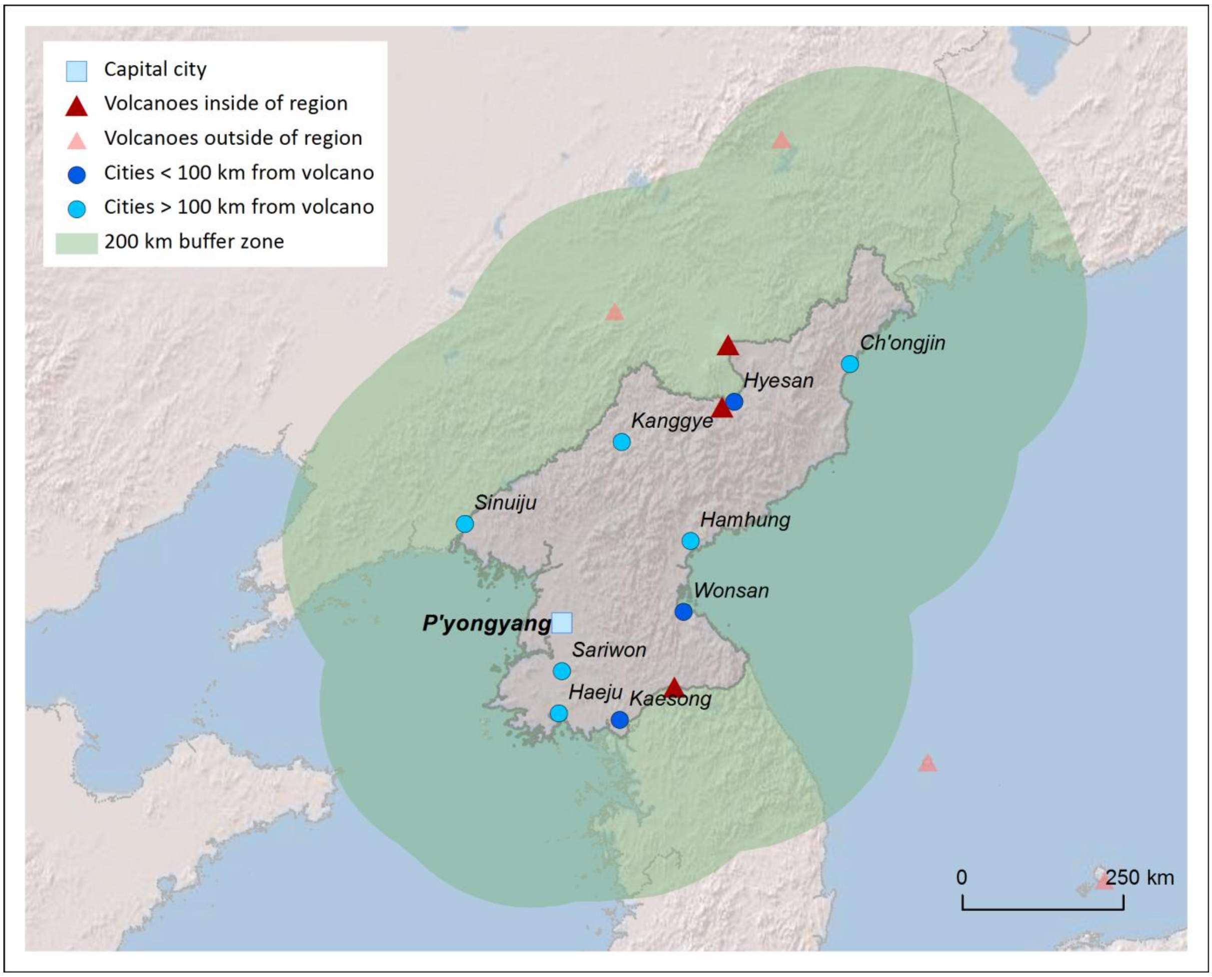


Figure 217: Location of the Democratic People’s Republic of Korea’s volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the DPRK.

Three Holocene volcanoes are recorded in the DPRK. One lies on the border with the Republic of Korea, whilst two others are located in the north of the country, on the border with China. These volcanoes are related to intra-plate processes, although this is not confirmed.

Changbaishan (the Chinese name for the volcano) is a large stratovolcano on the border with China. It is also known as Baektu, Paektu, Baegdu and Baitoushan, amongst other names. This is the only volcano in the DPRK to have a Holocene record of confirmed eruptions. The other two are suspected of having Holocene age activity.

Eight eruptions of VEI 2 to 7 are recorded at Changbaishan between 2160 BC and 1903. In 1000 AD the Millennium Eruption occurred. At VEI 7 this is one of the world’s largest Holocene eruptions, depositing rhyolitic and trachytic tephra as far as northern Japan and forming the present caldera. This caldera, measuring 5km wide and 850 m deep is now filled by Lake Tianchi.

The eruptive histories of volcanoes in the DPRK are limited, and further research is required to better understand volcanism in this country and the hazards posed.

The China Seismological Bureau has installed monitoring equipment on the China side of Changbaishan. In 2002-2005 this began to show seismic activity and deformation of the flanks. Following this, scientists in the DPRK reached out for international collaboration to install monitoring equipment in the DPRK to more fully understand the workings of the volcano. A network of seismometers has been installed in collaboration with scientists from the UK and US. Ongoing collaboration with scientists in the DPRK should permit further understanding of the volcanic processes here and will hopefully expand the DPRK's ability to monitor and research volcanic activity using techniques and research not otherwise easily accessible to them.

See also:

Stone, R. (2013) Sizing up a slumbering giant, Science, 6 September 2013: 1060-1061

Volcano Facts

Number of Holocene volcanoes	3, inclusive of one on the border with China and one on the border with the Republic of Korea
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	The M7 Oga eruption of Changbaishan at 448 ka.
Largest recorded Holocene eruption	The 950 BP Baegdusan-Tomakomai tephra eruption from Changbaishan on the border with China at M7.4.
Number of Holocene eruptions	8 confirmed eruptions. 5 uncertain eruptions.
Recorded Holocene VEI range	2 – 7 and unknown.
Number of historically active volcanoes	1
Number of historical eruptions	4

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Trachytic / Andesitic (1)
1	Shield(s)	Basaltic (1)
1	Unknown	Unknown (1)

Table 204: The number of volcanoes in the DPRK, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	24,763,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	-
Gross National Income (GNI) per capita (2005 PPP $)	-
Human Development Index (HDI) (2012)	-

Population Exposure

Capital city	Pyongyang
Distance from capital city to nearest Holocene volcano	157.2 km
Total population (2011)	24,457,492
Number (percentage) of people living within 10 km of a Holocene volcano	23,737 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	406,248 (1.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	2,430,099 (9.9%)

Ten largest cities, as measured by population, and populations:

P'yongyang	3,222,000
Hamhung	559,056
Kaesong	338,155
Wonsan	329,207
Ch'ongjin	327,000
Sinuiju	288,112
Haeju	222,396
Kanggye	209,530
Sariwon	154,942
Hyesan	97,794

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	4,147
Total length of railroads within 100 km of a volcano (km)	829

The volcanoes in the DPRK border China to the north and the Republic of Korea to the south, thus exposing parts of these countries to the volcanic hazard. Two of the largest cities in the DPRK are located within the 100 km radii – Kaesong and Hyesan, thus exposing an extensive road and rail network. Pyongyang lies at over 150 km from a Holocene volcano.

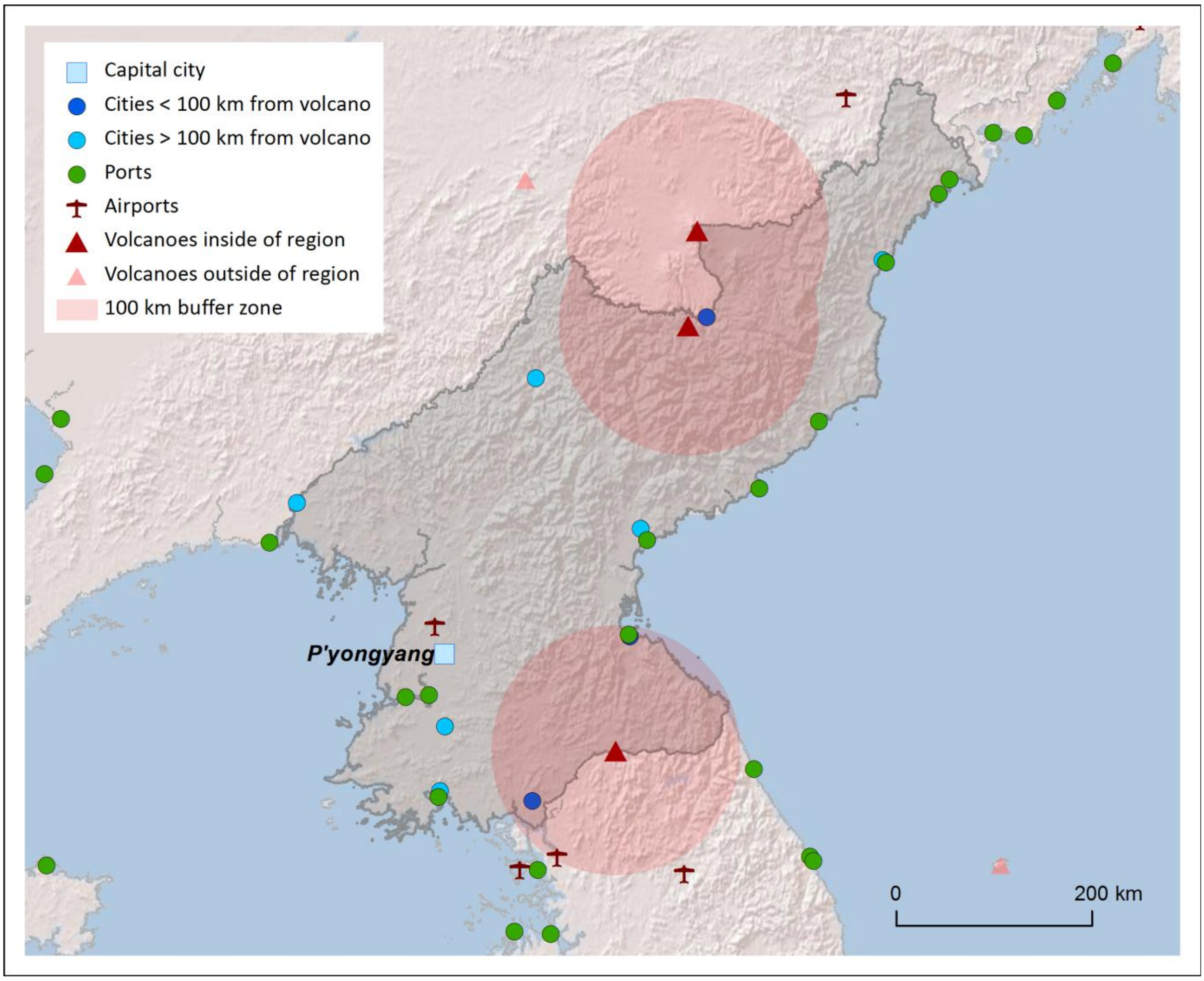


Figure 218: The location of the DPRK's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Only Changbaishan on the border between the DPRK and China has a Holocene eruption record here; Xianjindao and Ch'uga-ryong have no confirmed Holocene eruptions. Without a detailed eruption record, inclusive of eruption sizes, hazard assessment through the calculation of the VHI is not viable without large uncertainties. These volcanoes are therefore unclassified. Changbaishan, though unclassified, is known to have a record of large explosive eruptions, including two Holocene VEI 4 events and one VEI 7 eruption in 1000 AD. This volcano also has erupted, on a smaller scale, since 1900 AD.

Changbaishan has the lowest PEI in the DPRK, at a PEI of 3. Xianjindao and Ch'uga-ryong both have larger local populations.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR			**Changbaishan**				
	U- HR							
	U- NHHR				Xianjindao	Ch'uga-ryong		
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 205: Identity of DPRK's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Only Changbaishan has a historical record of activity. This volcano is monitored on the China side of the border by the China Seismological Bureau using both permanent and mobile seismic stations and mobile deformation stations. In the DPRK, a seismic network comprising six seismic stations was installed and is monitored by scientists at Imperial College London and Cambridge University (UK) along with scientists in North Korea, in a collaborative effort that began in 2011.

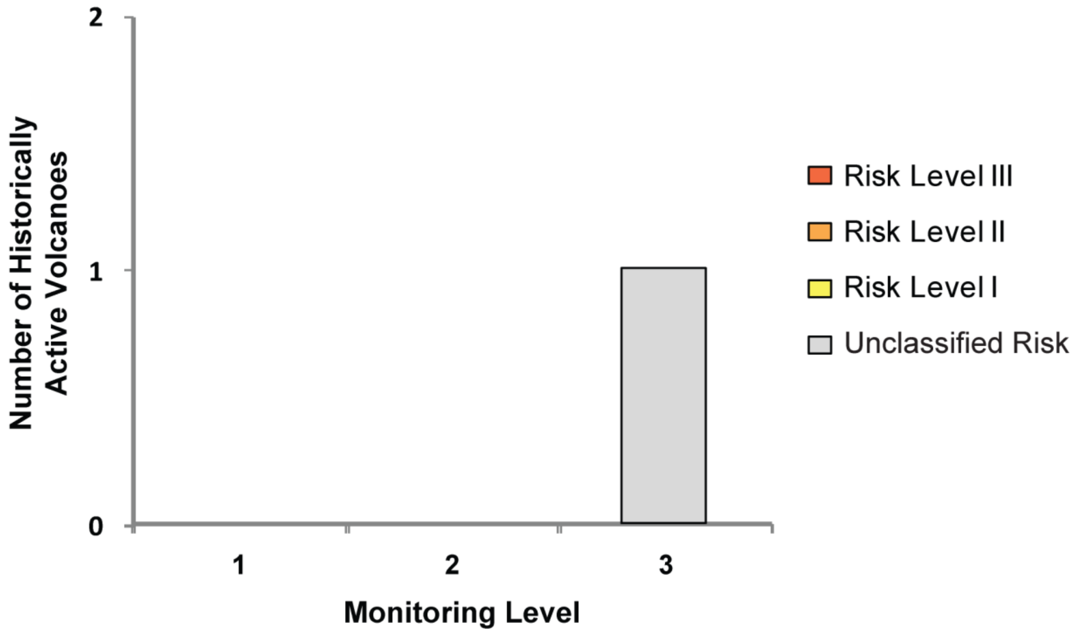


Figure 219: The monitoring and risk levels of the historically active volcanoes in the DPRK. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Mongolia

Description

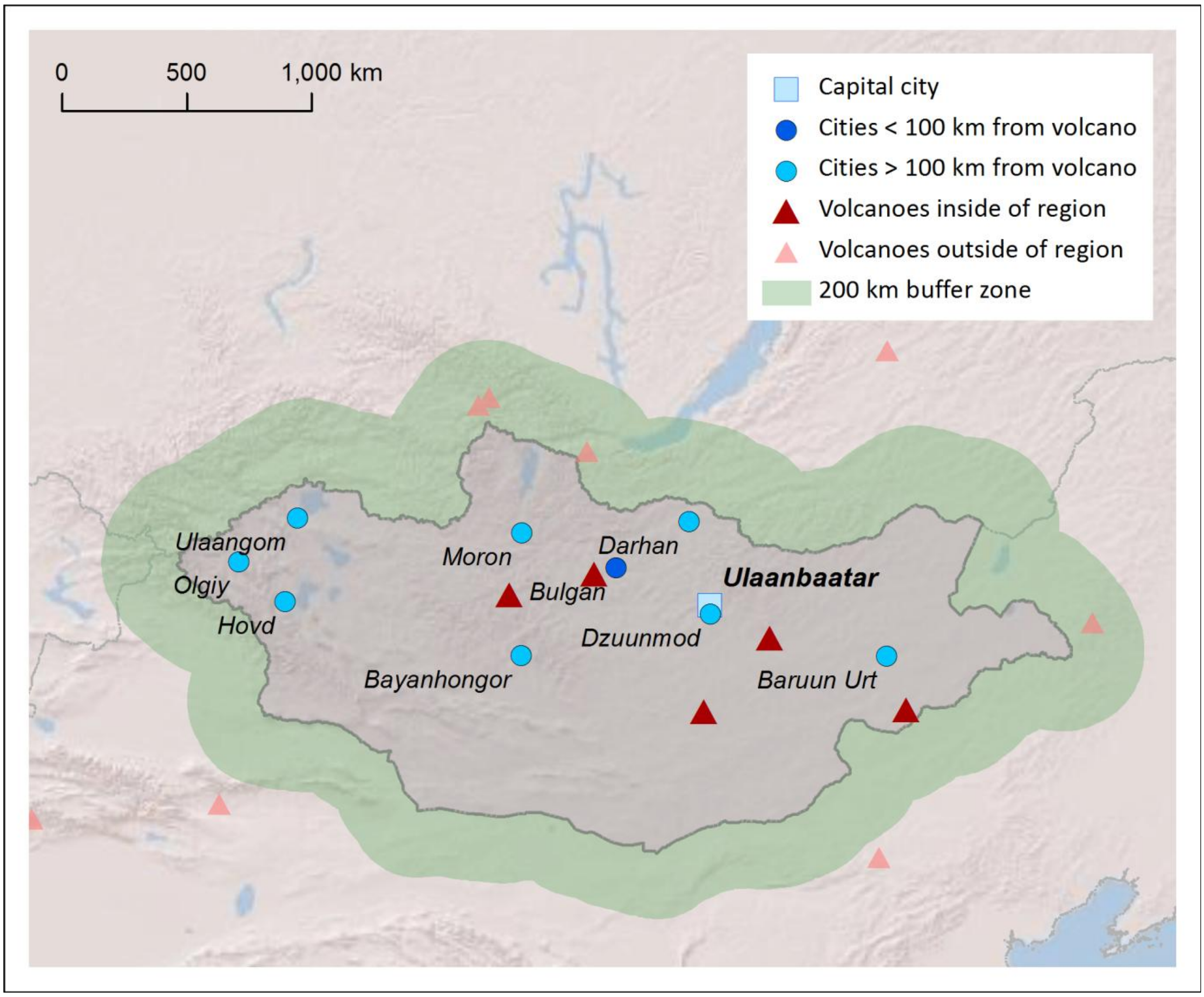


Figure 220: Location of Mongolia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Mongolia.

Five Holocene volcanoes are distributed throughout central to eastern Mongolia. These volcanoes are related to intra-plate processes. All volcanoes here are volcanic fields and cinder cones and are dominantly basaltic in composition.

Only one volcano, Taryatu-Chulutu, has an eruption recorded in the Holocene, however Holocene activity is suspected at the others. The eruption of Taryatu-Chulutu occurred in 2980 BC. The eruption size is unknown, however lava flows were produced at this time.

The absence of detailed eruption histories at Mongolia's volcanoes makes assessment of hazard difficult and therefore associated with large uncertainties. Although one of the largest cities in Mongolia, Bulgan, lies about 60 km from Khanuy Gol volcano, all the other volcanoes have moderate proximal population sizes.

The Asian Disaster Reduction Center (ADRC) have presented country reports on hazards in Mongolia since 1998. These do not consider volcanoes as it describes these as extinct. They describe the disaster management system in Mongolia and how the National Emergency Management Agency (NEMA) is "responsible for the implementation of the State disaster protection policy and legislation, as well as for the professional organization of nation wide activities". They also describe the structure of emergency response, numbers of emergency personnel and the activities within Mongolia towards addressing the Hyogo Framework for Action (HFA). See their report (given below) for full details.

See also:

NEMA: http://nema.gov.mn/

ADRC information on Disaster Risk Reduction of the Member Countries: Mongolia:
http://www.adrc.asia/nationinformation.php?NationCode=496&Lang=en&NationNum=18

Volcano Facts

Number of Holocene volcanoes	5
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	
Largest recorded Holocene eruption	The eruption has no known VEI.
Number of Holocene eruptions	1 confirmed eruption.
Recorded Holocene VEI range	Unknown
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
5	Small cone(s)	Andesitic (1), Basaltic (4)

Table 206: The number of volcanoes in Mongolia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	2,793,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,178
Gross National Income (GNI) per capita (2005 PPP $)	4,245
Human Development Index (HDI) (2012)	0.675 (Medium)

Population Exposure

Capital city	Ulan Bator
Distance from capital city to nearest Holocene volcano	185 km
Total population (2011)	3,133,318
Number (percentage) of people living within 10 km of a Holocene volcano	1,391 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	13,413 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	120,899 (3.9%)

Ten largest cities, as measured by population, and populations:

Ulaanbaatar	844,818
Darhan	74,300
Olgiy	28,400
Ulaangom	28,085
Hovd	27,924
Moron	27,690
Bayanhongor	23,234
Dzuunmod	17,738
Bulgan	17,348
Baruun Urt	15,805

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	2,041
Total length of railroads within 100 km of a volcano (km)	191

The Mongolian volcanoes are located through central Mongolia. The Dariganga Volcanic Field lies near the border with China, thus an area of China lies within the 100 km radius of this volcano. Part of eastern Mongolia lies within the radius of the Arshan volcano in north-western China. Being an inland country, no ports are exposed to the volcanic threat. One of the largest cities in Mongolia, Bulgan, lies within 100 km of the Khanuy Gol volcano, exposing the infrastructure here. However the capital, Ulaanbaatar, lies at nearly 200 km distance. A considerable road network is exposed in Mongolia.

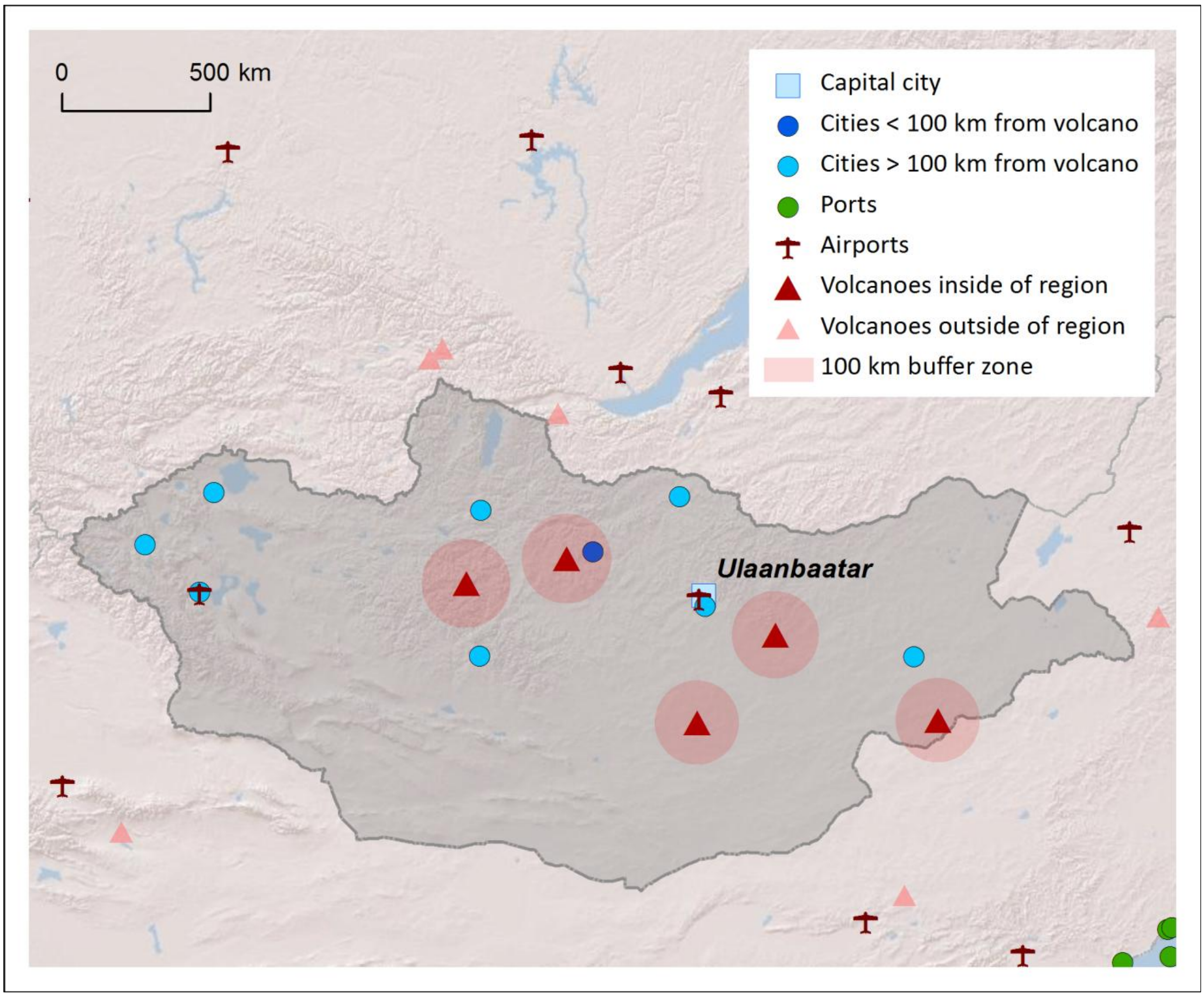


Figure 221: The location of Mongolia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Of Mongolia's volcanoes, only Tayatu-Chulutu has a Holocene eruption record, and this comprises just one eruption of unknown size. The absence of extensive eruption histories prevents the assessment of hazard through the calculation of the VHI without large associated uncertainties. These volcanoes are therefore unclassified.

The PEI ranges from low to moderate, from PEI 2 – 4. The risk is unclassified with the absence of hazard information.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR			Taryatu-Chulutu				
	U- NHHR		Bus-Obo	Khanuy Gol; Middle Gobi	Dariganga Volcanic Field			
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 207: Identity of Mongolia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Mongolia have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Mongolia.

Republic of Korea

Description

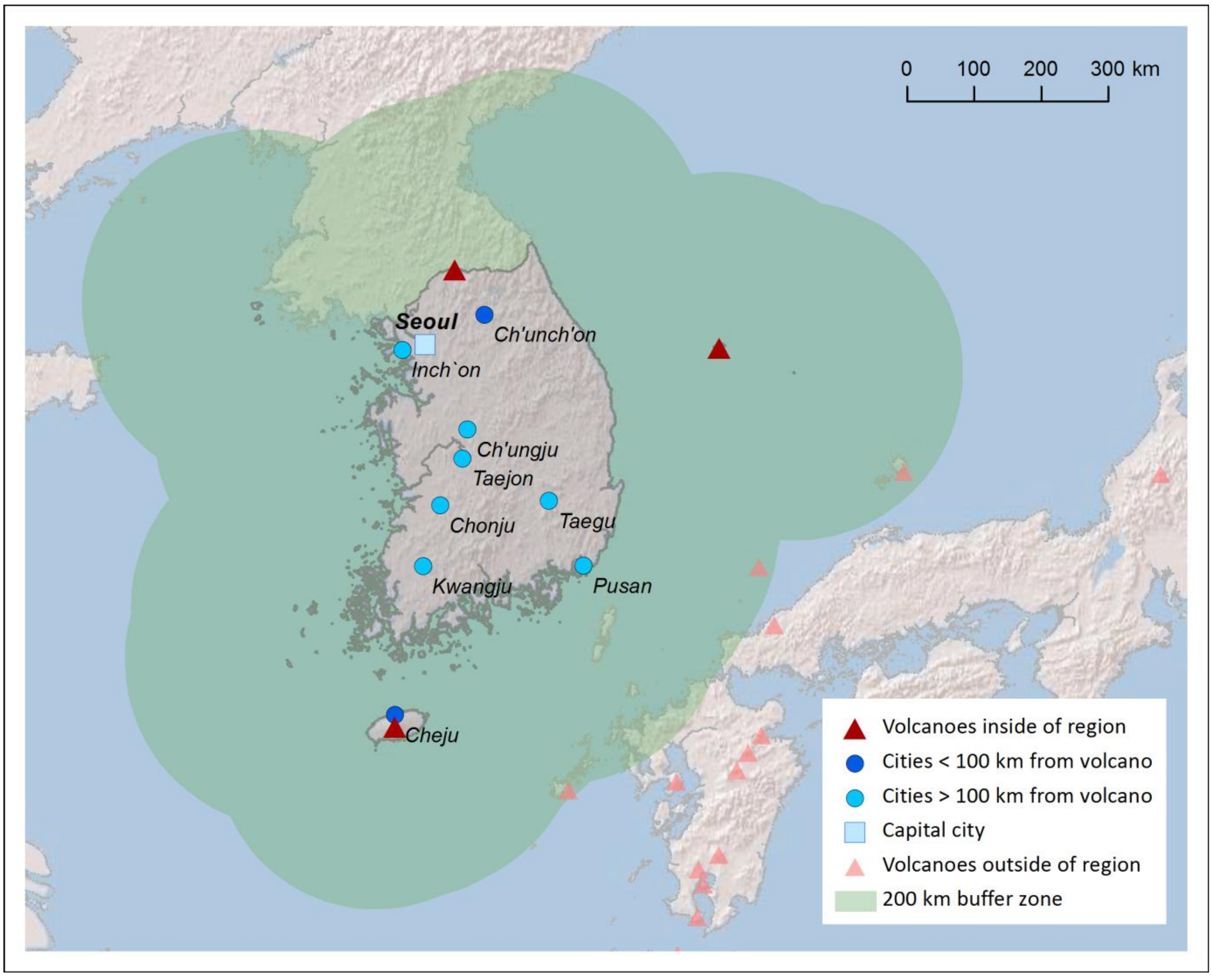


Figure 222: Location of the Republic of Korea's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Republic of Korea.

Three Holocene volcanoes are located in the Republic of Korea – Ch'uga-ryong (now called Chugaryeong) on the border with the DPRK, Ulreung (now called Ulleung) off the east coast and Mt. Halla (also called Hallasan, Jeju Island) off the south coast. Volcanism here is attributed to intra-plate processes. We use the older names as currently used in VOTW4.0 for this report.

Ch'uga-ryong and Halla are basaltic shields. Ulreung is more felsic, being a dominantly trachy-andesitic stratovolcano.

Only Ulreung and Mt. Halla have confirmed eruptions recorded during the Holocene, with several eruptions recorded between about 9300-6300 BP and 2700 BP. Only one of these eruptions has an attributed size, with the 8750 BC eruption of Ulreung being a VEI 6 eruption which produced pyroclastic flows and deposited ash in central Japan. No historical activity has been recorded, with the most recent activity being the 1002 AD and 1007 AD eruptions of Mt. Halla.

The absence of detailed eruptive histories for the volcanoes in the Republic of Korea, particularly with eruptions of unknown magnitudes, makes assessment of hazard difficult and associated with uncertainties. Both Ulreung and Halla form small populated islands, which are at particular risk due to the logistics of evacuating islands in a timely manner.

Monitoring of Mt. Halla is undertaken by the Jeju Volcanological Institute in collaboration with the Korea Institute of Geoscience and Mineral Resources (KIGAM) through the use of seismic and deformation instrumentation. This institute was founded in 2003 to undertake scientific research and monitoring. The personnel in this institute have some experience of responding to an eruption and have some resources and plans in place to respond to developing unrest and eruptions. Research into volcanic hazards is also ongoing focussed on the potential activity of Baekdusan (Mt. Baekdu, or Changbaishan in Chinese) in the neighbouring DPRK and the potential for the expansion of ash clouds from this volcano into the Republic of Korea.

The Asian Disaster Reduction Center (ADRC) produced a report on hazards in the Republic of Korea in 2008, with five previous versions dating back to 1998. In these they do not consider volcanic hazards. They describe the disaster management system in the country comprising the National Emergency Management Agency (NEMA), the National Disaster Management Institute and the National Institute for Disaster Prevention (NIDP). See the ADRC report for full details.

See also:

Jeju Island Geopark: http://geopark.jeju.go.kr/english/?mid=0101

Korea Institute of Geoscience and Mineral Resources: http://www.kigam.re.kr/english/index.asp

Asian Disaster Reduction Center: Republic of Korea:
http://www.adrc.asia/nationinformation.php?NationCode=410&Lang=en&NationNum=21

Volcano Facts

Number of Holocene volcanoes	3, inclusive of one on the border with the DPRK
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	2
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	The M6.7 Ulreung eruption of 10.7 ka would be the largest Pleistocene eruption recorded here, however as this is also

	included in the Holocene dataset, the M6 Yamato eruption of Ulreung at 42 ka will be considered the largest Pleistocene event.
Largest recorded Holocene eruption	The M6.7 eruption of Ulreung at 10.7 ka producing the Oki tephra is just outside of the Holocene but is included in the Holocene dataset of VOTW4.0.
Number of Holocene eruptions	7 confirmed eruptions.
Recorded Holocene VEI range	6 and Unknown.
Number of historically active volcanoes	-
Number of historical eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Andesitic (1)
2	Shield(s)	Basaltic (2)

Table 208: The number of volcanoes in the Republic of Korea, their volcano type classification and dominant rock type according to VOTW4.0.

The shield volcano of Halla has more than 360 monogenetic cones, producing flank eruptions as recently as the 11th century.

Socio-Economic Facts

Total population (2012)	48,943,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	27,541
Gross National Income (GNI) per capita (2005 PPP $)	28,231
Human Development Index (HDI) (2012)	0.909 (Very High)

Population Exposure

Capital city	Seoul
Distance from capital city to nearest Holocene volcano	89.3 km
Total population (2011)	48,754,657

Number (percentage) of people living within 10 km of a Holocene volcano	3,400 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	538,158 (1.1%)
Number (percentage) of people living within 100 km of a Holocene volcano	3,997,131 (8.2%)

Ten largest cities, as measured by population, and populations:

Seoul	10,349,312
Busan (Pusan)	3,678,555
Incheon (Inch`on)	2,628,000
Daegu (Taegu)	2,566,540
Daejeon (Taejon)	1,475,221
Gwangju (Kwangju)	1,416,938
Jeonju (Chonju)	711,424
Cheongju (Ch'ungju)	634,596
Jeju (Cheju)	329,068
Chuncheon (Ch'unch'on)	209,746

Infrastructure Exposure

Number of airports within 100 km of a volcano	3
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	3,953
Total length of railroads within 100 km of a volcano (km)	175

Ulreung lies more than 100km off the east coast of the Republic of Korea and is about 12 km across and thus the small settlements on the island lie entirely within the 100 km radius. Mt. Halla volcano lies off the coast to the south, exposing the island of Jeju Do (Cheju Do) in its entirety, as well as small islands closer to the mainland, with the 100 km radius extending to the southern tip of the mainland. Two airports and a port are exposed here. In the north, Ch'uga-ryong borders the DPRK, and the 100 km radius encompasses much of the northern Republic of Korea and southern DPRK. Seoul, the capital of the Republic of Korea, lies less than 90 km from this volcano, therefore considerable critical infrastructure is exposed.

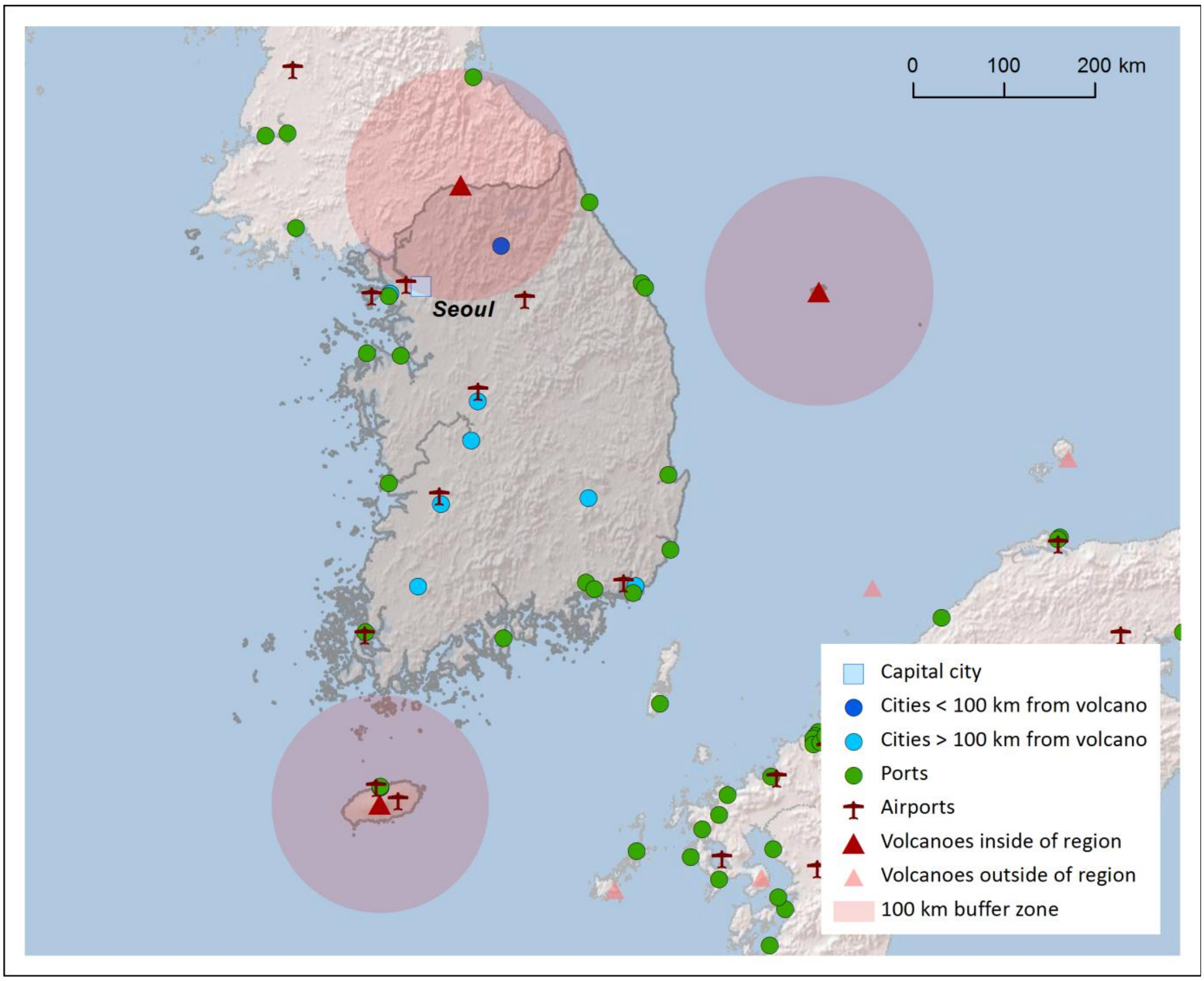


Figure 223: The location of the volcanoes in the Republic of Korea and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The eruption records for the volcanoes in the Republic of Korea are not sufficiently extensive for hazard assessment through the calculation of the VHI without large associated uncertainties, with just one eruption having an attributed VEI here. These volcanoes are therefore unclassified. Ulreung and Halla have seven Holocene eruptions between them, however Ch'uga-ryong has no confirmed Holocene events.

The PEI is moderate to high in the Republic of Korea, ranging from 3 to 5. Risk Levels are not classified here due to the absence of hazard information.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR			Ulreung	Halla			
	U- NHHR					Ch'uga-ryong		
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 209: Identity of the Republic of Korea's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in the Republic of Korea have recorded historical eruptions. However the Juju Volcanological Institute operates two seismometers and deformation instrumentation at Mt. Halla volcano, which has a Holocene record of activity from the 11th Century.

Russia

Note that we include Elbrus volcano from Region 1 here. See Region 9 for description of the Kuril Islands and Russian volcanoes here.

Description

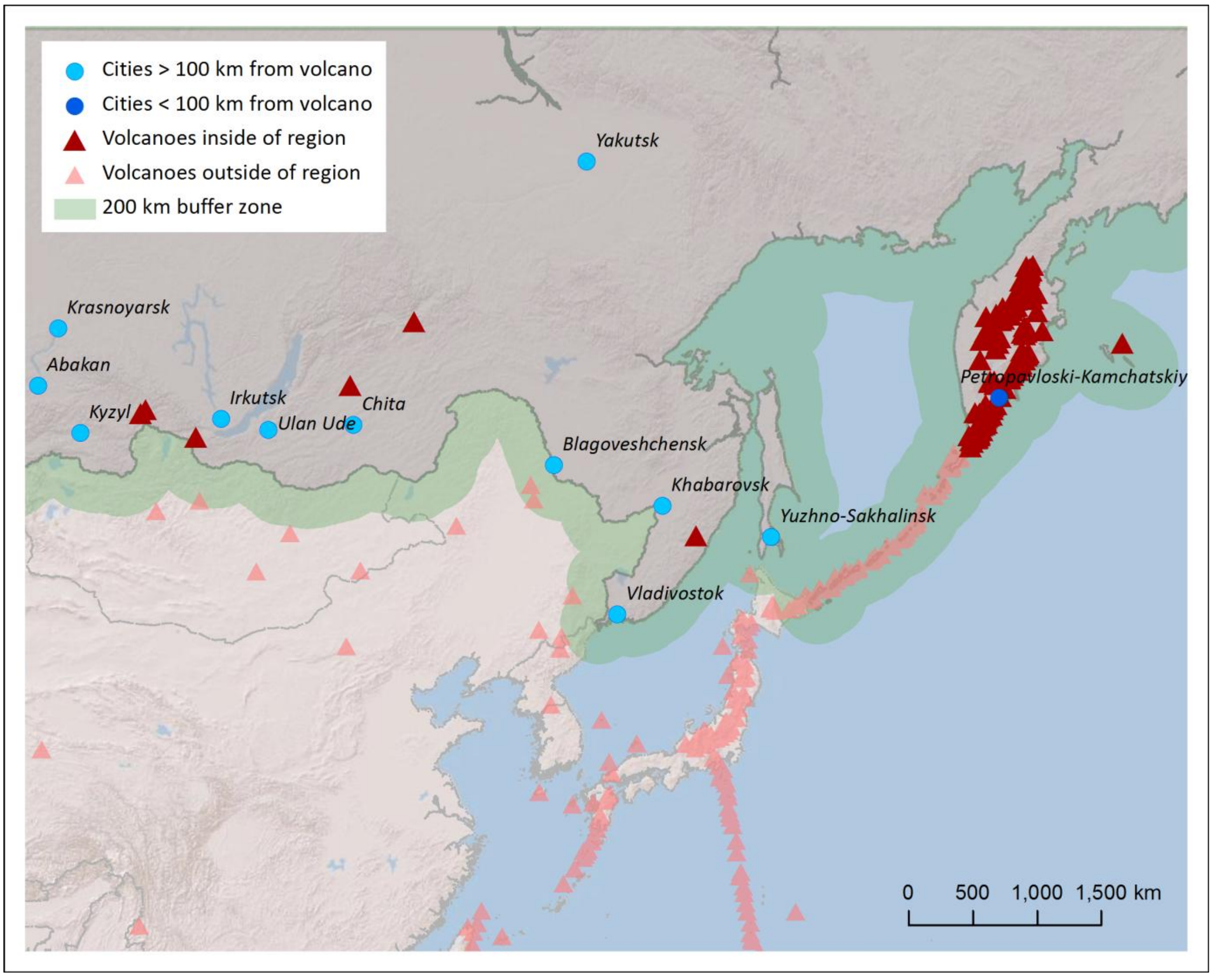


Figure 224: Location of Russia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Russia.

Volcanic activity in Russia is concentrated in the country's easternmost region - on the Kamchatka peninsula and the Kurile island arc which stretches from Kamchatka in the north to Japan in the south. The activity arises due to the subduction of the Pacific Plate and forms part of the Pacific Ring of Fire. In addition, volcanism caused by tectonic rifting has occurred in the mainland part of Russia but is small and infrequent in comparison to the Kurile-Kamchatka volcanic arc. According to IVS volcano observatory, 3-5 volcanoes on the Kurile-Kamchatka arc are erupting on a daily basis.

Over half of the erupted material on the Kurile-Kamchatka volcanic arc is produced by the Central Kamchatka Depression on the Kamchatka peninsula. Here we find one of the largest volcanic centres in the world which includes the Klyuchevskoy volcano group and Sheveluch volcano. Frequent and vigorous volcanic activity continues SSE along the Eastern Volcanic Belt which is 850 km long and 50-100 km wide.

Highly active volcanism in Kamchatka has been ongoing for the past 2-2.5 million years. Holocene activity has been dominated by formation of large and spectacular stratovolcanoes. The largest of them, Klyuchevskoy, reaches 4750 m a.s.l. and is the tallest volcano in Eurasia. The number of active volcanoes is 29, where active is defined as having erupted since the 17th century, although several additional volcanoes are included based on other evidence of activity.

Kurile island arc has both on-land and submarine volcanoes. Volcanoes on land include 37 active and potentially active volcanoes. The number of submarine volcanoes is estimated to be around 100. The largest recent eruption in the Kuriles was in 2009 at Sarychev volcano (VEI 4).

The volcanoes in this region are capable of producing large explosive eruptions with ash-rich plumes, pyroclastic flows, direct blasts and deposits of ballistic material. Long-duration effusive eruptions can produce extensive lava flows, such as demonstrated by the eruption of Plosky Tolbachik 2012-2013. However, due to the sparse population of the region, the greatest volcanic hazard is ash on aviation routes. The tectonic nature of the region may also cause large earthquakes.

In Kamchatka, populated centres are located at over 30 km distance from volcanic centres. There have been 3 casualties in 3 separate eruptions of Klyuchevskoy since 1960 where scientists were killed near the summit. The largest eruptions over the last century, such as Bezymianny in 1956 (eruption column of 40 km a.s.l. and directed blast of 25-30 km, VEI 5) have not caused casualties or significant damage to infrastructure.

Regular monitoring of Kamchatkan volcanoes began in 1935 when the Kamchatka Volcanological Station was founded in Kliuchi. This is now the Institute of Volcanology and Seismology (IVS). The Kamchatka Volcanic Eruption Response Team (KVERT) was established in 1993. KVERT is responsible for issuing alerts (including aviation colour codes) for Kamchatka and Northern Kurile volcanoes.

See also:

Kamchatka Volcanic Eruption Response Team (KVERT):
http://www.kscnet.ru/ivs/kvert/index_eng.php

Institute of Volcanology and Seismology: http://www.kscnet.ru/ivs/eng/

Volcano Facts

Number of Holocene volcanoes	154
Number of Pleistocene volcanoes with M≥4 eruptions	20
Number of volcanoes generating pyroclastic flows	28
Number of volcanoes generating lahars	17
Number of volcanoes generating lava flows	54
Number of fatalities caused by volcanic eruptions	6

Tectonic setting	147 subduction zone, 2 intra-plate, 4 rift-zone, 1 unknown.
Largest recorded Pleistocene eruption	The M7.6 eruption of the Golygin Ignimbrite from Diky Greben at 443 ka.
Largest recorded Holocene eruption	The KO eruption of Kurile Lake, at M7.2 in 8387 BP.
Number of Holocene eruptions	891 confirmed eruptions. 32 uncertain eruptions and 8 discredited eruptions.
Recorded Holocene VEI range	0 – 7 and unknown.
Number of historically active volcanoes	25
Number of historical eruptions	330

Number of volcanoes	Primary volcano type	Dominant rock type
10	Caldera(s)	Andesitic (5), Basaltic (4), Dacitic (1)
71	Large cone(s)	Andesitic (36), Basaltic (31), Dacitic (3), Unknown (1)
4	Lava dome(s)	Andesitic (1), Basaltic (2), Dacitic (1)
44	Shield(s)	Andesitic (2), Basaltic (42)
20	Small cone(s)	Andesitic (4), Basaltic (13), Unknown (3)
5	Submarine	Dacitic (1), Unknown (4)

Table 210: The number of volcanoes in Russia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	143,021,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	14,808
Gross National Income (GNI) per capita (2005 PPP $)	14,461
Human Development Index (HDI) (2012)	0.788 (High)

Population Exposure

Capital city	Moscow
Distance from capital city to nearest Holocene volcano	1423.5 km

Total population (2011)	138,739,892
Number (percentage) of people living within 10 km of a Holocene volcano	4,718 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	84,639 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	2,369,815 (1.7%)

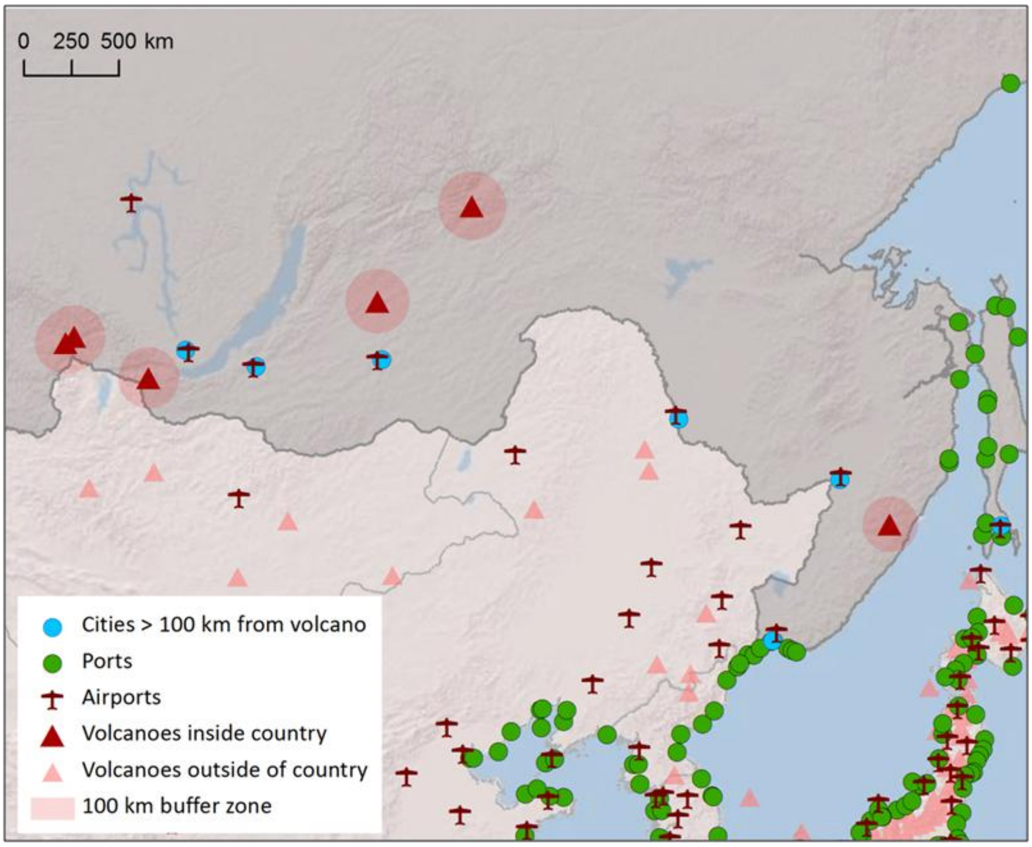
Ten largest cities, as measured by population, and populations:

Moscow	10,381,222
Novosibirsk	1,419,007
Ekaterinburg	1,287,573
Nizny Novgorod	1,284,164
Samara	1,134,730
Omsk	1,129,281
Kazan'	1,104,738
Rostov-on-Don	1,074,482
Chelyabinsk	1,062,919
Ufa	1,033,338

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	2
Total length of roads within 100 km of a volcano (km)	3,042
Total length of railroads within 100 km of a volcano (km)	863

Volcanoes in Russia are distributed between two main groups: those on the Kamchatka Peninsula and those inland, north of Mongolia. Volcanoes in the Kuril Islands are discussed in the separate Kuril Island profile. The concentration of volcanoes in the Kamchatka Peninsula means this is exposed in its entirety, however being sparsely populated the exposed population is small. This does however mean that all critical infrastructure here is exposed, including that in the largest city, Petropavlovsk-Kamchatsky.



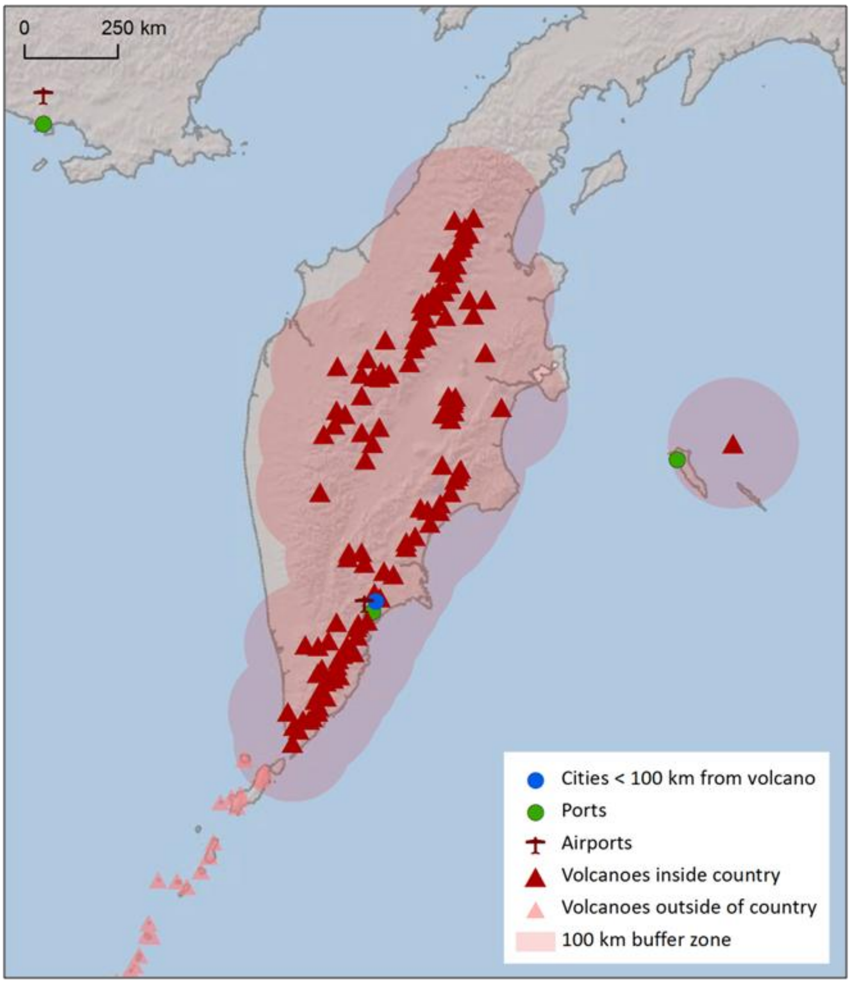


Figure 1: The location of Russia's volcanoes and the extent of the 100 km zone surrounding them. (Top) the eastern section of Mainland Russia; (Left) the Kamchatka Peninsula. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The volcanoes of Russia have varying levels of data available in the eruption record. Just 12% of volcanoes have appropriate eruptive histories to define the hazard. These volcanoes are classified across all three hazard levels, and all but three have erupted since 1900 AD. Of the classified volcanoes, just Kostakan has no historical record.

Most volcanoes in Russia lack a sufficiently extensive eruption record to determine the hazard through calculation of the VHI without large associated uncertainties, and these are therefore unclassified. Indeed, 61 of these volcanoes have no confirmed eruptions during the Holocene. Of these, one, Asacha, has experienced unrest since 1900 AD. Of the remaining unclassified volcanoes with Holocene eruptions, 12 have records of historical activity, including eruptions since 1900 AD at six volcanoes. Thirteen of the unclassified volcanoes have Holocene records of large explosive VEI ≥4 eruptions.

Most volcanoes in Russia have a low local population, categorising these as PEI 2 volcanoes. In combination with the Hazard Levels this makes most classified volcanoes Risk Level I with just four classed at Risk Level II.

Volcano	Population Exposure Index	Risk Level
Avachinsky	3	II
Koryaksky	3	II
Bezymianny	2	II
Shiveluch	2	II
Gorely	2	I
Karymsky	2	I
Kikhpinych	2	I
Kliuchevskoi	2	I
Kostakan	2	I
Krasheninnikov	2	I
Maly Semiachik	2	I
Mutnovsky	2	I
Tolbachik	2	I
Zhupanovsky	2	I

Table 211: Classified volcanoes of Russia ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 10 volcanoes; Risk Level II – 4 volcanoes; Risk Level III – 0 volcanoes.

CLASSIFIED	**Hazard III**		Bezymianny; Shiveluch	Koryaksky; Avachinsky				
	Hazard II		Karymsky; Maly Semiachik; Kikhpinych; Krasheninnikov; Tolbachik; Kliuchevskoi					
	Hazard I		Mutnovsky; Gorely; Zhupanovsky; Kostakan					
UNCLASSIFIED	**U – HHR**		Koshelev; **Ilyinsky**; **Zheltovsky**; **Ksudach**; Opala; **Akademia Nauk**; **Kronotsky**; **Kizimen**; Ushkovsky; Khangar; **Ichinsky**; Alney-Chashakondzha					
	U- HR		Kambalny; Yavinsky; Diky Greben; Kurile Lake; Khodutka; Tolmachev Dol; Vilyuchik; Barkhatnaya Sopka; Veer; Bakening; Zavaritsky; Bolshoi Semiachik; Taunshits; **Uzon**; Gamchen; Komarov; Vysoky; Piip; Cherpuk Group; Bolshoi-Kekuknaysky; Shisheika; Terpuk; Sedankinsky; Gorny Institute; Kinenin; Bliznetsy; Titila; Elovsky; Nylgimelkin; Spokoiny; Ostry; Severny; Udokan Plateau					
	U- NHHR		Mashkovtsev; Kell; Belenkaya; Ozernoy; Olkoviy Volcanic Group; Plosky; Piratkovsky; Ostanets; Otdelniy; Golaya; **Asacha**; Visokiy; Unnamed; Bely; Bolshe-Bannaya; Dzenzursky; Schmidt; Unnamed; Udina; Zimina; Kamen; Maly Payalpan; Bolshoi Payalpan; Akhtang; Kozyrevsky; Romanovka; Uksichan; Kulkev; Geodesistoy; Anaun; Krainy; Kekurny; Eggella; Cherny; Unnamed; Verkhovoy; Pogranychny; Zaozerny; Bliznets; Kebeney; Uka; Fedotych; Leutongey; Tuzovsky; Mezhdusopochny; Shishel; Alngey; Kaileney; Plosky; Snezhniy; Iktunup; Snegovoy; Iettunup; Voyampolsky; Vitim Plateau; Tunkin Depression; Oka Plateau; Azas Plateau			Unnamed; Unnamed; Sikhote-Alin		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 212: Identity of Russia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

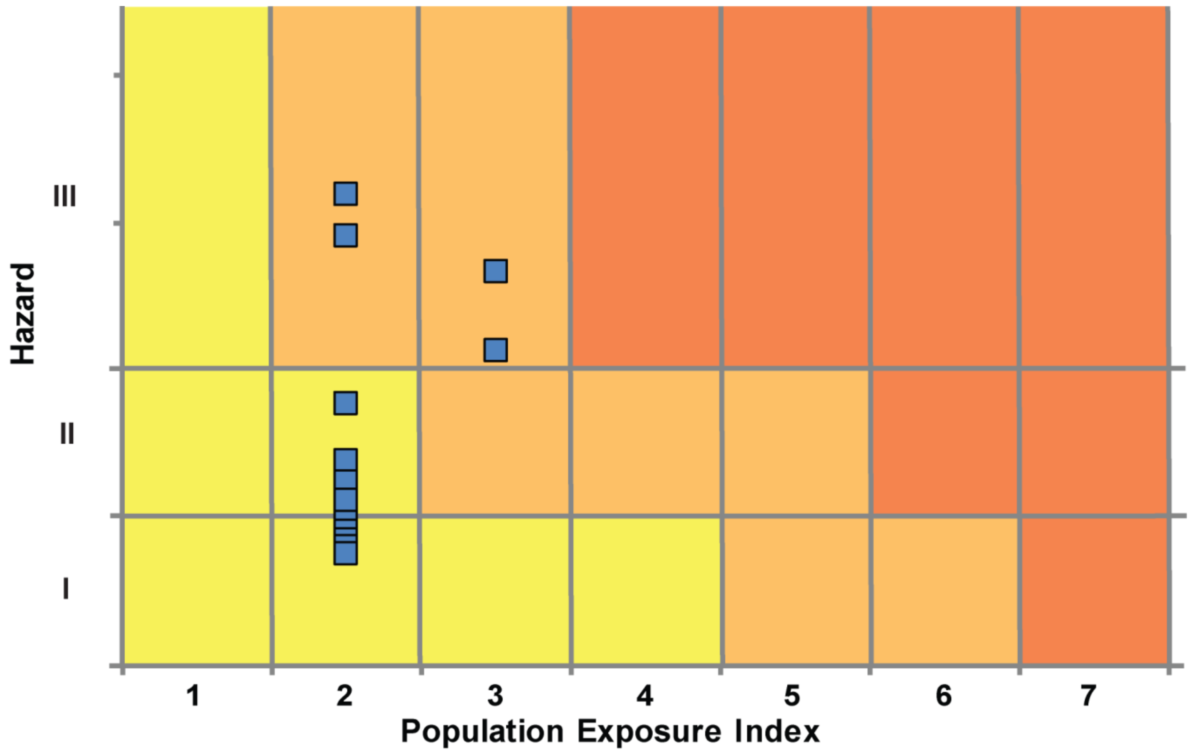


Figure 225: Distribution of Russia's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The Institute of Volcanology and Seismology (IVS FEB RAS) and Kamchatka Volcanic Eruption Response Team (KVERT) are responsible for monitoring volcanoes and providing aviation alerts. Twenty-five Russian volcanoes are recorded as having historical activity. Of these fourteen have no continuous monitoring. The remaining have dedicated seismic monitoring, from three or fewer stations at five volcanoes, to networks of seven or more stations. At least three volcanoes have additional deformation monitoring (Karymsky, Kliuchevskoi and Bezymianny).

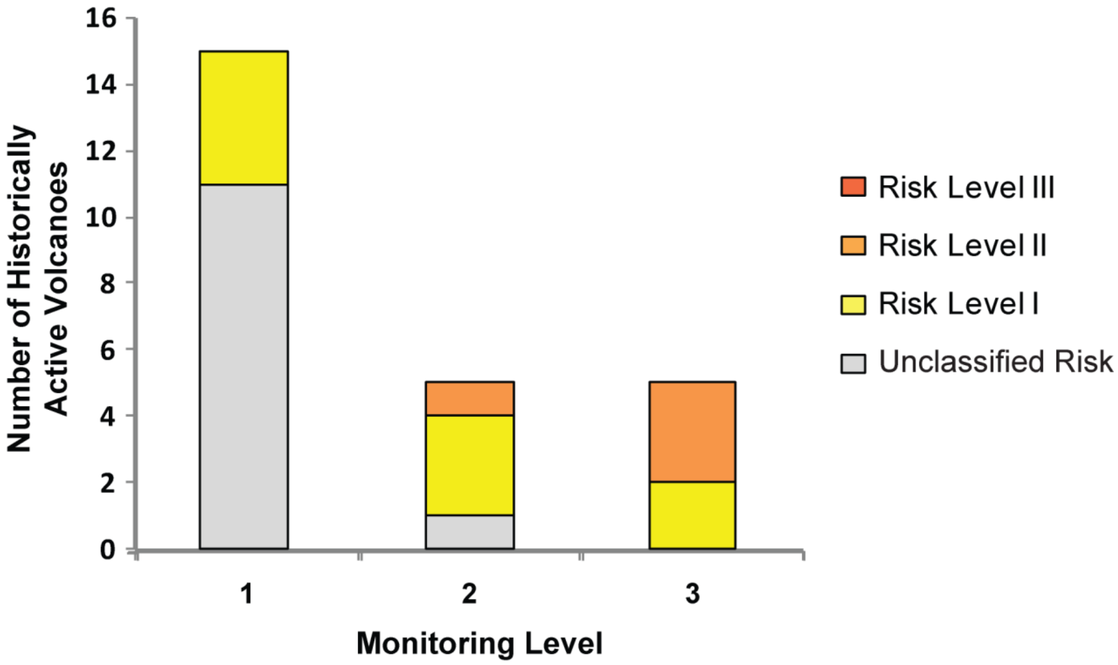


Figure 226: The monitoring and risk levels of the historically active volcanoes in Russia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 11: Alaska

Here volcanism in the U.S. state of Alaska is discussed. See Region 4 for American Samoa, Region 8 for the U.S. Marianas Islands, Region 12 for the contiguous states of the U.S.A. and Region 13 for Hawaii.

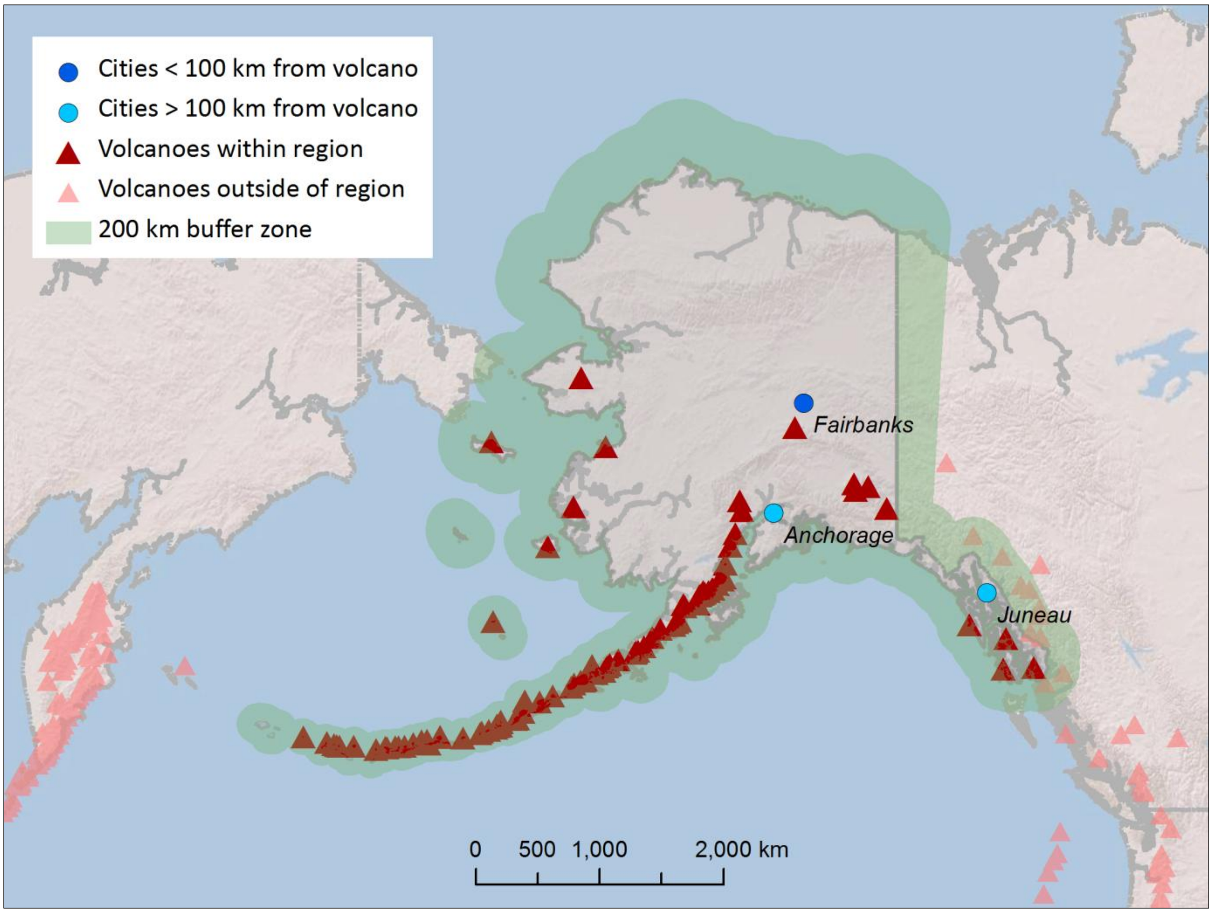


Figure 227: Location of Alaska's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Alaska

Description

This region comprises the American state of Alaska and the Aleutian Islands. Ninety-two Holocene volcanoes are located here, dominantly through the 2,500km Aleutian Arc, which extends towards Kamchatka forming the northern section of the Ring of Fire. Further volcanoes are situated in the interior of Alaska, south on the border with Canada and to the most northerly of Alaska's volcanoes – Imuruk Lake on the Seward Peninsula. Volcanism in Alaska and the Aleutians is dominantly due to the subduction of the Pacific Plate beneath the North American Plate, however eleven volcanoes are due to intra-plate processes. Volcanoes of Alaska are dominantly andesitic in composition and most are stratovolcanoes.

During the Holocene 526 eruptions of VEI 0 – 6 are recorded in Alaska from 59 volcanoes. The remaining volcanoes are suspected of having eruptions of Holocene age. 44 of these volcanoes have records of 333 historical eruptions, of which 13 were large explosive eruptions of VEI 4 to 6. The VEI 6 1912 eruption of Katmai/Novarupta was the largest in the 20th Century anywhere in the world, producing voluminous air fall and ash flow. With a record of such explosive events, many have produced pyroclastic flows and lahars, yet due to the sparse population in Alaska only three eruptions have resulted in fatalities. Indeed, fewer than 20,000 people live within 30 km of volcanoes throughout the state.

The Alaska Volcano Observatory (AVO) list Akutan, Pavlof and Shishaldin as the most frequently active volcanoes historically, though emphasise that even today, there may not be a complete catalogue of activity as many of Alaska's volcanoes are remote and visual observations may be hampered by inclement weather. The historic records indicate about 2 eruptions per year here.

The AVO monitors volcanoes throughout Alaska and is a partnership of the U.S. Geological Survey, the Geophysical Institute of the University of Alaska Fairbanks and the Alaska Division of Geological and Geophysical Surveys. The AVO was set up in 1988 to monitor and study volcanism in Alaska. The AVO relies on federal, state and university resources.

The volcanoes in Alaska are potentially hazardous to aircraft, with more than 80,000 large aircraft per year over and possibly downwind of volcanoes here (Schaefer and Nye, 2008). A passenger aircraft with 231 people on board lost all power after encountering the ash cloud from Redoubt Volcano in 1989. Fortunately, the engines restarted after free-falling about 3,000 metres (Casadevall, 1994 in Schaefer and Nye, 2008). Schaefer and Nye (2008) describe eruptions here during 1989 to 1990 as the second-most costly eruptions in the history of the United States, having impacted on the aviation and oil industries. The AVO notifies the public and Volcanic Ash Advisory Centres (VAAC's) of Volcano Alert Levels (Normal, Advisory, Watch, and Warning), and separate Aviation Color Codes are issued – Green to Red. See CS11, Main Technical Report.

The AVO conducts monitoring activities and scientific research, produces hazard assessments and is involved in hazard mitigation. Monitoring activities are widespread, with networks of seismometers and deformation instrumentation, in addition to satellite observations and deployment of other monitoring systems. About 30 volcanoes are monitored in Alaska and the Aleutians, including eighteen historically active volcanoes which have regular dedicated ground-based monitoring systems in place.

In the event of unrest or eruption, the AVO informs the public and emergency managers. The AVO communicates activity information to the Federal Aviation Administration, the National Weather Service, local military, civil authorities and the Alaska Department of Emergency Services and the Governor's Office of the State of Alaska. Information is released in line with the NVEWS method: VAN (Volcano Activity Notice) are important announcements of volcanic activity, change in activity, aviation colour code or alert levels; VONA (Volcano Observatory Notice for Aviation) focuses on ash cloud hazards; Daily Status Reports provide short statements on the activity of volcanoes at an elevated alert level; Weekly Summaries describe the week's activity and activity status of monitored volcanoes; and Information Statements provide further information on a variety of background topics.

See also:

Shaefer, J. and Nye, C. (2008) Monitoring the Active Volcanoes of Alaska, Alaska GeoSurvey News, Vol. II., No. 1. http://www.avo.alaska.edu/pdfs/cit4443.pdf

Alaska Volcano Observatory website: http://www.avo.alaska.edu/volcanoes/about.php

Volcano facts

Number of Holocene volcanoes	92
Number of Pleistocene volcanoes with M≥4 eruptions	7
Number of volcanoes generating pyroclastic flows	40
Number of volcanoes generating lahars	41
Number of volcanoes generating lava flows	90
Number of eruptions with fatalities	3
Number of fatalities attributed to eruptions	4
Tectonic setting	81 subduction zone, 11 intra-plate
Largest recorded Pleistocene eruption	The Old Crow Tephra eruption of Emmons Lake in Alaska is the largest Quaternary eruption recorded at M7.5. This eruption occurred at 96 ka.
Largest recorded Holocene eruption	Nine VEI 6 eruptions are recorded during the Holocene, with the most recent at Novarupta in 1912 AD.
Number of Holocene eruptions	526 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 6 and unknown.
Number of historically active volcanoes	44
Number of historical eruptions	333

Number of volcanoes	Primary volcano type	Dominant rock type
3	Caldera(s)	Andesitic (2), Rhyolitic (1)
67	Large cone(s)	Andesitic (43), Basaltic (13), Dacitic (3), Rhyolitic (2), Unknown (6)
3	Lava dome(s)	Andesitic (1), Dacitic (1), Unknown (1)
9	Shield(s)	Andesitic (3), Basaltic (6)
9	Small cone(s)	Andesitic (2), Basaltic (7)
1	Submarine	Andesitic (1)

Table 213: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	30

Table 214: Average recurrence interval (years between eruptions) for small and large eruptions in Alaska.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 30 years.

Eruption Size

Eruptions are recorded throughout Alaska and the Aleutian Islands of VEI 0 to 6, representing a range of eruption styles from mild events to large explosive eruptions. VEI 2 events dominate the record, with about 45% of all Holocene eruptions of a known size classed as such, and nearly 90% are small to moderate at VEI 0 to 3. Over 11% of eruptions are large explosive events at VEI≥4.

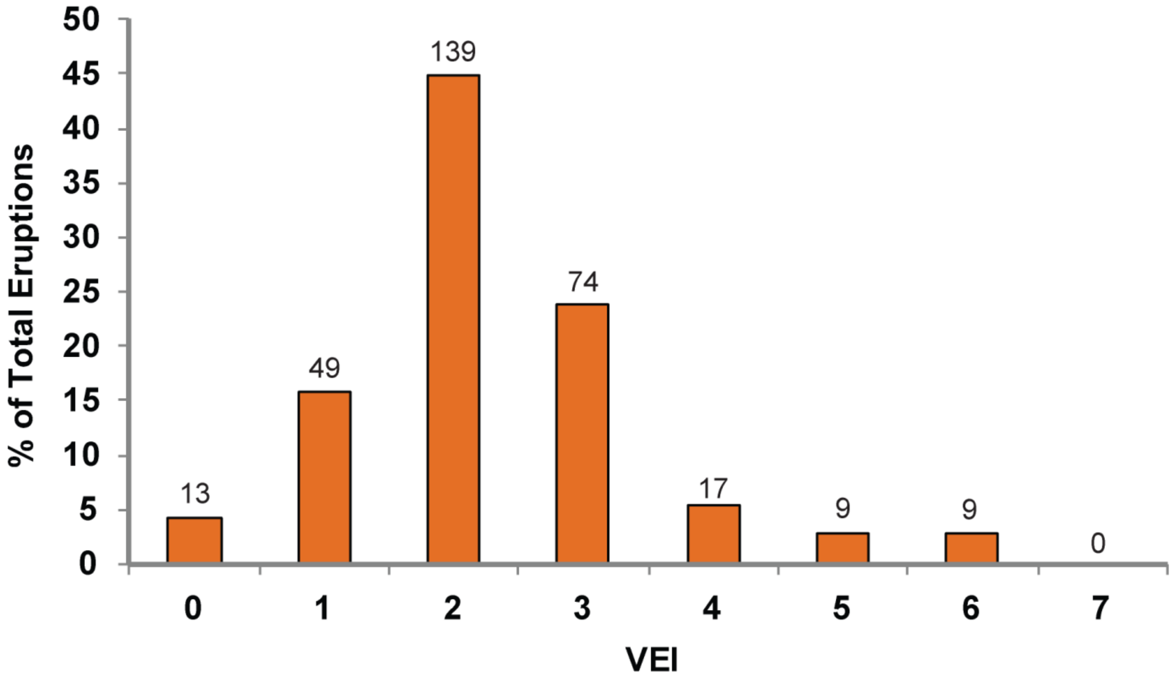


Figure 228: Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI (310 events). A further 216 eruptions were recorded with unknown VEI.

Population Exposure

Capital city (of the State)	Juneau
Distance from capital city to nearest Holocene volcano	161 km

Total Population (2013)	735,132 (US Census Bureau)
Number (percentage) of people living within 10 km of a Holocene volcano	<2,000
Number (percentage of people living within 30 km of a Holocene volcano	<20,000
Number (percentage of people living within 100 km of a Holocene volcano	<230,000

Largest cities as measured by population, and populations (from 2010 United States Census):

Anchorage	291,826
Fairbanks	31,535
Juneau	30,711

Infrastructure exposure

Number of airports within 100 km of a volcano	6
Number of ports within 100 km of a volcano	80
Total length of roads within 100 km of a volcano (km)	6,431
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes of Alaska and the Aleutian Islands are concentrated in the south and west of Alaska. Of the largest cities, only Fairbanks lies within 100 km of a volcano (Buzzard Creek), while the capital, Juneau, lies over 160 km away from a Holocene volcano. With the volcanoes primarily located on islands and along the coastline of southern Alaska, 80 ports are situated within 100 km of these. Six airports and an extensive road network also lie within 100 km of Alaskan volcanoes, and numerous small settlements, with no towns besides the three largest described here having a population higher than 10,000.

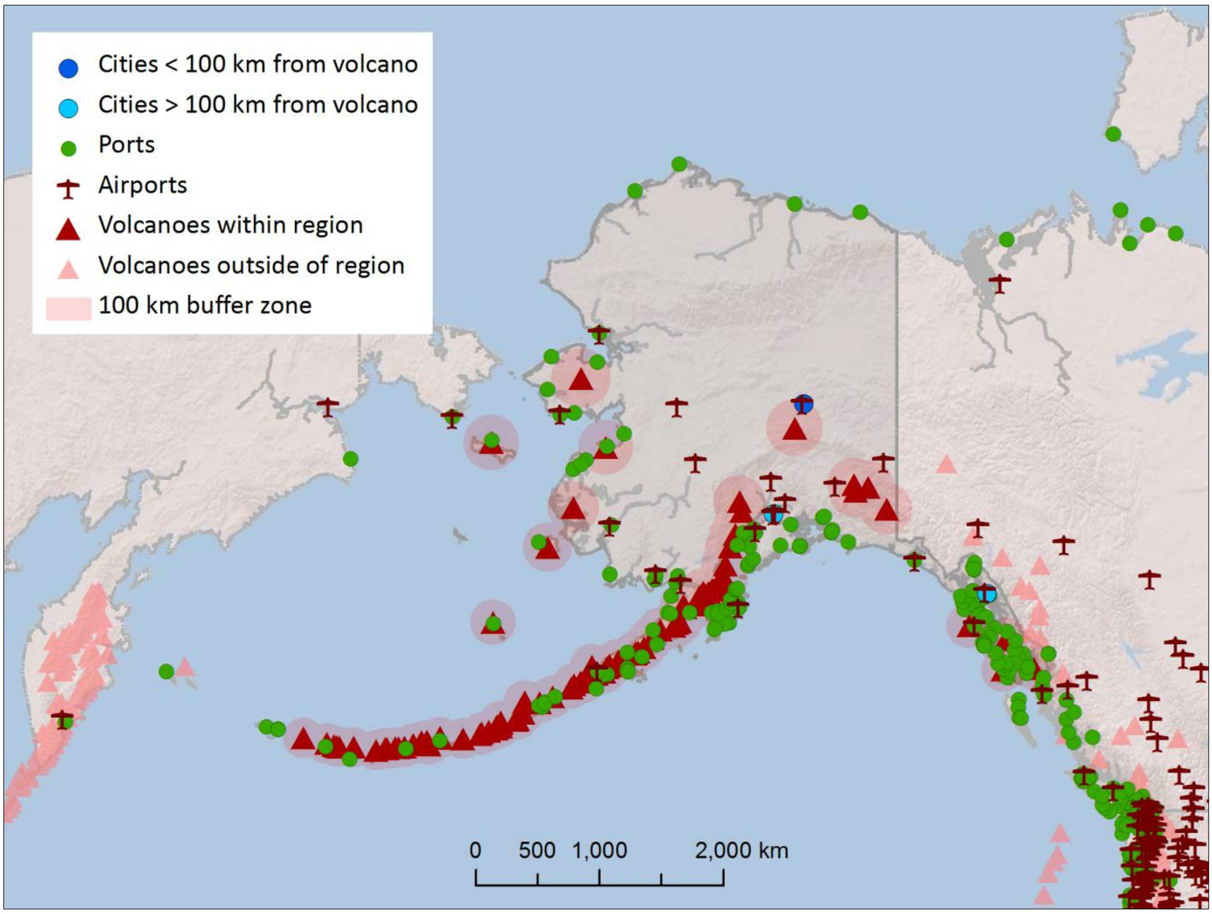


Figure 229: The location of Alaska's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Of the 92 volcanoes in Alaska, just 22 have an assigned hazard level based on their eruptive history. These volcanoes classify across all three hazard levels, with most at Hazard Level II. Just four volcanoes are classed at Hazard Level III – Fisher, Augustine, Iliamna and Redoubt. These four volcanoes all have records of explosive, pyroclastic flow producing eruptions.

Of the unclassified volcanoes, 33 have no confirmed eruptions during the Holocene, though Kukak, Douglas, Dutton and Emmons Lake all have periods of unrest above background levels since 1900. 22 unclassified volcanoes have confirmed historical (post 1500 AD) eruptions, and of these 15 have erupted since 1900 AD. Eleven unclassified volcanoes have Holocene records of large explosive (VEI ≥4) eruptions.

The small population in Alaska, particularly in proximity to the volcanoes, is evidenced by the classification of all volcanoes here at PEI 1 and 2. Of the classified volcanoes, all but the three Hazard Level III volcanoes are classed at Risk Level I.

CLASSIFIED	**Hazard III**	Fisher	Augustine; Iliamna; Redoubt					
	Hazard II	Seguam; Cleveland; Okmok; Trident	Bogoslof; Akutan; Westdahl; Shishaldin; Pavlof; Veniaminof					
	Hazard I	Kiska; Gareloi; Kanaga; Great Sitkin; Amukta	Korovin; Makushin; Wrangell					
UNCLASSIFIED	**U – HHR**	**Little Sitkin**; **Semisopochnoi**; **Tanaga**; Takawangha; **Yunaska**; Carlisle; **Kagamil**; Vsevidof; **Chiginagak**; Ugashik-Peulik; **Katmai**; **Fourpeaked**	**Kasatochi**; **Atka**; Amak; **Kupreanof**; **Aniakchak**; **Ukinrek Maars**; **Martin**; **Novarupta**; Snowy Mountain; **Spurr**					
	U- HR	Moffett; Koniuji; Yantarni; Kaguyak; Hayes; Imuruk Lake; Churchill	Roundtop; Dana; Black Peak; Mageik; Griggs; St. Paul Island; Buzzard Creek; Edgecumbe					
	U- NHHR	Buldir; Segula; Davidof; Bobrof; Chagulak; Herbert; Tana; Uliaga; Recheschnoi; Kialagvik; Unnamed; Denison; Steller; **Kukak**; **Douglas**	Sergief; Isanotski; Frosty; **Dutton**; **Emmons Lake**; Pavlof Sister; Stepovak Bay 2; Stepovak Bay 3; Stepovak Bay 4; Nunivak Island; Ingakslugwat Hills; St. Michael; Kookooligit Mountains; Sanford; Gordon; Duncan Canal; Tlevak Strait-Suemez Is.; Behm Canal-Rudyerd Bay					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 215: Identity of Alaska's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
0	5
0	4
0	3
48	2
44	1

Table 216: The number of volcanoes in Alaska classed in each PEI category.

Risk Levels

Volcano	Population Exposure Index	Risk Level
Augustine	2	II
Fisher	1	I
Iliamna	2	II
Redoubt	2	II
Akutan	2	I
Bogoslof	2	I
Cleveland	1	I
Korovin	2	I
Makushin	2	I
Okmok	1	I
Pavlof	2	I
Shishaldin	2	I
Trident	1	I
Veniaminof	2	I
Westdahl	2	I
Wrangell	2	I
Amukta	1	I
Gareloi	1	I
Great Sitkin	1	I
Kanaga	1	I
Kiska	1	I
Seguam	1	I

Table 217: Classified volcanoes of Alaska ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given.

Number of Volcanoes	Risk Level
0	III
3	II
19	I
70	Unclassified

Table 218: The number of volcanoes in the Alaska region classified at each Risk Level.

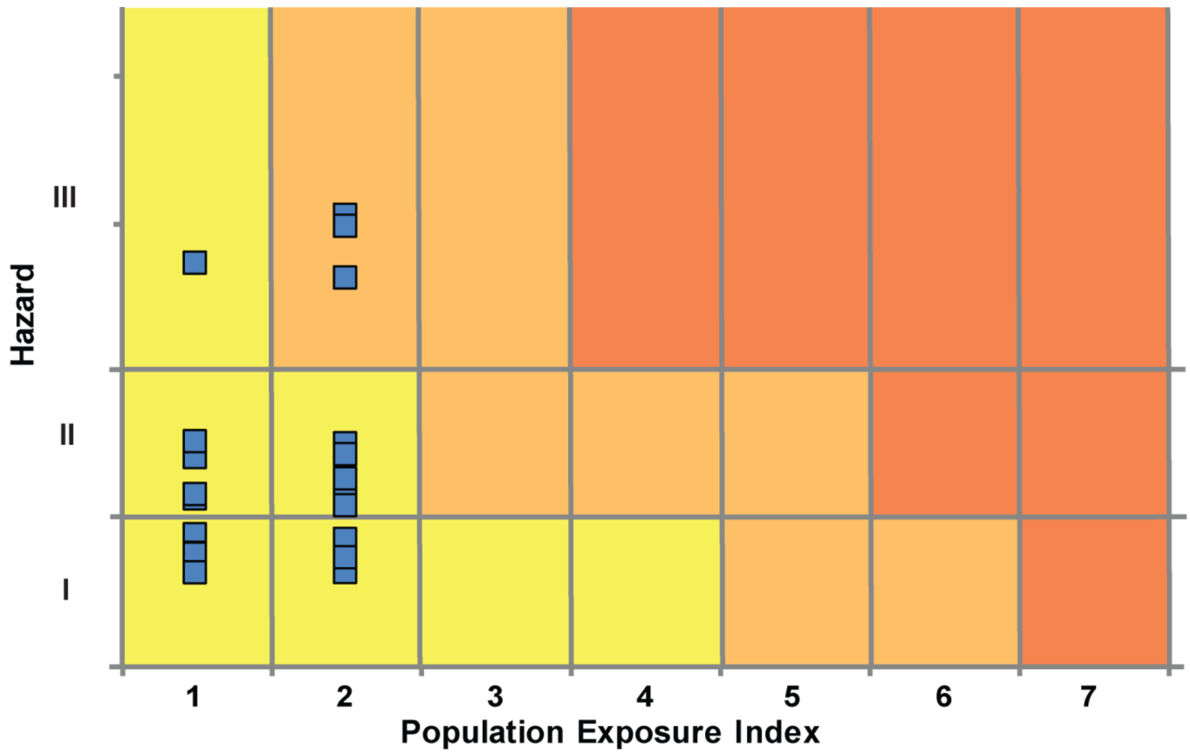


Figure 230: Distribution of the classified volcanoes of Alaska across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Forty-four volcanoes in Alaska have records of historical activity in VOTW4.22. These volcanoes are mainly Unclassified and Risk Level I, with just three at Risk Level II – Augustine, Ilimna and Redoubt. The AVO classes at least another six volcanoes as having historical activity. The AVO provides a list of volcanoes which have dedicated seismic monitoring. Twenty-one historically active volcanoes in Alaska do not have dedicated seismic monitoring, however, five of these have 3 or more seismometers located within 20 km according to the AVO map of monitoring stations. Eighteen volcanoes (10 Risk Level I, 3 Risk Level II, 5 unclassified) are monitored by the AVO with dedicated seismic networks and some with additional deformation networks.

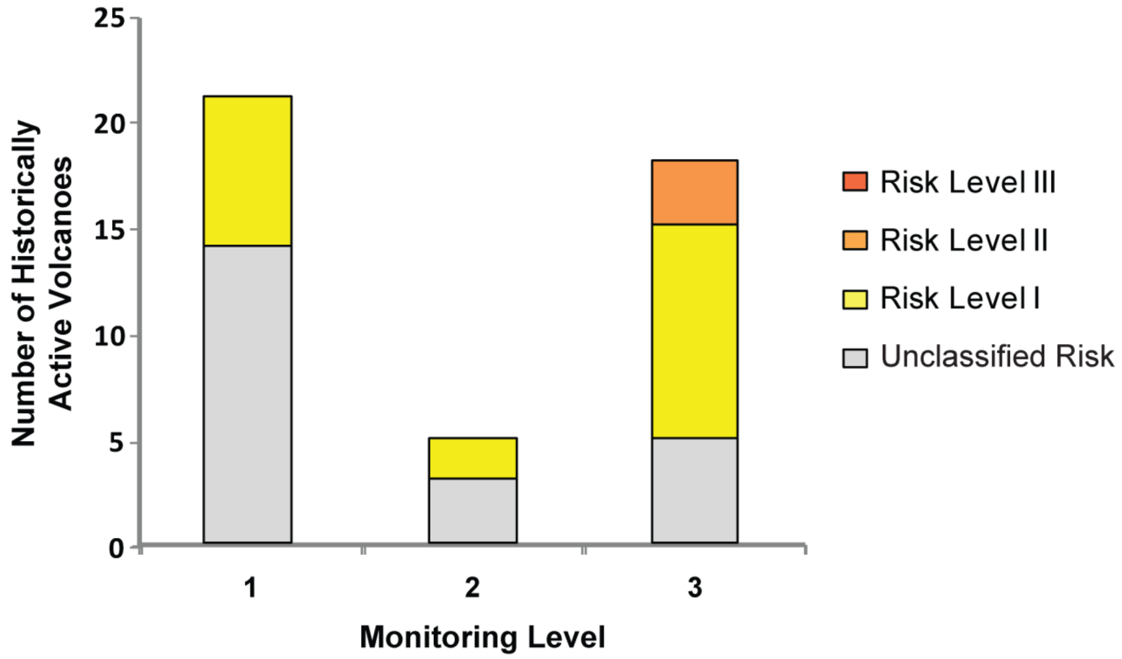


Figure 231: The monitoring and risk levels of the historically active volcanoes in Alaska. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 12: Canada and Western USA

Description

Region 12: Canada and Western USA comprises volcanoes throughout Canada and the contiguous states of the USA.

Country	Number of volcanoes
Canada	22
USA	48

Table 219: The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

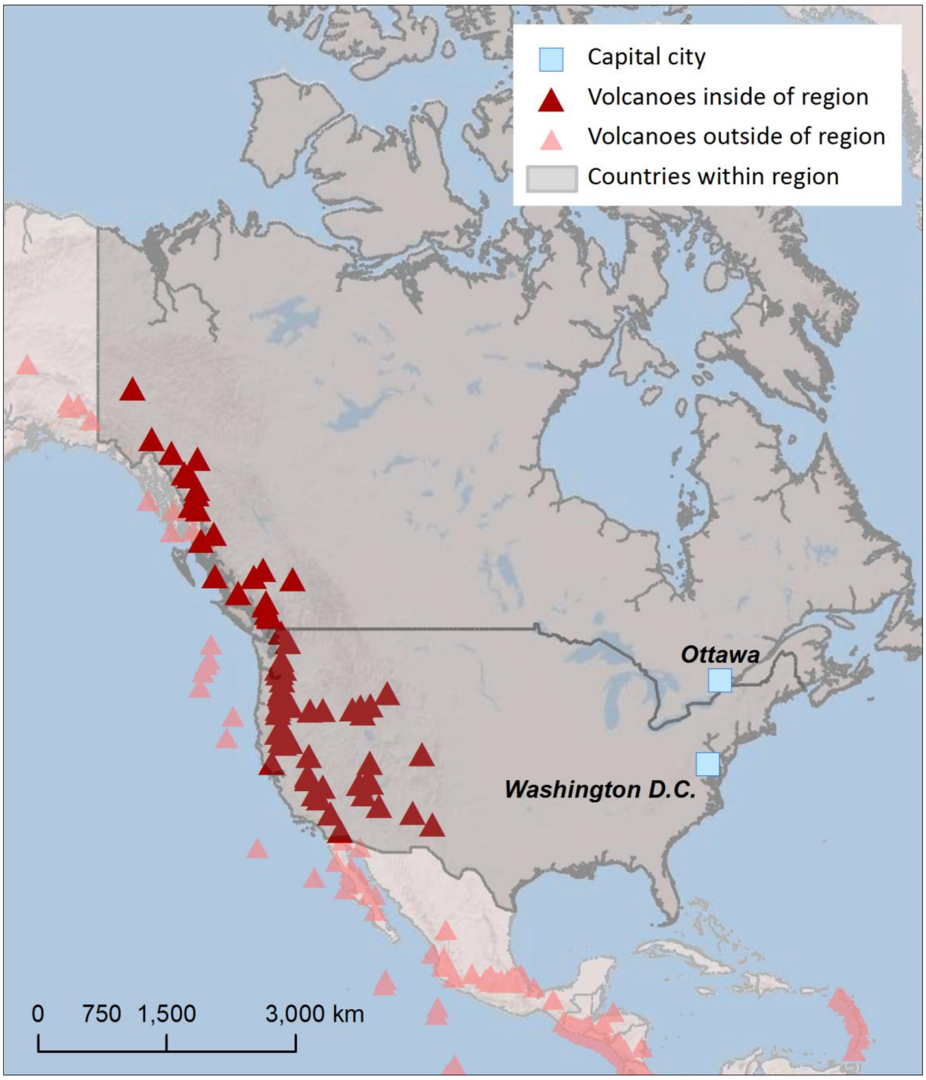


Figure 232: The distribution of Holocene volcanoes through the Canada and Western USA region. The capital cities of the constituent countries are shown.

Seventy Holocene volcanoes are located in Canada and the Western USA. Most of these volcanoes are in Washington, Oregon and California in the USA. Volcanism here is largely related to the subduction of the Juan de Fuca Plate beneath the North American Plate. Further north a range of tectonic environments give rise to volcanism, including subduction, rifting and intra-plate processes. Much of the volcanism of the western interior is due to extensional tectonics.

Volcanoes in this region adopt a variety of forms, with volcanic fields and cinder cones being most common (41 such volcanoes). Large cones are also common, with 16 stratovolcanoes and complex volcanoes, primarily found in the USA. Shields, lava domes, calderas and subglacial volcanoes are also located here. The rock type through this region is dominantly basaltic and andesitic, though a range of compositions is present, including silicic rhyolites, chiefly restricted to the western interior of the USA.

Along with volcano morphology and composition, a range of activity styles and eruption magnitudes are recorded through the Holocene, with eruptions of VEI 0 to 7. About 66% of eruptions here have been small, at VEI 0 to 2, however 23 eruptions (about 18%) have been large explosive VEI ≥4 events. All but one of these VEI ≥4 eruptions are recorded from volcanoes in the USA. The largest Holocene eruption recorded in this region was the VEI 7 eruption of Crater Lake in about 5677BC, which produced ash fall into Canada and pyroclastic flows that travelled 40 km.

Eleven volcanoes have historical records of 40 eruptions, about 70% of which were recorded through direct observations. The record of over 200 eruptions before 1500 AD indicates a reasonable geological record, reflecting geological studies here. 23% of historical eruptions have records of producing pyroclastic flows, one of the highest proportions in any region. Similarly, about 30% resulted in lahars. Lava flows are also recorded in 23% of eruptions, though many regions have a greater proportion.

8% of historical eruptions resulted in loss of life. Most volcanoes here have low proximal populations, and as such are considered relatively low risk. However, the hazard is unclassified at about 85% of volcanoes.

In the USA the U.S. Geological Survey runs a series of Volcano Observatories monitoring the activity here, undertaking scientific research and providing advice and alerts. In Canada, Natural Resources Canada is responsible for the volcanic hazard, however no volcanoes here have dedicated monitoring systems, though plans and resources are available if unrest occurs.

Volcano facts

Number of Holocene volcanoes	70
Number of Pleistocene volcanoes with M≥4 eruptions	14
Number of volcanoes generating pyroclastic flows	14 (65 eruptions)
Number of volcanoes generating lahars	12 (59 eruptions)
Number of volcanoes generating lava flows	45 (117 eruptions)
Number of eruptions with fatalities	4
Number of fatalities attributed to eruptions	84

Largest recorded Pleistocene eruption	The largest Quaternary eruption recorded was the M8.4 Lava Creek Tephra eruption at Yellowstone at 639 ka.
Largest recorded Holocene eruption	The largest recorded Holocene eruption in LaMEVE in this region is the O (Caldera) formation at Crater Lake, at M6.8 in 7627 BP.
Number of Holocene eruptions	245 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 7 and unknown
Number of historically active volcanoes	11
Number of historical eruptions	40

Number of volcanoes	Primary volcano type	Dominant rock type
3	Caldera(s)	Andesitic (1), Dacitic (1), Rhyolitic (1)
15	Large cone(s)	Andesitic (10), Dacitic (4), Trachytic / Andesitic (1)
5	Lava dome(s)	Rhyolitic (4), Trachytic / Andesitic (1)
10	Shield(s)	Andesitic (2), Basaltic (6), Rhyolitic (1), Trachytic / Andesitic (1)
36	Small cone(s)	Andesitic (3), Basaltic (31), Dacitic (2)
1	Subglacial	Phonolitic (1)

Table 220: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	10
Large (> VEI 3)	170

Table 221: Average recurrence interval (years between eruptions) for small and large eruptions in Canada and Western USA.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about 10 year, whilst the ARI for large eruptions is longer, at about 170 years.

Eruption Size

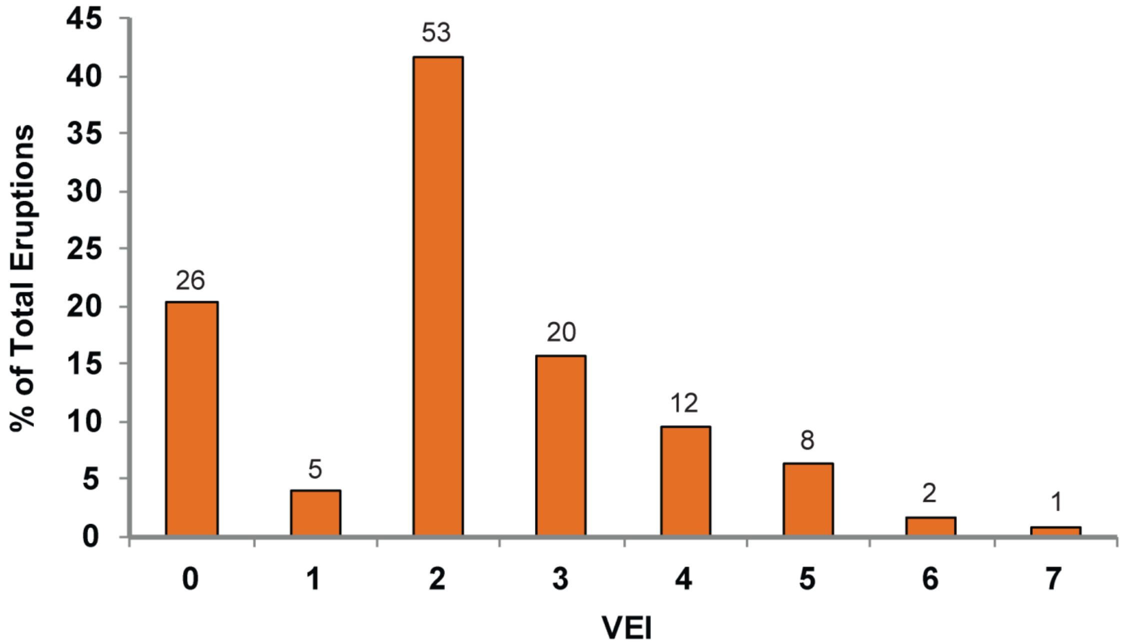


Figure 233: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 118 eruptions were recorded with unknown VEI.

Eruptions are recorded through the Canada and Western USA region of VEI 0 to 7, representing a range of eruption styles from gentle effusive events to very large explosive eruptions. VEI 2 events dominate the record, with nearly 45% of all Holocene eruptions classed as such. Over 18% of eruptions here are explosive at VEI≥4.

Socio-Economic Facts

Gross Domestic Product (GDP) per capita (2005 PPP $)	35,716 – 42,486 (Mean 39,101)
Gross National Income (GNI) per capita (2005 PPP $)	35,369 – 43,480 (Mean 39,425)
Human Development Index (HDI) (2012)	0.911 – 0.937 (Very High)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	24,610 (0.01 %)
Number (percentage) of people living within 30 km of a Holocene	375,305 (0.11 %)

volcano	
Number (percentage) of people living within 100 km of a Holocene volcano	4,187,725 (1.22 %)

Infrastructure Exposure

Number of airports within 100 km of a volcano	102
Number of ports within 100 km of a volcano	49
Total length of roads within 100 km of a volcano (km)	29,259
Total length of railroads within 100 km of a volcano (km)	8,443

CLASSIFIED	**Hazard III**		Shasta	Rainier; St. Helens				
	Hazard II			Baker				
	Hazard I		Adams; Sand Mountain Field; Three Sisters; Newberry; Medicine Lake; Craters of the Moon					
UNCLASSIFIED	**U – HHR**		**Lassen Volcanic Center;** Mono Lake Volcanic Field; Iskut-Unuk River Cones; Tseax River Cone; Wells Gray-Clearwater	Glacier Peak; **Hood**				
	U- HR		Jefferson; Blue Lake Crater; Belknap; Bachelor; Davis Lake; Crater Lake; Diamond Craters; Jordan Craters; Mono Craters; Ubehebe Craters; Golden Trout Creek; Shoshone Lava Field; Wapi Lava Field; Hell's Half Acre; **Yellowstone**; Markagunt Plateau; Carrizozo; Zuni-Bandera; Uinkaret Field; Edziza; Hoodoo Mountain; Nazko; Meager	West Crater; Indian Heaven; Inyo Craters; **Mammoth Mountain;** Salton Buttes; Black Rock Desert; Dotsero; Garibaldi	San Francisco Volcanic Field			
	U- NHHR	**Cayley Volcanic Field**	Devils Garden; Cinnamon Butte; Silver Lake; **Coso Volcanic Field;** Fort Selkirk; Alligator Lake; Atlin Volcanic Field; Tuya Volcanic Field; Heart Peaks; Level Mountain; Spectrum Range; Crow Lagoon; Milbanke Sound Group; Satah Mountain; Silverthrone; Bridge River Cones	Lavic Lake	Soda Lakes; Garibaldi Lake	Clear Lake		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 222: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
1	5
3	4
14	3
51	2
1	1

Table 223: The number of volcanoes in Canada and Western USA classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
0	III
4	II
6	I
60	Unclassified

Table 224: The number of volcanoes in the Canada and Western USA region classified at each Risk Level.

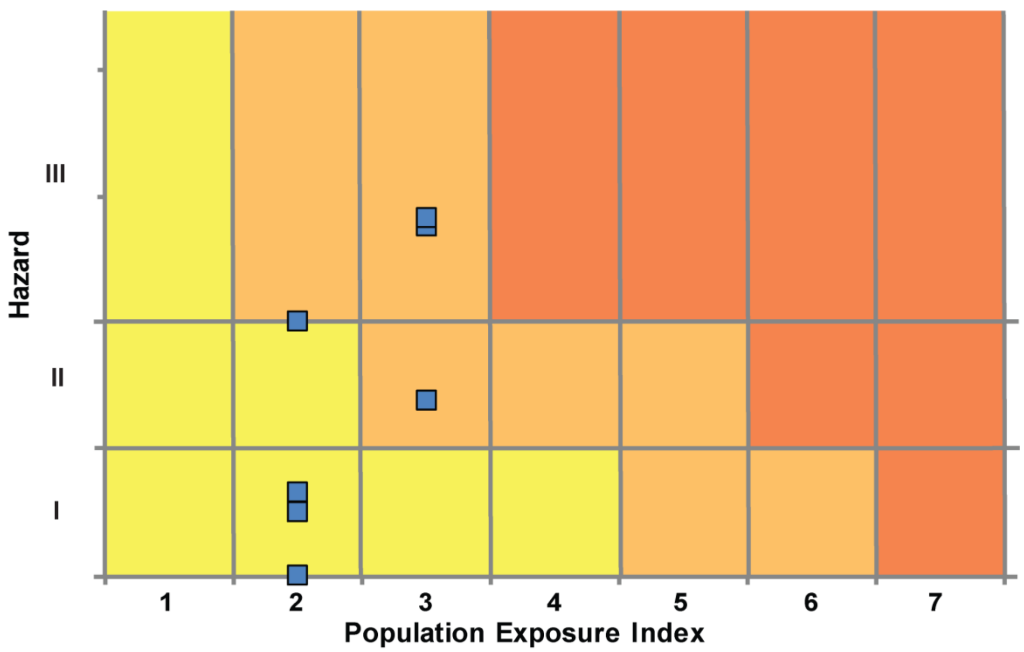


Figure 234: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

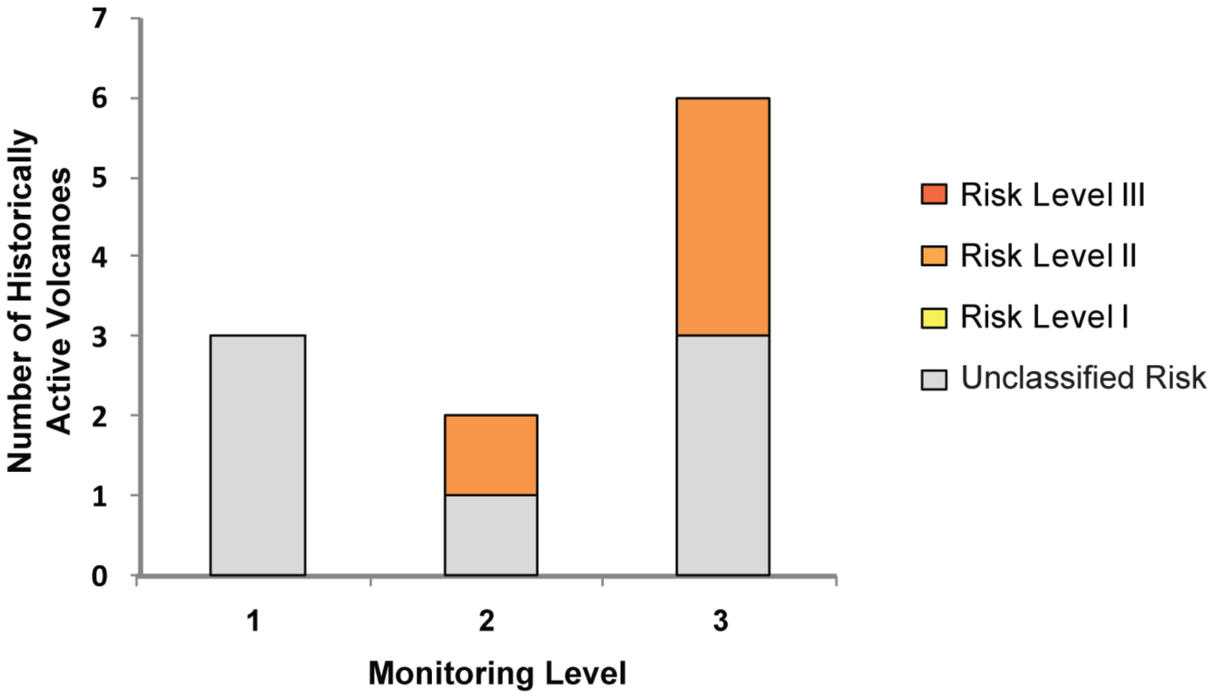


Figure 235: The monitoring and risk levels of the historically active volcanoes in Canada and the Western USA. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Canada

Description

Twenty-two volcanoes of Holocene age are listed by the GVP in western Canada, all in British Columbia and the Yukon Territory, from the border with Washington State (USA) in the south to Alaska (USA) in the north. Many of these volcanoes are volcanic fields comprising dozens of vents over thousands of square kilometres. Volcanism in Canada arises through compressional, subduction zone processes between the North American Plate and the Juan de Fuca Plate, and crustal extension within the North American Plate; intra-plate hotspot volcanism may also play a role. The range of origins for volcanism here results in a correspondingly large range of volcano morphologies and magma compositions. Although a number of stratovolcanoes are located in Canada, volcanic fields comprising many small discrete centres are the most common form of volcanism in Canada.

During the Holocene nineteen eruptions are recorded from eight volcanoes in VOTW4.22, however if eruptions from individual vents are considered then this number is far greater. It is highly probable that many more Canadian volcanoes have had Holocene activity, but this has not been confirmed quantitatively. Recorded activity ranges from VEI 0 to 5, indicating a range from small effusive activity to large explosive activity, however the size of most eruptions is unknown.

The largest Holocene eruption of VEI 5 occurred at the stratovolcano Mount Meager in 410 BC. This large explosive eruption generated pyroclastic flows, lahars, and lava domes, and the formation and failure of a dam made of welded pyroclastic material, with an accompanying flood. Ash was distributed across British Columbia and neighbouring Alberta. Hot springs are active at Mount Meager, indicative of an ongoing heat source. A debris avalanche, not of volcanic origin, occurred at this volcano in 2010, with debris extending to nearly 13 km, damming rivers and leading to the evacuation of 1500 residents, resulting in about costs of about $10m CAD (Guthrie et al., 2011).

Historical activity has occurred at only one volcano, Tseax Cone, and is recorded in the oral histories of the Nisga'a people. The ~ AD 1700 eruption of Tseax River cone produced lavas which inundated a village. Evacuations, property damage, and fatalities occurred. Several other eruptions have occurred in the last few centuries and are documented geologically but not historically, probably due to the isolation of the volcanoes.

Despite the number of volcanoes in Canada, the exposed population is relatively small with much of the population, and therefore infrastructure, concentrated in the south of Canada, towards the border with the US. Much of the Greater Vancouver Regional District lies within 100 km of Mount Baker (Washington State, USA) and the southernmost Canadian volcano, Garibaldi, however most volcanoes in Canada have a very low proximal population within 30 km. No detailed risk assessments have been undertaken for any Canadian volcanoes by the Geological Survey of Canada. All Canadian volcanoes have considerable uncertainty associated with the assessment of hazard, and research is needed to better understand the eruptive history.

Natural Resources Canada (NRCan) is the agency responsible for the provision of technical and scientific information regarding volcanic unrest, hazard and eruptions affecting Canada. The Geological Survey of Canada (GSC) is part of NRCan, and is funded by the federal government. There is currently no dedicated ground-based monitoring at any of the Canadian volcanoes, however a national seismic network is in place, monitored by NRCan. A seismologist is always on-call, and would be alerted to earthquakes of M≥3 detected through the continuous and automatic monitoring network. Small earthquakes and swarms near volcanoes might not be noticed by the seismologist on-call until the visual inspection of all data the next working day. Should seismic unrest be detected via this network, NRCan would respond by augmenting monitoring, as the resources are available to respond to developing situtations.

The most recent eruption in Canada took place around 1800 at the Lava Fork volcano in the Iskut-Unuk River cones. As such, no current employees at NRCan have experience in responding to an eruption. However, in 2007 an earthquake swarm occurred in the Nazko region, near Nazko cone. NRCan responded with additional monitoring and provided advice regarding the probable activity styles were an eruption to occur, and a preliminary volcanic hazard map was produced from existing data. Many of the personnel involved in the response to this swarm are still at NRCan.

NRCan has set protocols and plans in place to respond to increasing unrest and eruptions. The Interagency Volcanic Event Notification Plan (IVENP) would be activated at the onset of an eruption in Canada. IVENP is a short-term communications plan that outlines the rapid notification procedures among the key Canadian agencies that would be involved in the response to a volcanic eruption within or near Canada; it is a communications plan, not a response plan. IVENP's primary objective is to ensure that volcanic ash information for Canada is rapidly and appropriately communicated to aviation agencies. Natural Resources Canada's Standard Operating Procedure: Volcanic Situations details the NRCan protocols for volcanic unrest and eruptions. During volcanic unrest or eruption, Natural Resources Canada would communicate with numerous agencies involved in public safety and scientific research. This would include (but would not be limited to) the agencies involved in Canada's Interagency Volcanic Event Notification Plan (IVENP): Environment Canada (which includes the Volcanic Ash Advisory Centre in Montréal), Public Safety Canada, Emergency Management British Columbia, the Airline Pilots Association, Nav Canada, the Royal Canadian Mounted Police (RCMP), Transport Canada, and the Yukon Emergency Measures Organization. There would also likely be extensive communications with specific organizations or stakeholders in the region of unrest.

No specific Alert Level system has been developed for use in Canada due to the absence of recent activity. NRCan plans to use the U.S. Geological Survey's Volcano Alert Levels and Aviation Colour Codes in the event of unrest.

The public is exposed to hazard education in volcanic regions provided by Public Safety Canada, Emergency Preparedness British Columbia, and the Yukon Emergency Measures Organization, who work closely with NRCan in dealing with potential volcanic hazards. NRCan provides hazard information to the public through research publications, fact sheets, books, maps, brochures, etc. In addition, NRCan engages with the public through school visits, meetings, and conferences, and the Geological Survey of Canada includes publicly-accessible libraries and bookstores.

See also:

Guthrie, R.H., Friele, P., Allstadt, K., Roberts, N., Evans, S.G., Delaney, K.B., Roche, D., Clague, J.J., and Jakob, M. (2011). The 6 August 2010 Mount Meager rock slide-debris flow, Coast Mountains, British

Columbia: characteristics, dynamics, and implications for hazard and risk assessment. Natural Hazards and Earth System Sciences, 12, 1277-1294.

Natural Resources Canada website: http://www.nrcan.gc.ca/home

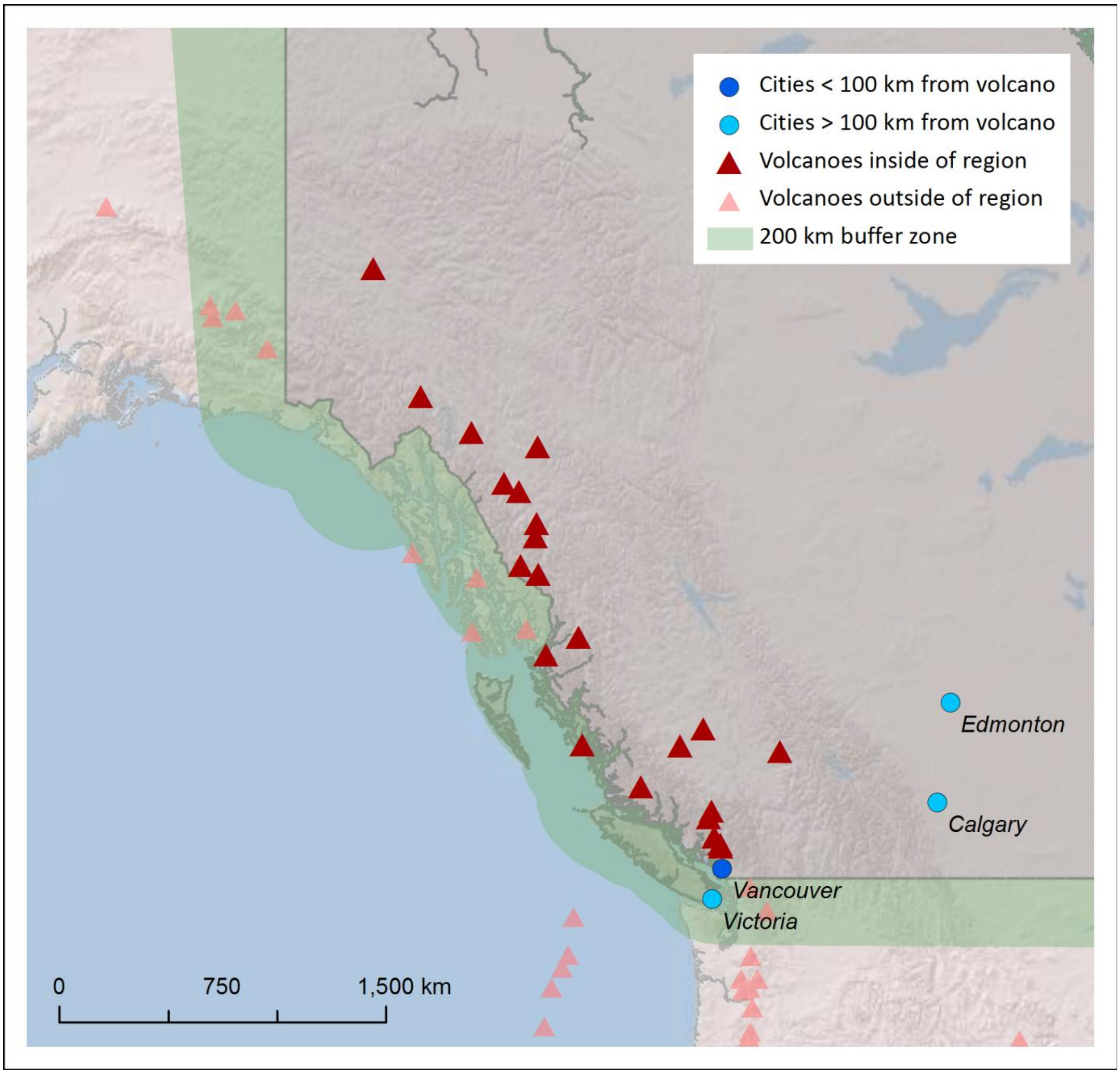


Figure 236: Location of Canada's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Canada.

Volcano Facts

Number of Holocene volcanoes	22
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	8, with many monogenetic vents

Number of fatalities caused by volcanic eruptions	Oral histories suggest ~2000 people, however the precise number is unknown.
Tectonic setting	16 intra-plate, 6 Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The M5.0 Bridge River Tephra/Pebble Creek Formation of Mount Meager in 2360 BP.
Number of Holocene eruptions	19 confirmed eruptions. 2 uncertain eruptions.
Recorded Holocene VEI range	0 – 5 and unknown.
Number of historically active volcanoes	3
Number of historical eruptions	4

Number of volcanoes	Primary volcano type	Dominant rock type
1	Caldera(s)	Andesitic (1)
4	Large cone(s)	Andesitic (1), Dacitic (2), Trachytic / Andesitic (1)
3	Shield(s)	Basaltic (1), Rhyolitic (1), Trachytic / Andesitic (1)
13	Small cone(s)	Andesitic (1), Basaltic (12)
1	Subglacial	Phonolitic (1)

Table 225: The number of volcanoes in Canada, their volcano type classification and dominant rock type according to VOTW4.0.

Silverthrone is the only caldera listed in Canada, however the age of the most recent activity at this volcano is uncertain as although the textures and degree of dissection suggests the lavas here are less than 10,000 years old this has not been confirmed with radiometric dating.

Hoodoo Mountain is classed in VOTW4.0 as a subglacial volcano. This is a complex, long-lived centre with both subaerial and subglacial deposits, and volcano-ice interaction has played a large role in its history. Many more volcanic centres in Canada have evidence for subglacial or ice-contact eruptions. Three monogenetic basaltic centres of Edziza are subglacial, and numerous further vents of Edziza could be classed as small cones, however Edziza itself is classed as a stratovolcano.

The age of the shield volcano Level Mountain is uncertain.

Socio-Economic Facts

Total population (2012)	34,828,000

Gross Domestic Product (GDP) per capita (2005 PPP $)	35,716
Gross National Income (GNI) per capita (2005 PPP $)	35,369
Human Development Index (HDI) (2012)	0.911 (Very High)

Population Exposure

Capital city	Ottawa
Distance from capital city to nearest Holocene volcano	3299.6 km
Total population (2011)	34,030,589
Number (percentage) of people living within 10 km of a Holocene volcano	14 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	2,703 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	>2 million (<10%)

Ten largest cities, as measured by population, and populations:

Toronto	4,612,191
Montreal	3,268,513
Vancouver	1,837,969
Calgary	1,019,942
Ottawa	812,129
Edmonton	712,391
Winnipeg	632,063
Quebec	528,595
Victoria	289,625
Saskatoon	198,958

Infrastructure Exposure

Number of airports within 100 km of a volcano	7
Number of ports within 100 km of a volcano	21
Total length of roads within 100 km of a volcano (km)	8,634
Total length of railroads within 100 km of a volcano (km)	1,127

The volcanoes in Canada are located in the west through the provinces of British Colombia and the Yukon. Many of these volcanoes are located near the coast, and as such 21 ports are situated within

100 km. Despite the number of volcanoes in Canada, the exposed population is relatively small with much of the population, and therefore infrastructure concentrated in the south of Canada, towards the border with the US. The southernmost volcano in Canada, Garibaldi, lies just within 100 km of the USA, meaning the 100 km radius for this volcano extends into the US. And indeed, Mt Baker in the USA lies within 100 km of Canada, placing much of the Greater Vancouver Regional District within the 100 km radius of this Holocene volcano. Seven airports lie within 100 km of a volcano in Canada, as does an extensive road and rail network.

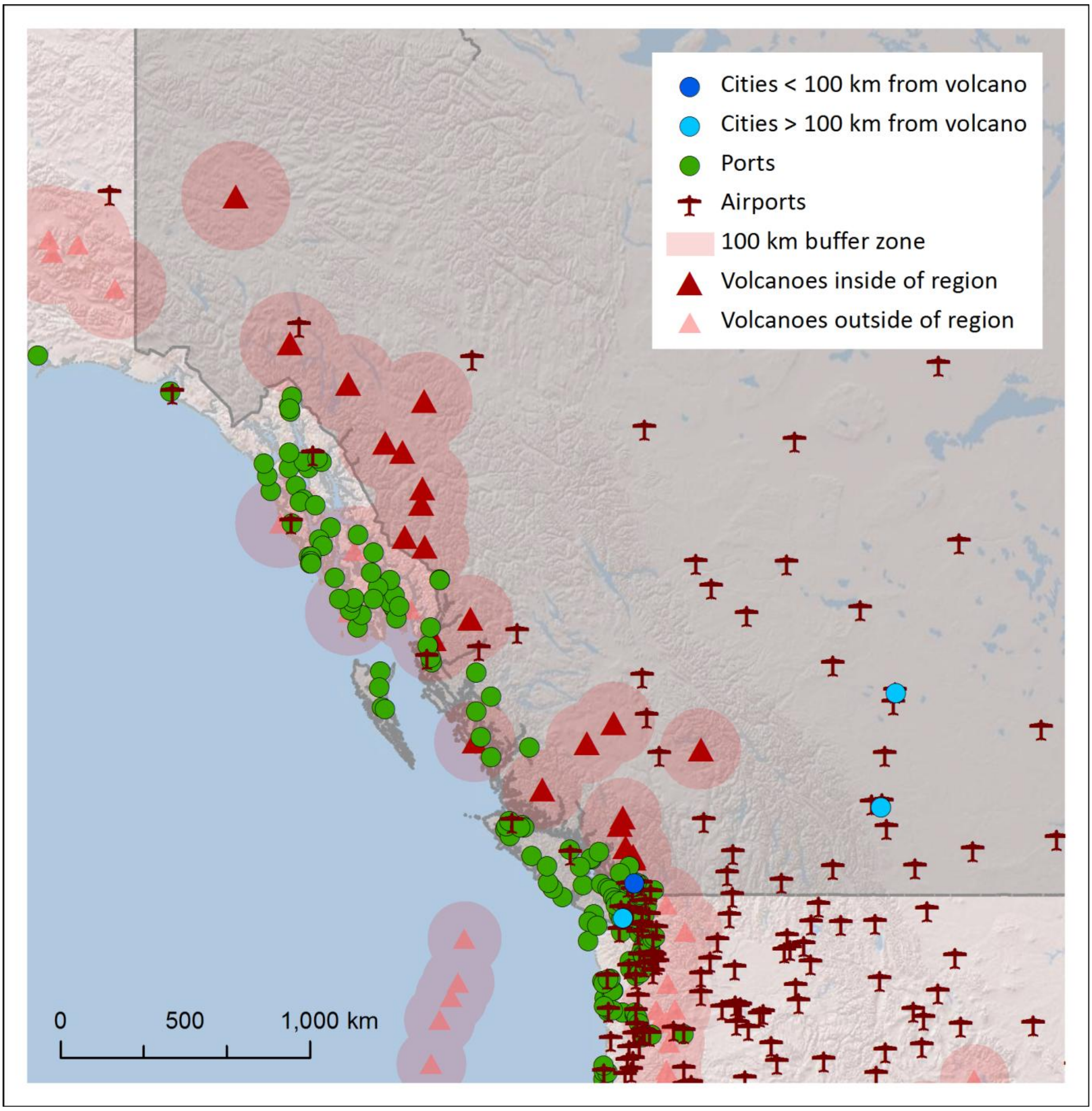


Figure 237: The location of Canada's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The eruption records for the volcanoes in Canada are not sufficiently extensive or detailed for determination of the hazard through the calculation of the VHI without large associated uncertainties. All volcanoes here are therefore unclassified. Fourteen volcanoes have no confirmed Holocene eruptions, though one of these, Cayley Volcanic Field, has experienced unrest since 1900 AD suggesting an active system. The remaining unclassified volcanoes have a Holocene record, and at three volcanoes a historical record, though none have erupted since 1900 AD.

Most Canadian volcanoes have very small proximal populations within 30 km, increasing substantially at 100 km radius, categorising these with low to moderate PEI of 1 – 4.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		Iskut-Unuk River Cones; Tseax River Cone; Wells Gray-Clearwater					
	U- HR		Edziza; Hoodoo Mountain; Nazko; Meager	Garibaldi				
	U- NHHR	**Cayley Volcanic Field**	Fort Selkirk; Alligator Lake; Atlin Volcanic Field; Tuya Volcanic Field; Heart Peaks; Level Mountain; Spectrum Range; Crow Lagoon; Milbanke Sound Group; Satah Mountain; Silverthrone; Bridge River Cones		Garibaldi Lake			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 226: Identity of Canada's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

The volcanoes of Canada do not currently have dedicated ground-based monitoring systems in place. Only three Canadian volcanoes have been active since AD 1500, and these are unclassified for risk with a low PEI . Natural Resources Canada monitors a regional network of seismometers, which may provide indication of unrest at these volcanoes.

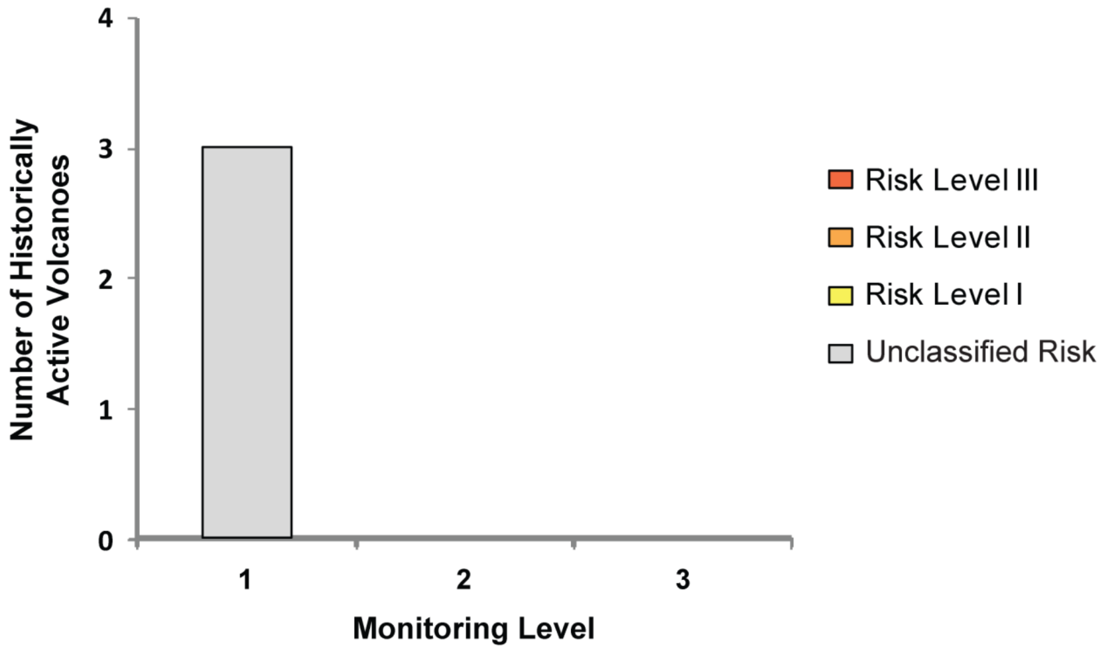


Figure 238: The monitoring and risk levels of the historically active (with eruptions since 1500 AD) volcanoes in Canada. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

U.S.A. (contiguous states)

See Region 4 for American Samoa, Region 8 for the Marianas, Region 11 for Alaska, Region 13 for Hawaii.

Description

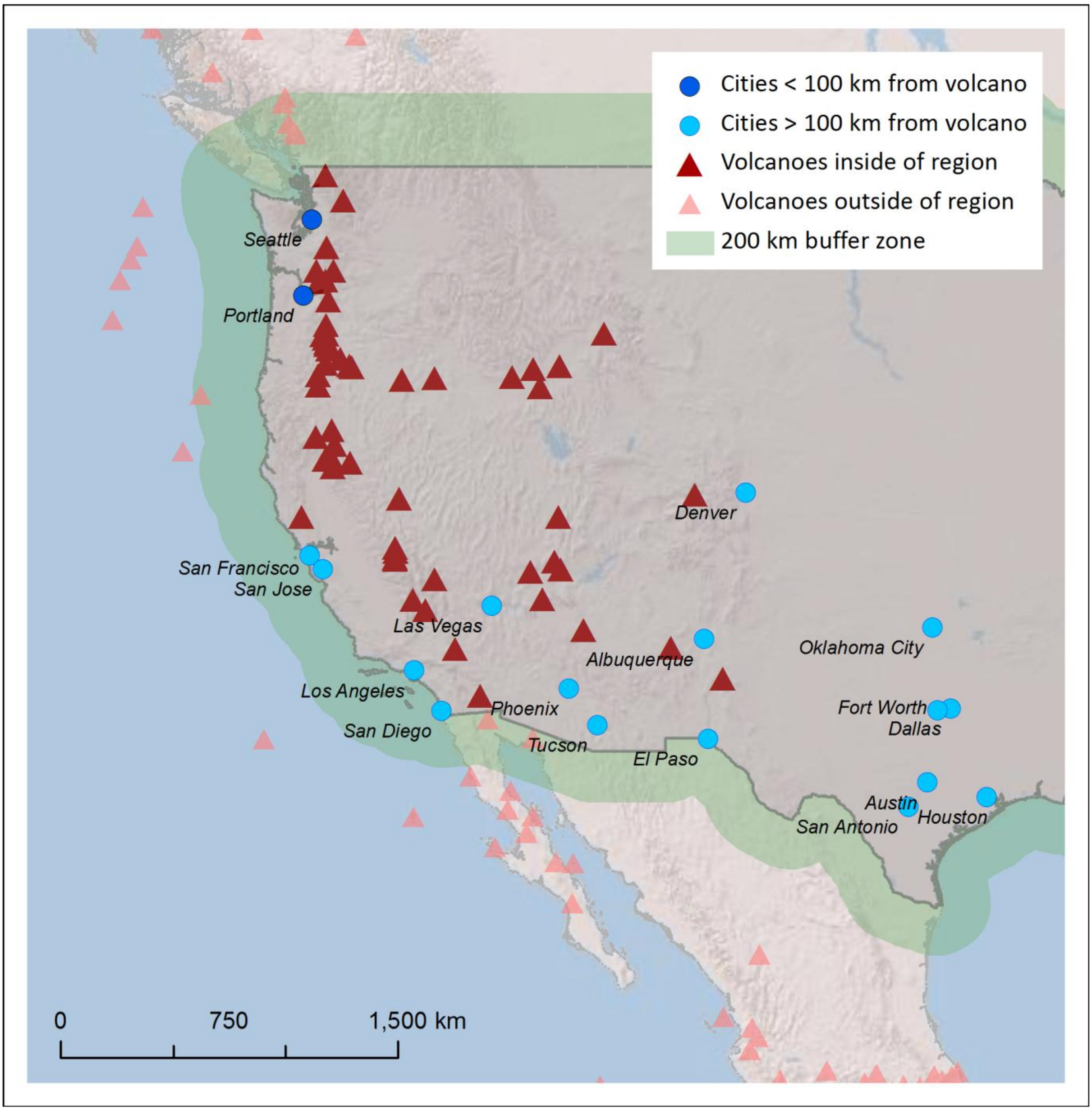


Figure 239: Location of the volcanoes in the contiguous United States, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect these states.

Forty-eight Holocene volcanoes are located in the contiguous 48 States of the U.S.A. (referred to from here as the U.S., excluding Alaska, Hawaii, Samoa and Marianas). Volcanism here is largely due to the subduction of the Pacific and Juan de Fuca Plates beneath the North American Plate and extensional tectonics inland. This has given rise to the formation of dominantly andesitic volcanic centres dominated by volcanic fields, cinder cones and stratovolcanoes.

The U.S. has an extensive Pleistocene record of large explosive eruptions, with 14 volcanoes recorded in LaMEVE with eruptions of VEI/M≥4. The largest recorded Pleistocene eruption was the M8.4 eruption of Yellowstone about 639,000 years ago, which ejected the 1000 cubic kilometre Lava Creek Tuff and formed the 45 x 85 km caldera.

Forty-two volcanoes have records of Holocene activity, with the remaining volcanoes having activity of suspected though unconfirmed Holocene age. 226 Holocene eruptions are recorded here, from VEI 0 to 7. This size range demonstrates the range in activity in the U.S., from small events to very large explosive eruptions. About 10% of eruptions here are recorded at VEI ≥4. Pyroclastic flows are recorded in about 28% of Holocene eruptions. The largest Holocene eruption was that of Mt. Mazama, about 7700 years ago, at the present day site of Crater Lake in Oregon. This VEI 7 eruption is one of the World's largest known Holocene eruptions, producing pyroclastic flows that extended to about 40 km, extensive ash fall into Canada and the 8-10km caldera. Most commonly small eruptions of VEI 0 -2 are recorded.

Of the Holocene record, about 16% of the eruptions have been recorded since 1500 AD, with 36 historic eruptions of VEI 1 to 5 from 8 volcanoes. Just 2 eruptions of VEI ≥4 (VEI 5) are recorded in 1800 and 1980 at Mt. St. Helens. The latter eruption produced a debris avalanche, lahars, pyroclastic flows and resulted in evacuations and loss of life.

In total, throughout the U.S., less than 2% of the population live within 100 km of one or more Holocene volcano. The size of the local population varies at each volcano, however over 60% are classed here with a low PEI on the basis of a small local population.

The U.S. Geological Survey (USGS) Volcano Hazards Program (VHP) runs monitoring and research institutions with five volcano observatories, three of which are active in the contiguous U.S. The California Volcano Observatory (CalVO) monitors volcanoes in California and Nevada. The volcanoes of Washington, Oregon and Idaho are monitored by the Cascades Volcano Observatory (CVO). The Yellowstone Volcano Observatory (YVO) monitors the Yellowstone volcano.

Dedicated ground-based monitoring is operated at many volcanoes in the U.S. The USGS VHP and the Consortium of U.S. Volcano Observatories (CUSVO) have developed the National Volcano Early Warning System (NVEWS). This is designed to ensure that all volcanoes of the U.S.A. are monitored at appropriate levels based on their relative threat. This relative threat is determined using hazard and exposure indicators. Scores are assigned for these factors (including, but not limited to: volcano type, maximum eruption size, recurrence rates, occurrence of various hazardous phenomena, population size and infrastructure location). The hazard and exposure scores are multiplied to give an overall threat score. These scores are divided into five categories: Very High, High, Moderate, Low and Very Low.

Those volcanoes currently classed by the USGS with a High to Very High Threat potential are:

CalVO
- Clear Lake
- Lassen Volcanic Center
- Long Valley Caldera
- Medicine Lake
- Mono-Inyo Chain
- Shasta

	Salton Buttes
CVO	Crater Lake
	Glacier Peak
	Mount Adams
	Mount Baker
	Mount Hood
	Mount Rainier
	Mount St. Helens
	Newberry
	Three Sisters
YVO	Yellowstone

Many volcanoes, particularly those that have not had historical activity, are insufficiently monitored for detection of early volcanic unrest. NVEWS would ensure that the most hazardous volcanoes are properly monitored to allow forecasts of activity to be made and risk reduced.

See also:

Ewert, J.W., Guffanti, M., and Murray, T.L. (2005) An assessment of volcanic threat and monitoring capabilities in the United States: framework for a National Volcano Early Warning System. USGS Open-File Report, 2005-1164. http://pubs.usgs.gov/of/2005/1164/

Ewert, J.W. (2007) System for ranking relative threats of U.S. volcanoes, Natural Hazards Review, v8, no.4, p112-124; http://dx.doi.org/10.1061/(ASCE)1527-6988(2007)8:4(112)

Guffanti, M., Diefenbach, A.K., Ewert, J.W., Ramsey, D.W., Cervelli, P.F., Schiling, S.P. (2009) Volcano-monitoring instrumentation in the United States, 2008, USGS Open-File Report 2009-1165. http://pubs.usgs.gov/of/2009/1165/

NVEWS: National Volcano Early Warning System: http://volcanoes.usgs.gov/publications/2009/nvews.php

USGS Volcanic Hazards Program: http://volcanoes.usgs.gov/index.php

Volcano Facts

Number of Holocene volcanoes	48
Number of Pleistocene volcanoes with M≥4 eruptions	14
Number of volcanoes generating pyroclastic flows	13
Number of volcanoes generating lahars	11
Number of volcanoes generating lava flows	37
Number of fatalities caused by volcanic eruptions	?79

Tectonic setting	27 Subduction zone, 28 Rift zone
Largest recorded Pleistocene eruption	The Yellowstone eruptions of the Lava Creek Tuff 639,000 years ago and the Huckleberry Ridge Tuff about 2,133,000 years ago were both over magnitude 8.
Largest recorded Holocene eruption	The M6.8 Crater Lake eruption of Mt. Mazama, Oregon, in about 7627 BP.
Number of Holocene eruptions	226 confirmed eruptions.
Recorded Holocene VEI rang	0 – 7 and unknown.
Number of historically active volcanoes	8
Number of historical eruptions	36

Number of volcanoes	Primary volcano type	Dominant rock type
2	Caldera(s)	Dacitic (1), Rhyolitic (1)
11	Large cone(s)	Andesitic (9), Dacitic (2)
5	Lava dome(s)	Rhyolitic (4), Trachytic / Andesitic (1)
7	Shield(s)	Andesitic (2), Basaltic (5)
23	Small cone(s)	Andesitic (2), Basaltic (19), Dacitic (2)

Table 227: The number of Holocene volcanoes in the contiguous states of the USA, their volcano type classification and dominant rock type according to VOTW4.0.

Note that the calderas here are Yellowstone (rhyolitic) and Crater Lake (dacitic). Long Valley caldera itself is not included as this is Pleistocene in age, however features within the area of Long Valley Caldera, considered distinct from the caldera, are included: Mammoth Mountain is a trachytic lava dome complex; Mono and Inyo Craters are rhyolitic lava domes and explosion craters; and Mono Lake Volcanic Field comprises cinder cones and lava domes.

Socio-Economic Facts

Total population (2012)	317,806,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	42,486
Gross National Income (GNI) per capita (2005 PPP $)	43,480
Human Development Index (HDI) (2012)	0.937 (Very High)

Population Exposure

Capital city	Washington D.C.
Distance from capital city to nearest Holocene volcano	2709.4 km
Total population (USA) (2011)	311,591,917
Number (percentage) of people living within 10 km of a Holocene volcano	26,309 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	388,808 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	4,196,889 (1.4%)

Ten largest cities, as measured by population, and populations:

New York	8,008,278
Los Angeles	3,694,820
Chicago	2,841,952
Houston	2,027,712
Philadelphia	1,517,550
Phoenix	1,321,045
San Antonio	1,256,810
San Diego	1,223,400
Detroit	951,270
San Jose	894,943

Infrastructure Exposure

Number of airports within 100 km of a volcano	95
Number of ports within 100 km of a volcano	28
Total length of roads within 100 km of a volcano (km)	20,625
Total length of railroads within 100 km of a volcano (km)	7,316

The volcanoes of the contiguous States are located in the western states, with most forming a chain north to south from Mexico to Canada in California, Oregon and Washington. Most volcanoes here are located far enough inland that ports are not located within their 100 km radius, however 28 ports are within this distance. Two of the largest cities in the USA, Seattle and Portland, are located within 100 km of volcanoes in the northern Cascade Range and nearly 100 airports are affected, along with numerous towns and cities. An extensive road and rail network falls within this distance of the volcanoes. The 100 km radius of volcanoes in the north and south extends into Canada and Mexico respectively, and indeed volcanoes in these countries also have 100 km radii extending into the USA.

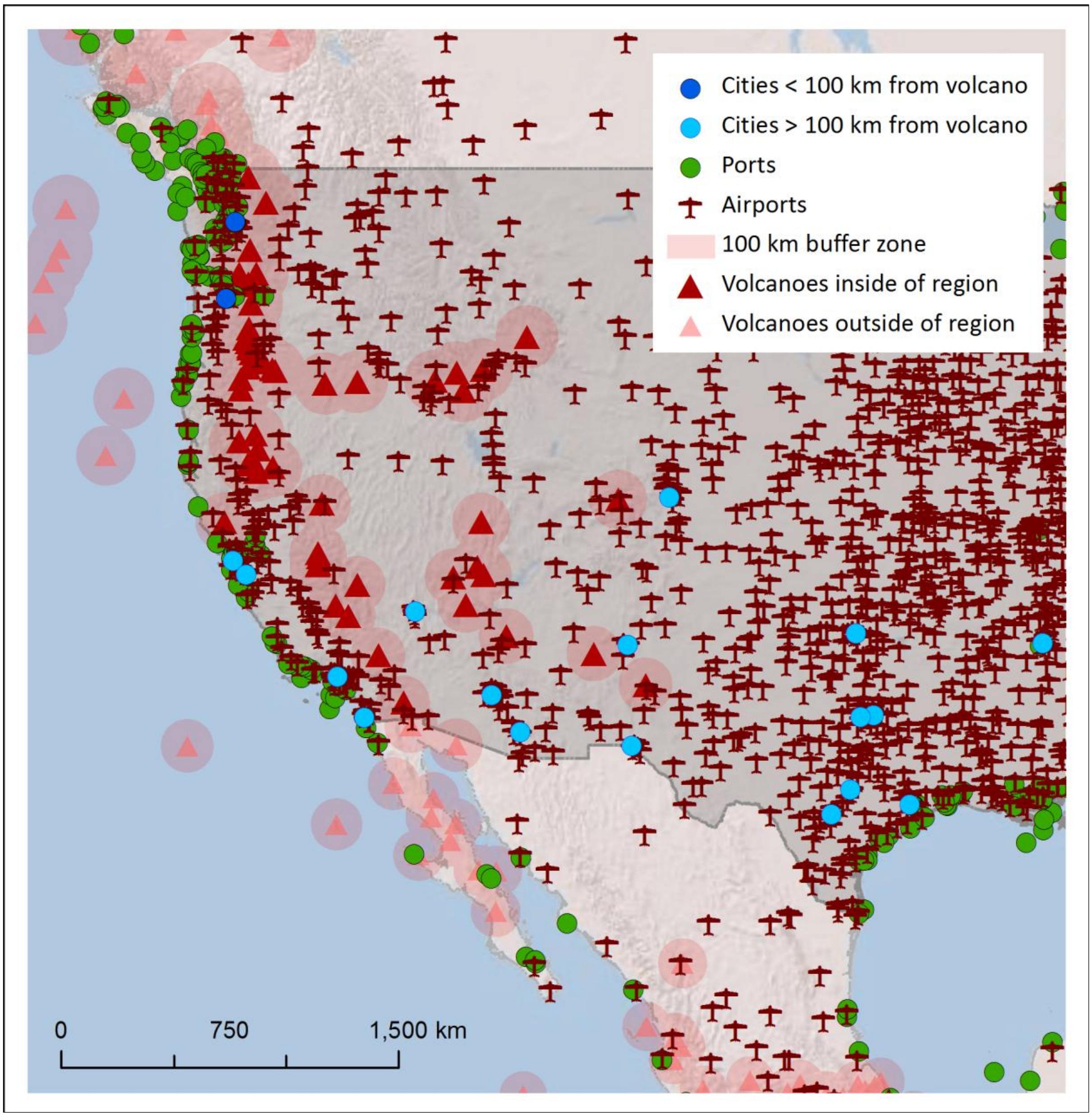


Figure 240: The location of the volcanoes in the contiguous United States and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The volcanoes of the contiguous states of the USA have varying levels of data available in their eruption record. About 20% of volcanoes have appropriate eruptive histories to determine a hazard level through calculation of the VHI. These classified volcanoes span all three hazard levels, though most are classed at Hazard Level I. With eruption histories including large explosive events and eruptions commonly producing pyroclastic flows, Shasta, Rainier and St. Helens all are classed at Hazard Level III.

Of the unclassified volcanoes, seven have no confirmed Holocene eruptions. The remaining unclassified volcanoes have a Holocene eruption record, including historic (post 1500 AD) events at four volcanoes. Only Lassen Volcanic Centre has erupted since 1900 AD, though unrest in this time has been recorded at Hood, Mammoth Mountain, Yellowstone and Coso Volcanic Field. Six unclassified volcanoes have Holocene records of large VEI ≥4 eruptions.

The PEI at these volcanoes ranges from low to high, at PEI 2 to 5. At most volcanoes the proximal population is relatively small, and all classified volcanoes are classed at Risk Levels of I and II.

CLASSIFIED	**Hazard III**		Shasta	Rainier; St. Helens				
	Hazard II			Baker				
	Hazard I		Adams; Sand Mountain Field; Three Sisters; Newberry; Medicine Lake; Craters of the Moon					
UNCLASSIFIED	**U – HHR**		**Lassen Volcanic Center;** Mono Lake Volcanic Field	Glacier Peak; **Hood**				
	U- HR		Jefferson; Blue Lake Crater; Belknap; Bachelor; Davis Lake; Crater Lake; Diamond Craters; Jordan Craters; Mono Craters; Ubehebe Craters; Golden Trout Creek; Shoshone Lava Field; Wapi Lava Field; Hell's Half Acre; **Yellowstone**; Markagunt Plateau; Carrizozo; Zuni-Bandera; Uinkaret Field	West Crater; Indian Heaven; Inyo Craters; **Mammoth Mountain;** Salton Buttes; Black Rock Desert; Dotsero	San Francisco Volcanic Field			
	U- NHHR		Devils Garden; Cinnamon Butte; Silver Lake; **Coso Volcanic Field**	Lavic Lake	Soda Lakes	Clear Lake		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 228: Identity of the volcanoes in the contiguous States in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed

*eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Baker	3	II
Rainier	3	II
St. Helens	3	II
Shasta	2	II
Adams	2	I
Craters of the Moon	2	I
Medicine Lake	2	I
Newberry	2	I
Three Sisters	2	I
Sand Mountain Field	2	I

Table 229: Classified volcanoes of the contiguous states of the U.S. ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 6 volcanoes; Risk Level II – 4 volcanoes; Risk Level III – 0 volcanoes.

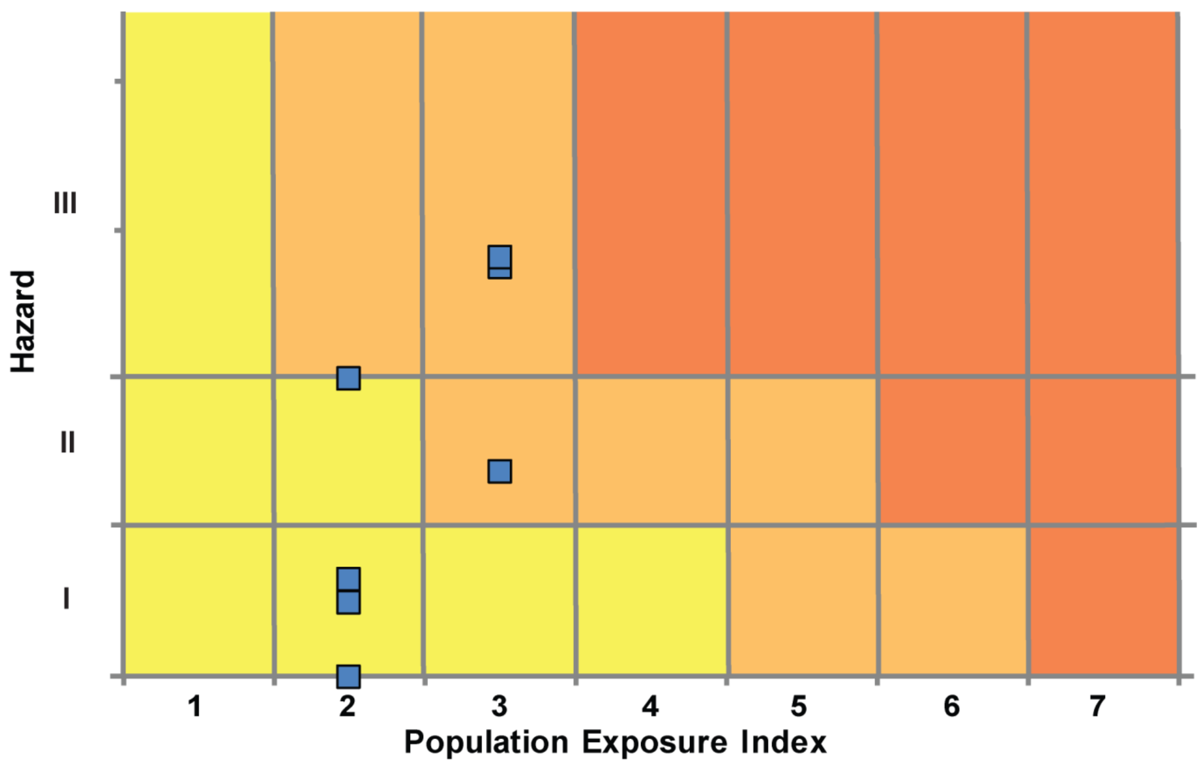


Figure 241: Distribution of the classified volcanoes in the contiguous states of the U.S. across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Eight volcanoes have records of historical activity in the U.S. Baker, Rainier, St. Helens and Shasta are classed at Risk Level II, while Glacier Peak, Hood, Lassen Volcanic Center and Mono Lake Volcanic Field are unclassified. These historically active volcanoes are monitored by the California Volcano Observatory (CalVO) and the Cascades Volcano Observatory (CVO) through seismic and deformation networks.

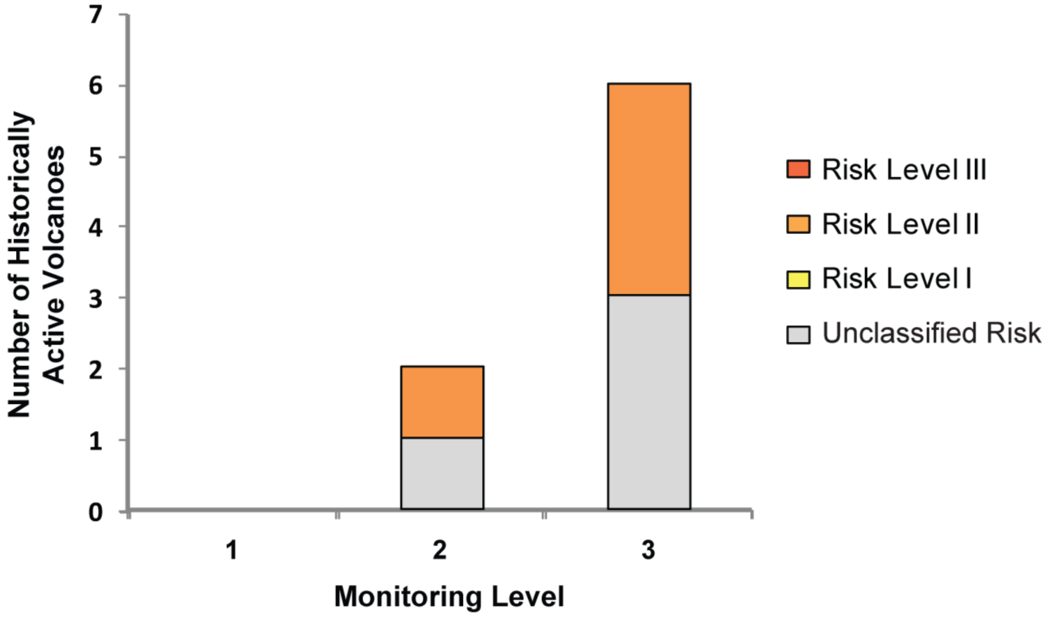


Figure 242: The monitoring and risk levels of the historically active volcanoes in the contiguous states of the U.S. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 13: Hawaii and Pacific Ocean

Region 13: Hawaii and the Pacific Ocean comprises volcanoes throughout the central Pacific, from the region's westernmost volcano of the Antipodes Island south of New Zealand to multiple volcanoes off the coast of the Americas. All are included in this regional discussion, and individual country profiles are provided. See Region 4 for the New Zealand profile.

Country	Number of volcanoes
France	4 + 4 from Regions 4 and 5
New Zealand (see Region 4)	1
USA	11

Table 230: The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

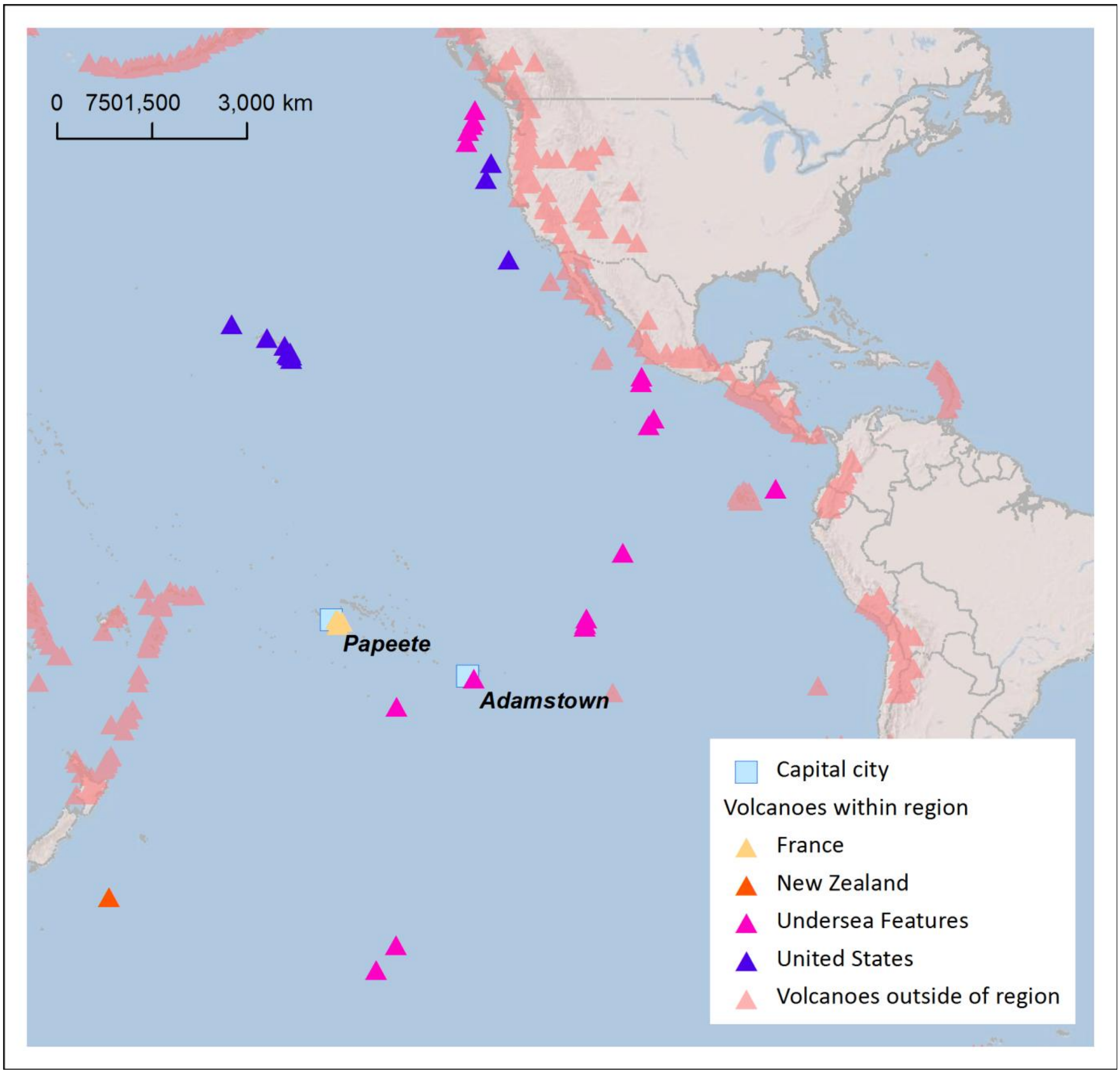


Figure 243: The distribution of Holocene volcanoes through the Hawaii and Pacific Ocean region. The capital cities of the constituent countries are shown.

Description

Thirty-four Holocene volcanoes are located in Hawaii and the Pacific Ocean. Most of these volcanoes are undersea features of no specific nationality. Volcanism here is largely due to intra-plate, hotspot activity.

Most volcanoes in this region are submarine, and indeed this region has the highest proportion of submarine volcanoes. Most subaerial volcanoes are shields, with five located in Hawaii. One stratovolcano, Mehetia, is located in French Polynesia while the Antipodes Island of New Zealand is a group of pyroclastic cones. The composition of these volcanoes and their products is dominantly basaltic.

348 Holocene eruptions are confirmed throughout this region of VEI 0 to 4. Despite this range of activity the record is dominated by VEI 0 events, with nearly 90% of all eruptions classed as such demonstrating the prevalence of effusive eruptions of lavas. Just one eruption is recorded of VEI ≥ 3. Lava flows are recorded in 300 eruptions in this region, whilst just one eruption with a pyroclastic flow is recorded at Kilauea.

Twenty-one volcanoes have historical records of 172 eruptions, indicating that the geological record for this region is reasonably well populated. About 81% of historical eruptions have associated records of lava flows.

Just 3% of historical eruptions have resulted in loss of life, largely due to the low proximal populations at most volcanoes (91%) and the number of submarine volcanoes. This low population coupled with the dominantly effusive nature of eruptions here means that all but one classified volcano are classed as Risk Level I. Hualalai in Hawaii is classed at Risk Level II with the largest proximal population in the region.

Away from the subaerial volcanoes of Hawaii dedicated ground-based monitoring is largely absent. Within Hawaii, the Hawaiian Volcano Observatory monitor the volcanoes and provide hazard data and advice.

Volcano facts

Number of Holocene volcanoes	34
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1 (1 eruption)
Number of volcanoes generating lahars	0
Number of volcanoes generating lava flows	23 (300 eruptions)
Number of eruptions with fatalities	6
Number of fatalities attributed to eruptions	5,497?

Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The 2560 and 2079 BP eruptions of the Older and Younger Uwekahuna Ash at Kilauea, Hawaii, are the largest recorded Holocene eruptions in this region at M4.2. No larger events are recorded in the Pleistocene in the LaMEVE database.
Number of Holocene eruptions	348 confirmed Holocene eruptions
Recorded Holocene VEI range	0 – 4 and unknown.
Number of historically active volcanoes	21
Number of historical eruptions	172

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Basaltic (1)
5	Shield(s)	Basaltic (5)
1	Small cone(s)	Basaltic (1)
27	Submarine	Basaltic (21), Trachytic/Andesitic (1), Unknown (5)

Table 231: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	

Table 232: Average recurrence interval (years between eruptions) for small and large eruptions in Hawaii and the Pacific.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year.

Eruption Size

Eruptions are recorded through the Hawaii and Pacific Ocean region of VEI 0 to 4, representing a range of eruption styles from gentle effusive events to explosive eruptions. VEI 0 events dominate the record, with nearly 90% of all Holocene eruptions classed as such. Just 0.3% of eruptions here are explosive at VEI≥4.

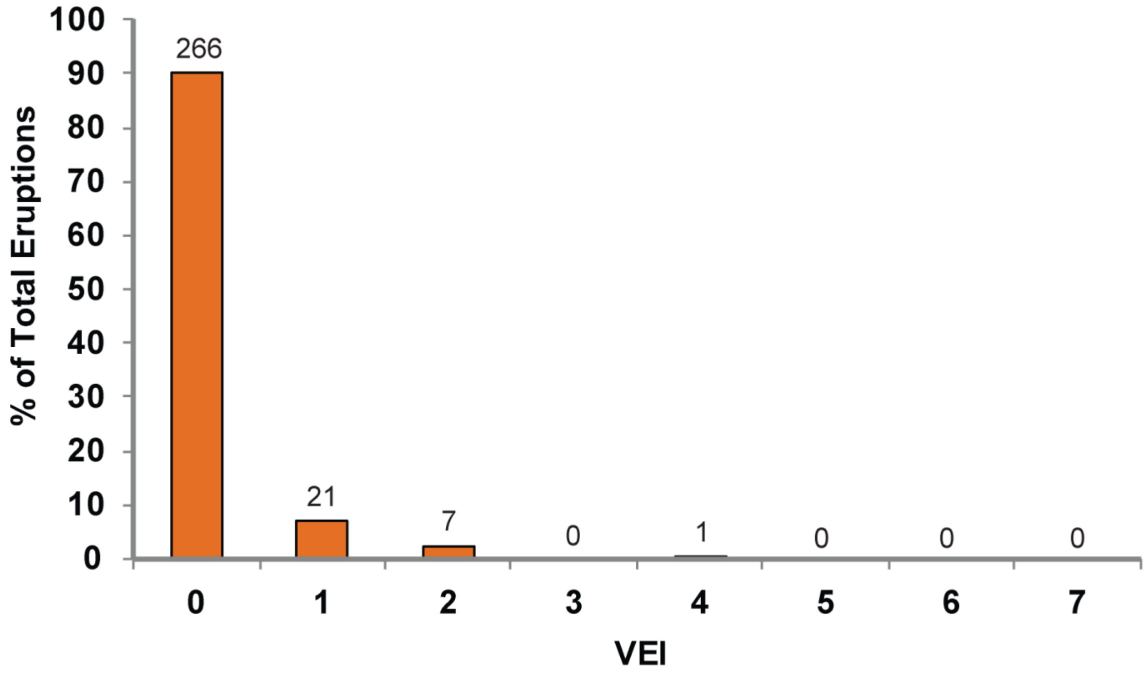


Figure 244: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 53 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	1,390,090
Gross Domestic Product (GDP) per capita (2005 PPP $)	
Gross National Income (GNI) per capita (2005 PPP $)	
Human Development Index (HDI) (2012)	

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	65,387 (4.70 %)
Number (percentage) of people living within 30 km of a Holocene volcano	132,822 (9.55 %)
Number (percentage) of people living within 100 km of a Holocene volcano	1,691,007 (>100 %)

Infrastructure Exposure

Number of airports within 100 km of a volcano	6
Number of ports within 100 km of a volcano	23
Total length of roads within 100 km of a volcano (km)	865
Total length of railroads within 100 km of a volcano (km)	0

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I	Adams Seamount; Macdonald; Unnamed; Southern EPR-Segment K	Mauna Loa; Teahitia	Kilauea		Hualalai		
UNCLASSIFIED	**U – HHR**	**CoAxial Segment**; **Axial Seamount**; **Cleft Segment**; **North Gorda Ridge**; **Unnamed (332090); Unnamed (334040); Galápagos Rift; Unnamed (334100);** Southern EPR-Segment J; **Southern EPR-Segment I**	**Loihi**; **Rocard**; **Moua Pihaa**		Haleakala			
	U- HR	**Endeavour Ridge**; Cobb Segment; Escanaba Segment; Northern EPR-Segment RO2; Northern EPR-Segment RO3	Mauna Kea					
	U- NHHR	Unnamed; Antipodes Island; Unnamed; Unnamed	Unnamed; **Mehetia**					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 233: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
1	5
1	4
1	3
8	2
23	1

Table 234: The number of volcanoes in Hawaii and the Pacific classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
0	III
1	II
7	I
26	Unclassified

Table 235: The number of volcanoes in the Hawaii and Pacific Ocean region classified at each Risk Level.

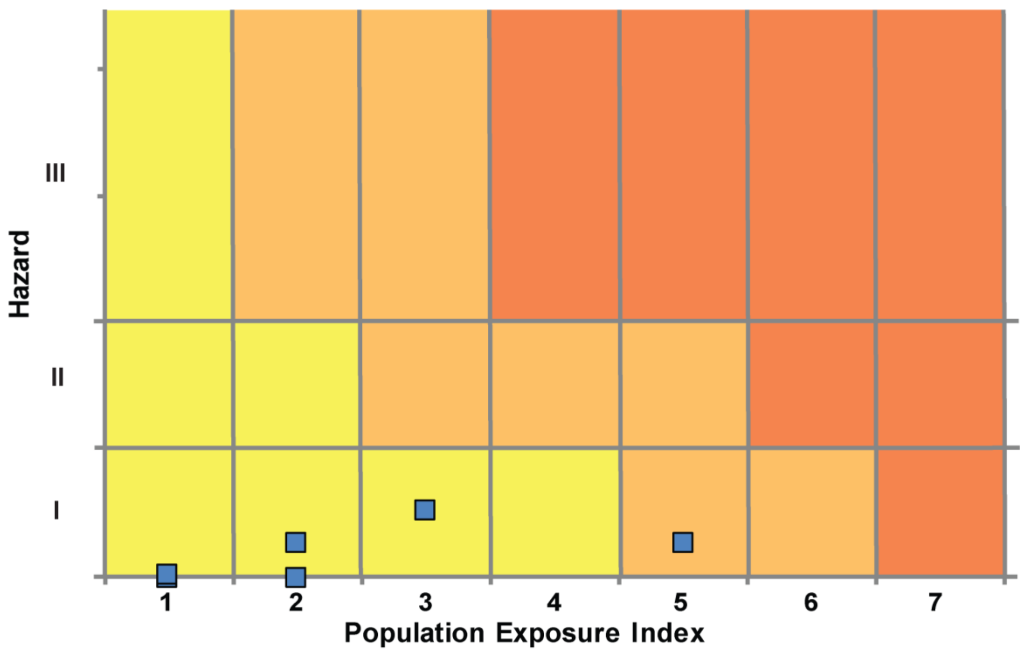


Figure 245: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

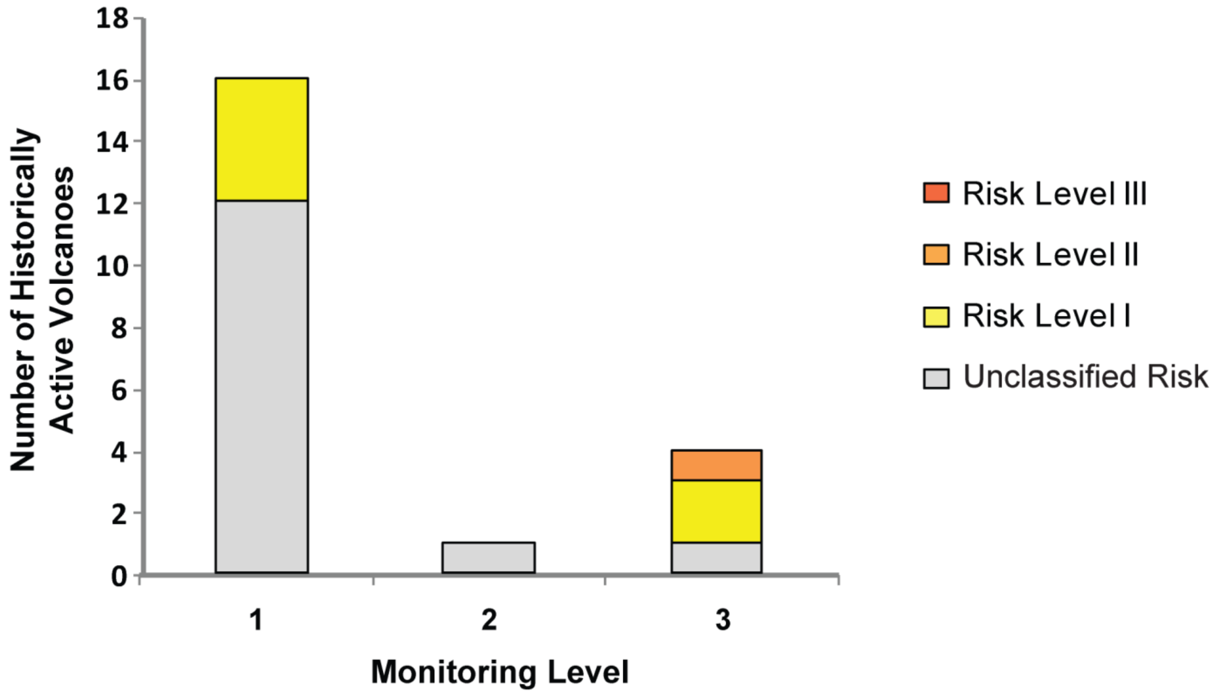


Figure 246: The monitoring and risk levels of the historically active volcanoes in Hawaii and the Pacific Ocean. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

France – Multiple Pacific Ocean islands

See Region 1 for mainland France, Region 3 for the French territories in the Indian Ocean. Note that here we include Region 13’s Teahitia, Rocard, Moua Pihaa and Mehetia of French Polynesia, Wallis Islands from Region 4 and Eastern Gemini Seamount, Matthew Island and Hunter Island from Region 5 in discussion.

Description

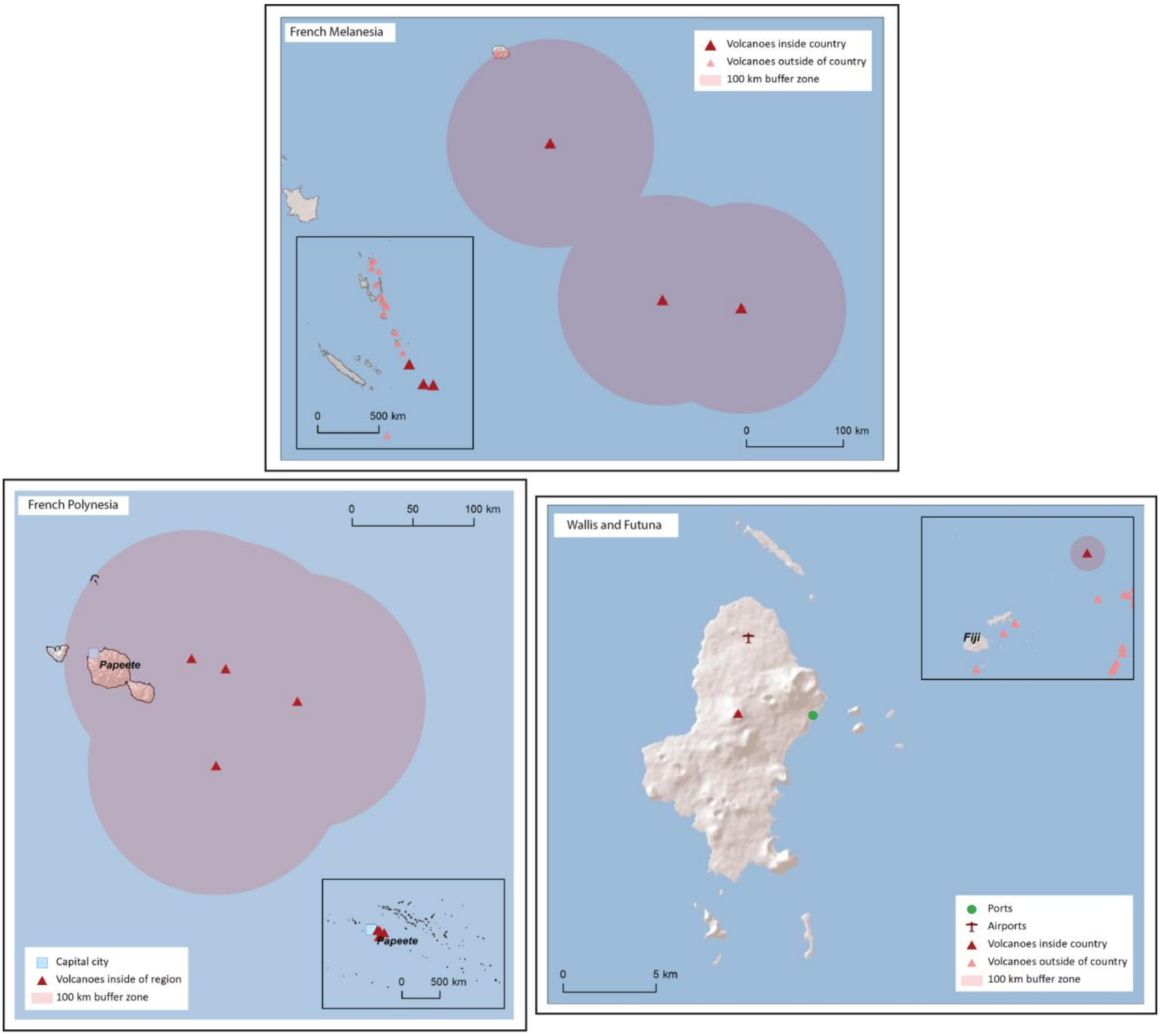


Figure 247: Location of the Pacific Ocean French volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Pacific Ocean French volcanoes.

A number of islands in the Pacific are French overseas territories. Eight Holocene volcanoes are located on these islands, with three located between Fiji and New Caledonia (Matthew Island, Hunter Island and the Eastern Gemini Seamount, these being located in a rift setting); the Wallis Islands located to the north-east of Fiji (in a subduction zone), and four located in French Polynesia (due to intra-plate hotspot processes). Four of these volcanoes are submarine, whilst the subaerial volcanoes comprise three stratovolcanoes and one shield volcano.

Seventeen Holocene eruptions of VEI 0 to 2 are recorded here, indicating predominantly mild activity and indeed lava flows are recorded in four events. All seventeen eruptions are recorded historically, with no geological record available for these volcanoes. All are recorded post-1835.

Only three of these volcanoes – Wallis Islands, Matthew Island and Mehetia have a population within 10 km. Assessment of hazard at these volcanoes is complicated by the sparse eruption history, but the risk here is considered relatively low. However, large eruptions cannot be ruled out.

Volcano Facts

Number of Holocene volcanoes	4 in Region 13, 1 in Region 4, 3 in Region 5
Number of Pleistocene volcanoes with M≥4 eruptions	
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	2
Number of fatalities caused by volcanic eruptions	
Tectonic setting	Region 13: Intra-plate, Region 4: Subduction zone, Region 5: Rift zone
Largest recorded Pleistocene eruption	
Largest recorded Holocene eruption	
Number of Holocene eruptions	17
Recorded Holocene VEI range	0 – 2 and unknown
Number of historically active volcanoes	6
Number of historic eruptions	17

Number of volcanoes	Primary volcano type	Dominant rock type
3	Large Cone(s)	Andesitic (2), Basaltic (1)
1	Shield(s)	Basaltic (1)
4	Submarine	Basaltic (3), Trachytic/Andesitic (1)

Table 236: The number of the Pacific Ocean French volcanoes, their volcano type classification and dominant rock type according to VOTW4.0.

Population Exposure

Number (percentage) of people living within 30 km of a Holocene volcano	115
Total population	295,587 (280,026 in French Polynesia and 15,561 in Wallis and Futuna in 2014, https://www.cia.gov/library/publications/the-world-factbook/)

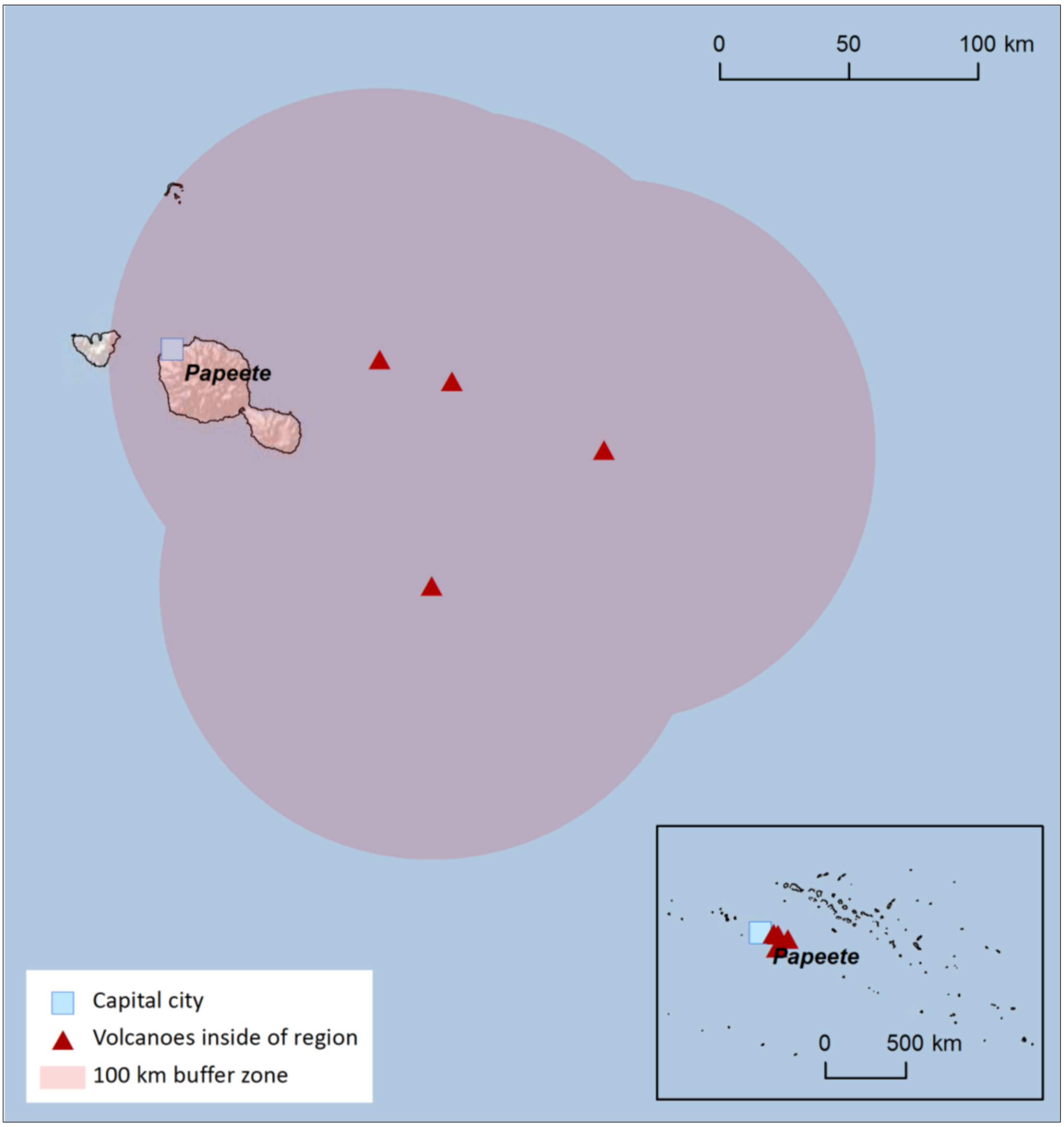
Largest cities, as measured by population, and their populations:

Papeete (French Polynesia)	26,357

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	2
Total length of roads within 100 km of a volcano (km)	-
Total length of railroads within 100 km of a volcano (km)	-

The volcanoes of French Polynesia are located to the east of the main island of Tahiti, with all but Mehetia lying within 100 km of this island. The 100 km radii of these volcanoes extend to fully encompass Tahiti, and much of the islands of Moorea and Tetiaroa. The capital, Papeete lies within these radii and all critical infrastructure is exposed.



The volcanoes of French Melanesia, Matthew Island, Hunter Island and Eastern Gemini Seamount lie beyond 100 km to the south of Vanuatu. No surface infrastructure lies within 100 km of these volcanoes.

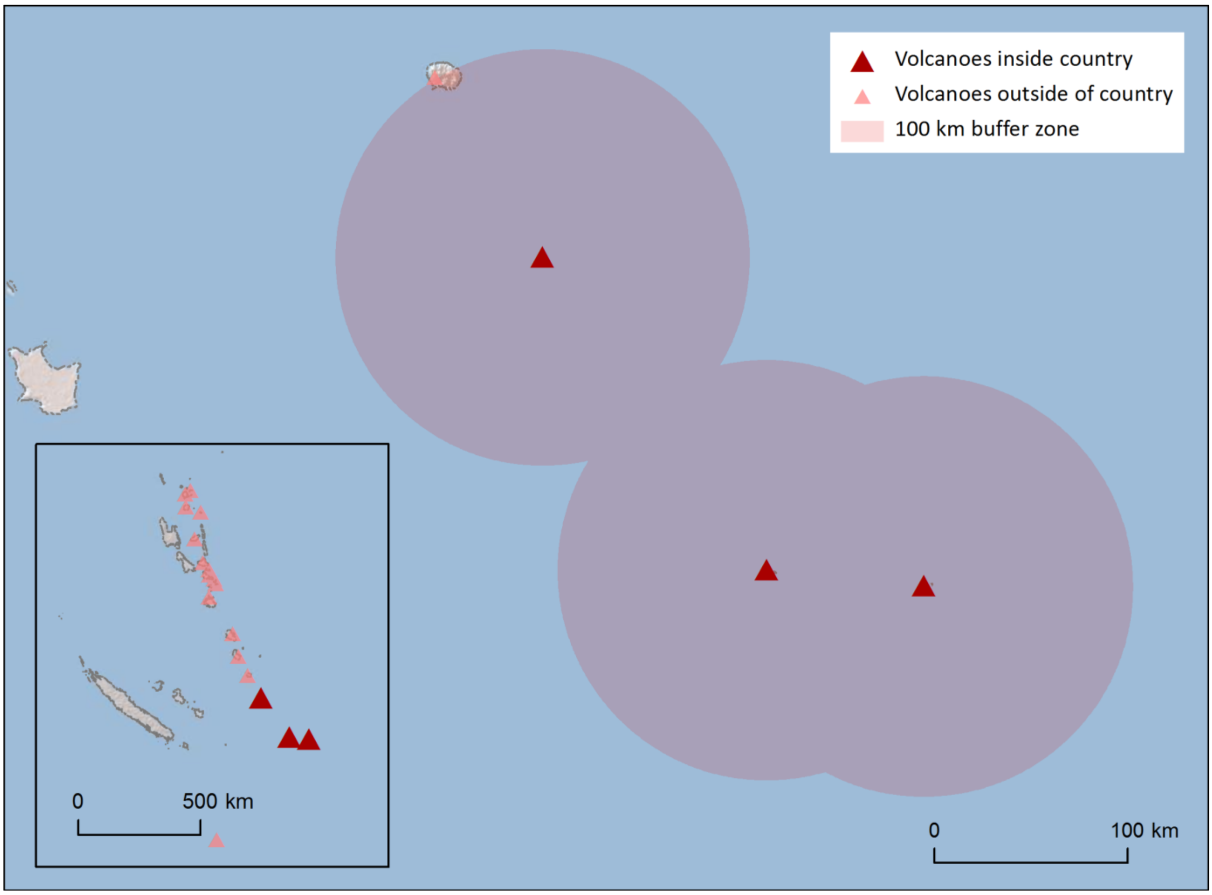


Figure 248: The location of French Melanesia and the volcanoes here and the extent of the 100 km zone surrounding them.

The Wallis Islands volcano is located on Wallis and Futuna, over 300 km from Samoa. The island measures no more than 30 km across and therefore all infrastructure here is exposed to volcanic hazards, lying within the 100 km radius of Wallis Islands volcano. This includes the capital, Mata-utu.

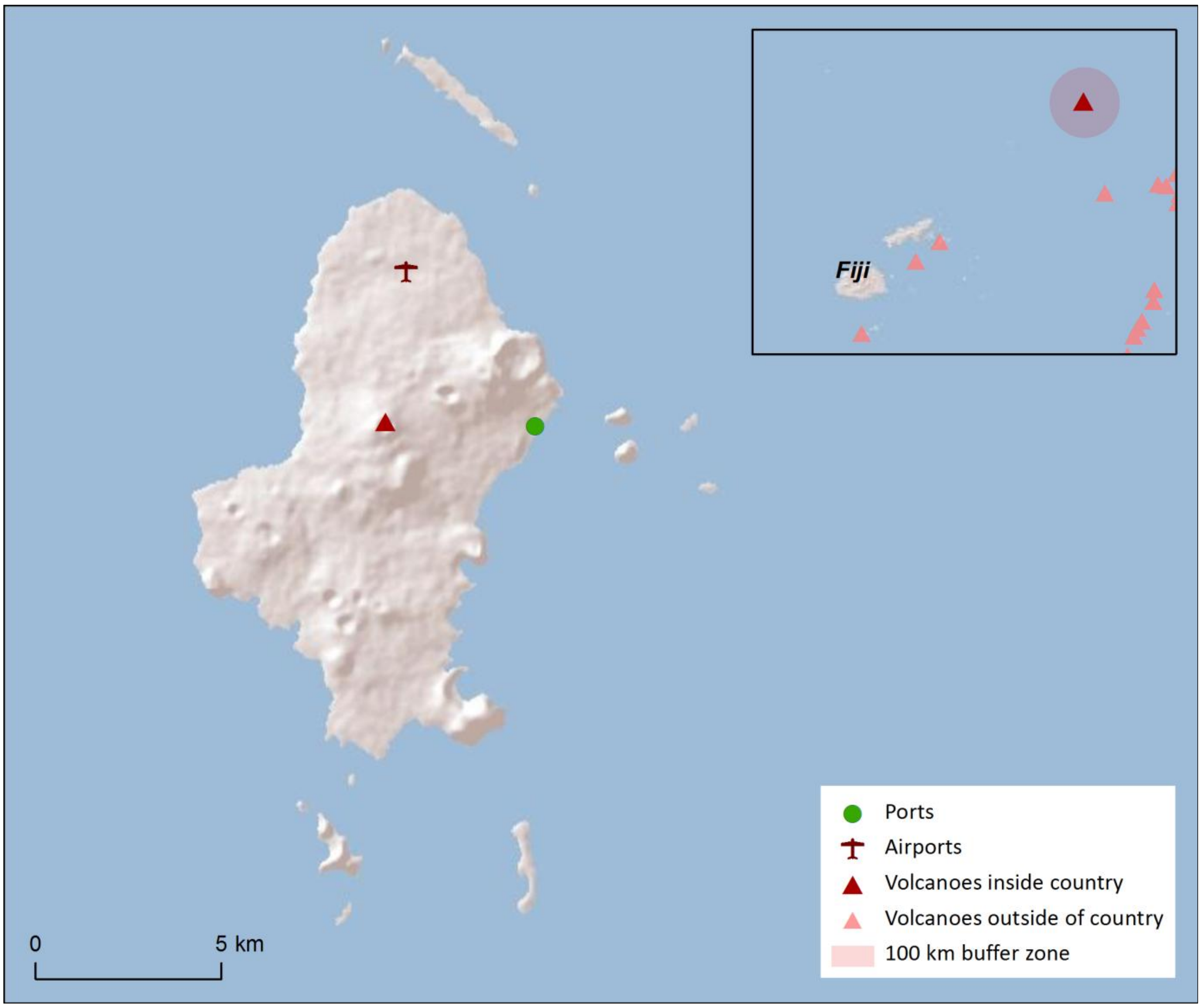


Figure 249: The location of Wallis and Futuna and the volcanoes here and the extent of the 100 km zone surrounding them.

Hazard, Uncertainty and Exposure Assessments

With the exception of Teahitia, the eruptive histories at all volcanoes here are insufficiently detailed to permit the determination of hazard through the calculation of the VHI without large associated uncertainties. Teahitia is classified at Hazard Level I, from historical VEI 0 eruptions. Of the unclassified volcanoes, two have no confirmed Holocene eruptions. The remaining unclassified volcanoes all have historical records only of eruptions of VEI 0 – 2.

The proximal population to these volcanoes is small, with only Wallis Islands, Matthew Island and Mehetia having a population within 10 km. For the latter two volcanoes, this doesn't increase within 100km. Whilst the islands of French Polynesia have a larger population within 100 km, all but Wallis Islands are classed with a low PEI of 2. With the population within 10 km at Wallis Islands, the PEI here is moderate at 4.

		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7
CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I		Teahitia					
UNCLASSIFIED	U – HHR	**Eastern Gemini Seamount; Hunter Island**	**Rocard; Moua Pihaa; Matthew Island**					
	U- HR							
	U- NHHR		**Mehetia**		Wallis Islands			

*Table 237: Identity of the volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Teahitia	2	I

Table 238: The classified Pacific Ocean French volcanoes ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

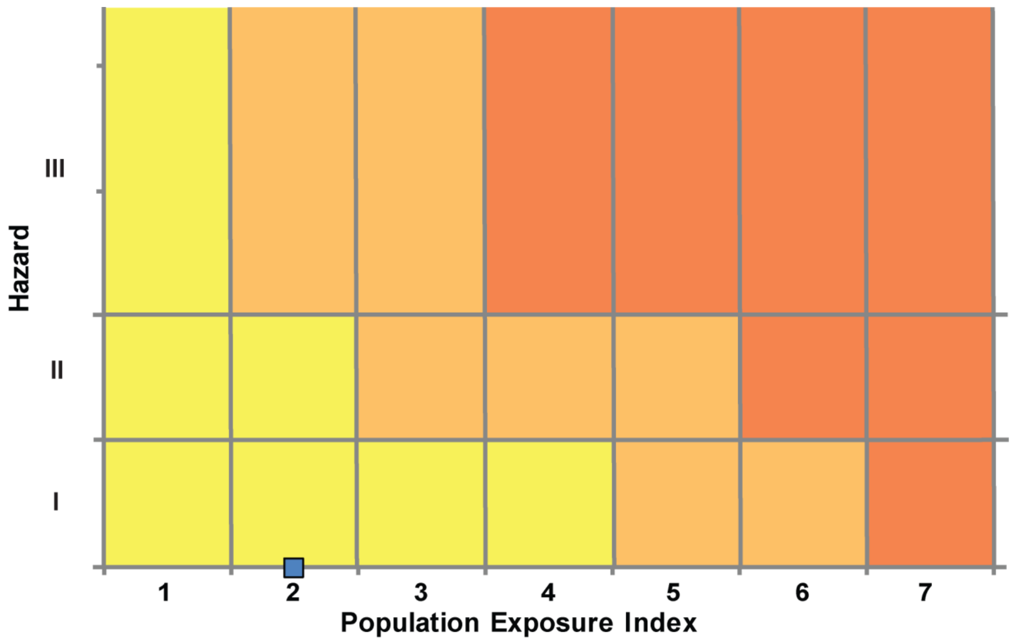


Figure 250: Distribution of the Pacific Ocean French classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Six volcanoes have records of historical activity in the French islands of the Pacific. At the time of the writing of this report there is no information available to indicate the presence of dedicated ground-based monitoring systems on these volcanoes.

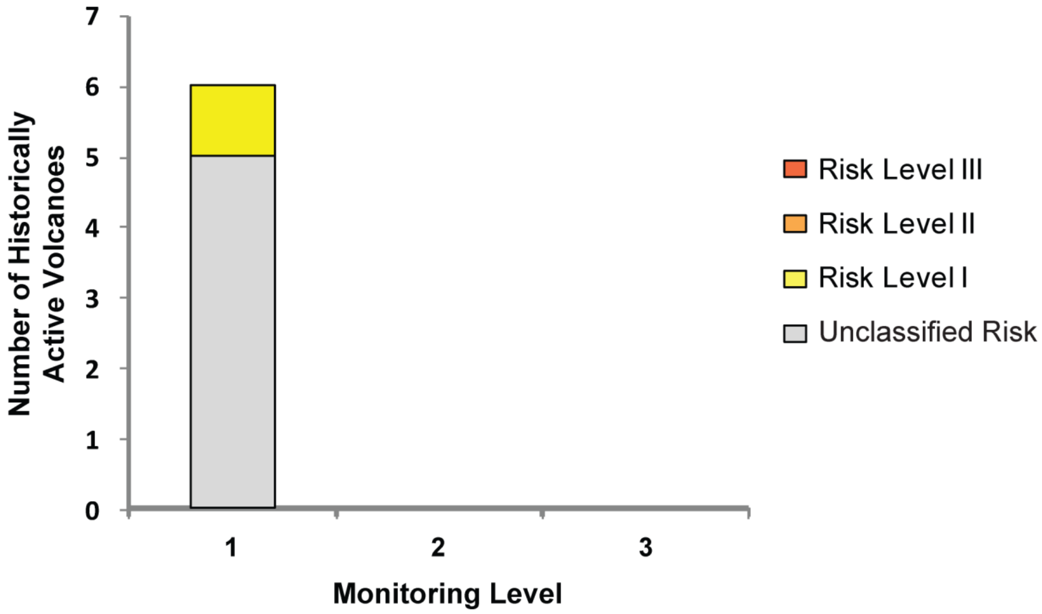


Figure 251: The monitoring and risk levels of the historically active volcanoes in the Pacific Ocean French volcanoes. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

USA – Hawaii and Pacific

See Region 4 for American Samoa, Region 8 for the Marianas, Region 11 for Alaska, Region 12 for the contiguous states.

Here we discuss the volcanism in the US-Pacific. The profile focuses on the subaerial volcanism in Hawaii, then goes on to provide analysis of the submarine volcanoes located in the northern Pacific – the North Gorda Ridge, Escanaba Segment and an Unnamed volcano.

Description

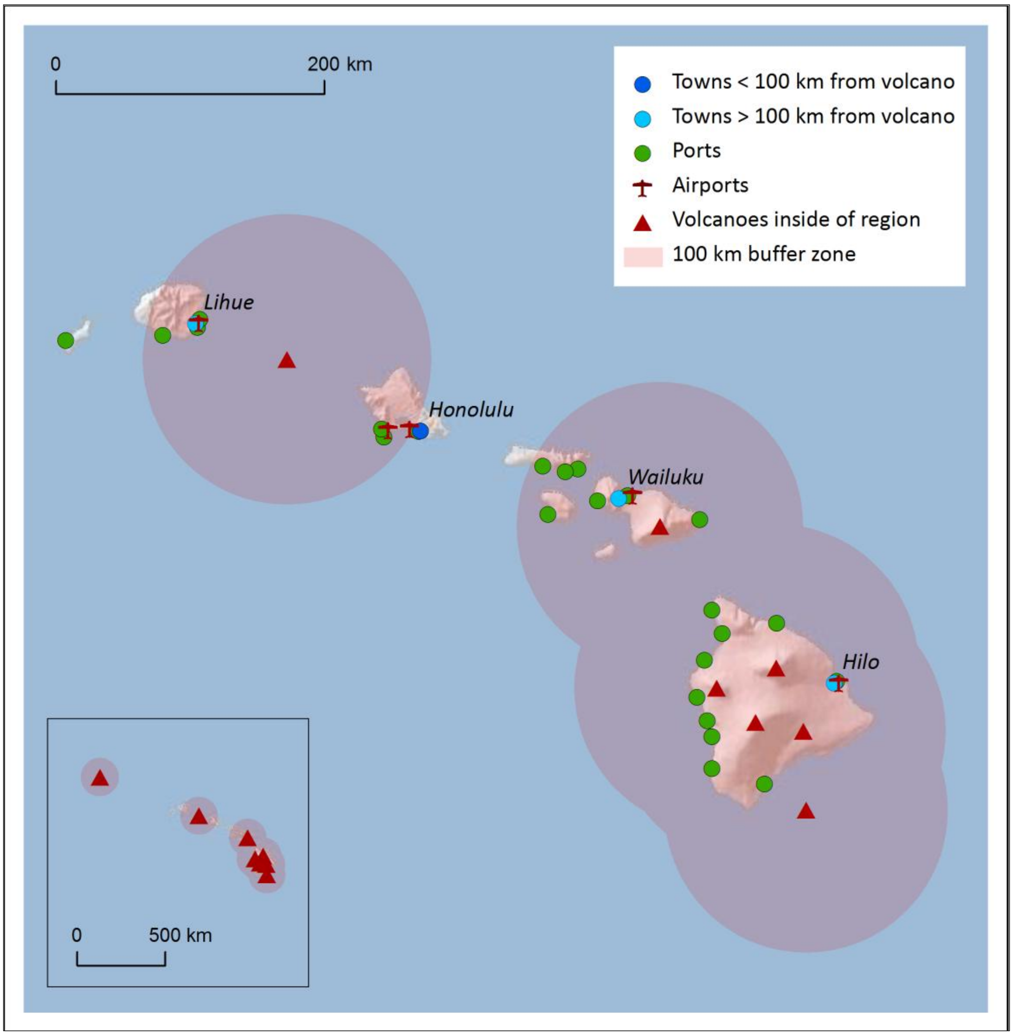


Figure 252: The location of Hawaii's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Eight Holocene volcanoes are located in Hawaii. Three submarine volcanoes are located off the southern coast of the Big Island (Hawaii), between Oahu and Kauai and beyond Kauai into the northwestern leeward islands. The remaining volcanoes are subaerial shields located on Hawaii and Maui. These volcanoes are dominantly basaltic in composition and result from intra-plate hotspot processes.

277 confirmed Holocene eruptions are recorded in Hawaii. These ranged from VEI 0 to 4. 123 of these eruptions are recorded historically, post-1500 AD.

The nature of the volcanoes in Hawaii are such that eruptions are not restricted to the summit, as rift zones are active across Hawaiian volcanoes including Hualalai, Mauna Loa and Kilauea. These rift zones are areas of weakness which are exploited by magma bodies. Eruptions therefore commonly occur along these rifts, some of which are over 100 km long. Indeed, the East Rift Zone of Haleakala is about 150 km long and extends into the ocean. Basaltic rift zones such as in Hawaii are typically associated with effusive events, producing extensive basaltic lava flows. These lavas can extend from many points along the rift zone, propagating downhill, and much of the surface of Mauna Loa and Kilauea comprises lava flows younger than 1000 years old. The population at risk cannot therefore be thought of in relation to a summit point, but is in fact more widespread along the lengths of the rifts and downhill from these features. With development of land expanding towards rift systems, the threat to life and property increases. Several eruptions of Kilauea, Mauna Loa have lead to property damage and several have resulted in loss of life.

Just one historical eruption of VEI 4 is recorded at Kilauea in 1790 in VOTW4.22. This explosive eruption produced pyroclastic flows and ballistics killing hundreds. Ongoing work investigating this eruption suggests that it was in fact a VEI 3 event (J.Kauahikaua, pers.comm., 2014). Indeed, explosive activity is rare here.

The U.S. Geological Survey's Hawaiian Volcano Observatory (HVO) was founded in 1912. Here scientific research and monitoring of the active volcanoes is undertaken, with a large monitoring network focussed on the island of Hawaii. Hazard assessment reports have been produced for Kilauea and Mauna Loa. The HVO provide Volcanic Activity Notices (VAN) for changes in alert levels and aviation colour codes. Regular updates are also released. See the profile for the U.S. contiguous states for description of the U.S. Geological Survey's NVEWS approach to monitoring.

See also:

Guffanti, M., Diefenbach, A.K., Ewert, J.W., Ramsey, D.W., Cervelli, P.F., and Schilling, S.P., 2009, Volcano-monitoring instrumentation in the United States, 2008: U.S. Geological Survey Open-file Report 2009-1165, 32 p. http://pubs.usgs.gov/of/2009/1165/

Hawaiian Volcano Observatory: http://hvo.wr.usgs.gov/observatory/

Volcano Facts

Number of Holocene volcanoes	8
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	0
Number of volcanoes generating lava flows	8

Number of fatalities caused by volcanic eruptions	Hundreds
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Three VEI 4 eruptions during the Holocene (VOTW4.22), however currently ongoing unpublished work indicates that these eruptions were no more than VEI 3 in size.
Number of Holocene eruptions	277 confirmed eruptions.
Number of historically active volcanoes	6
Number of historical eruptions	123

Number of volcanoes	Primary volcano type	Dominant rock type
5	Shield(s)	Basaltic (5)
3	Submarine	Basaltic (1), Unknown (2)

Table 239: The number of volcanoes, their volcano type classification and dominant rock type according to VOTW4.0.

Population Exposure

Capital city	Honolulu
Distance from capital city to nearest Holocene volcano	100 km
Total population (2010) (US Census Bureau[i])	1,360,301

Ten largest cities, as defined by population size, and populations (2010 US Census):

Honolulu	337,256
East Honolulu	49,914
Pearl City	47,698
Hilo	43,263
Kailua	38,635
Waipahu	38,635
Waipahu	38,216
Kaneohe	34,597
Mililani Town	27,629
Kahului	26,337

Infrastructure Exposure

Number of airports within 100 km of a volcano	5
Number of ports within 100 km of a volcano	22
Total length of roads within 100 km of a volcano (km)	865
Total length of railroads within 100 km of a volcano (km)	0

With the exception of the island Ni'ihau, almost the entirety of the main islands of the Hawaiian island chain fall within 100 km of a Holocene volcano, therefore including much of the critical infrastructure and the largest cities, including the capital, Honolulu. Being volcanic islands, a large number of ports lie within the 100 km radii, 5 airports and a substantial road network is also affected.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information in the eruption records of Hawaii's volcanoes. Mauna Loa, Kilauea and Hualalai have sufficient detail to determine hazard through the calculation of the VHI and all are classified at Hazard Level I due to a largely effusive eruptive history.

There is insufficient data to calculate the VHI at the remaining volcanoes without large associated uncertainties. With the exception of an unnamed volcano, all unclassified volcanoes have a Holocene record of activity, with historical eruptions at Haleakala, Loihi and another unnamed volcano.

The PEI ranges from low to high in Hawaii, and with a Hazard Level of I, the classified volcanoes are classed at Risk Levels I and II. Just Hualalai is classed as Risk Level II, with the largest population within 10 km of all Hawaiian volcanoes.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I		Mauna Loa	Kilauea		Hualalai		
UNCLASSIFIED	**U – HHR**	**Unnamed (332090)**	**Loihi**		Haleakala			
	U- HR		Mauna Kea					
	U- NHHR		Unnamed (332080)					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 240: Identity of volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Hualalai	5	II
Kilauea	3	I
Mauna Loa	2	I

Table 241: Classified volcanoes ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 2 volcanoes; Risk Level II – 1 volcano; Risk Level III – 0 volcanoes.

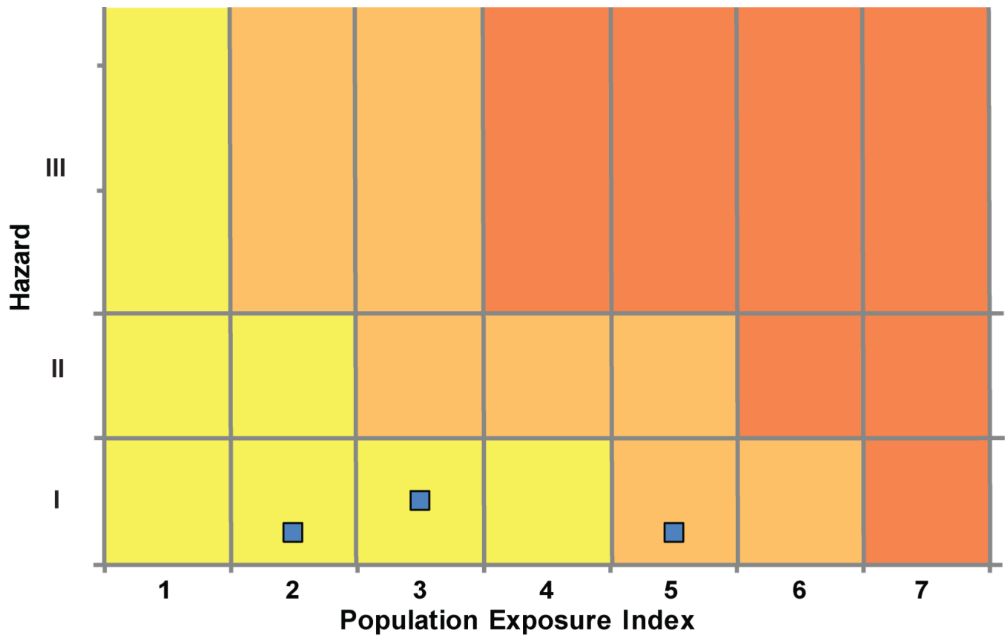


Figure 2532: Distribution of classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Seven volcanoes in Hawaii have historical records of activity. The unnamed submarine volcano does not have dedicated ground-based monitoring. The volcanoes on the Big Island, Loihi, Kilauea, Mauna Loa and Hualalai are monitored through an extensive seismic network, with additional deformation and gas monitoring at Kilauea and Mauna Loa. Numerous seismic stations are also located near Haleakala on Maui.

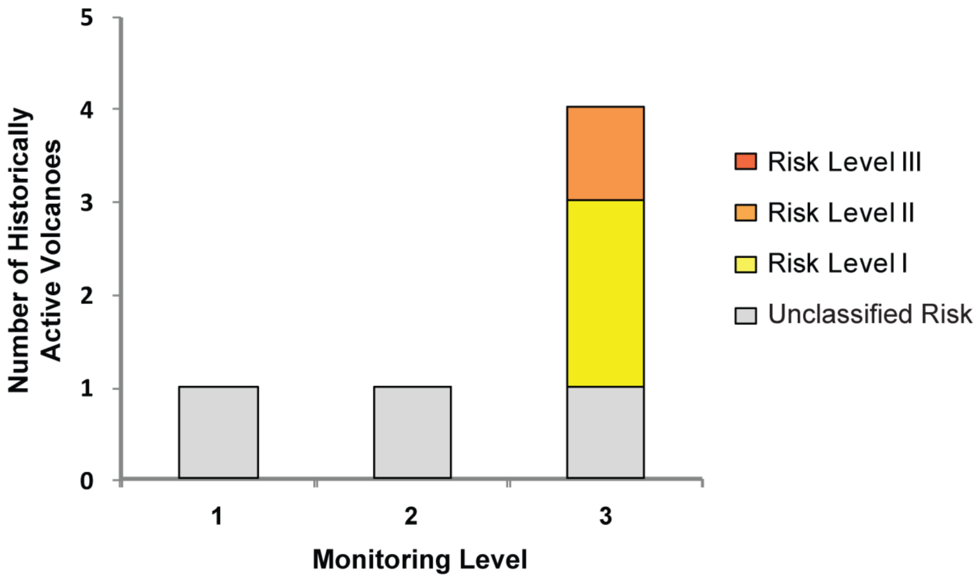


Figure 254: The monitoring and risk levels of the historically active volcanoes. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

USA –Pacific-Other

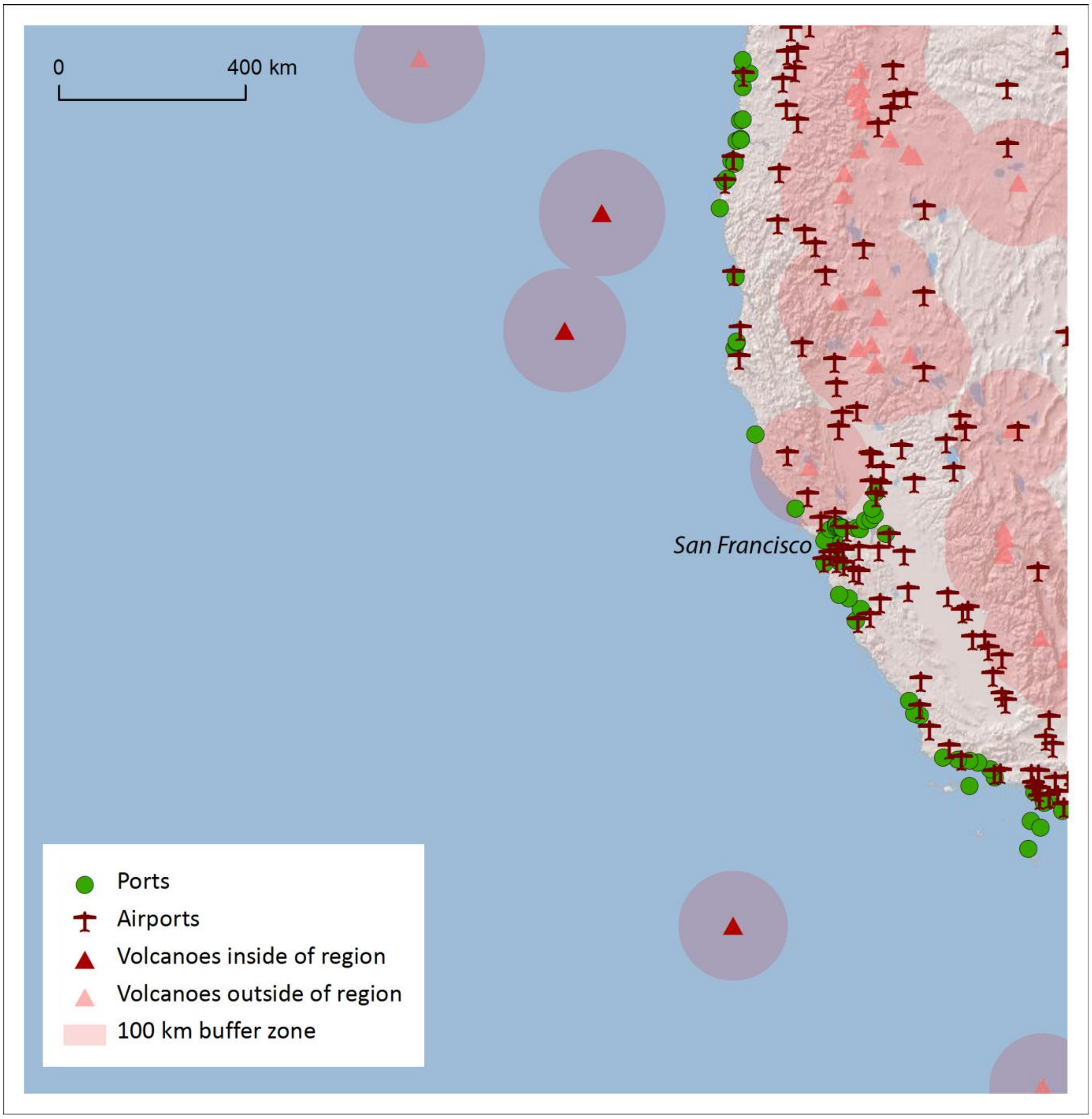


Figure 255: The location of the Pacific US volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Three submarine volcanoes are located beyond about 200 km off the coast of Oregon and California. These volcanoes – the North Gorda Ridge, Escanaba Segment and an unnamed volcano, are submarine features.

North Gorda Ridge formed on a spreading centre south of the Juan de Fuca ridge. An eruption occurred here in 1996, forming a submarine lava flow.

Being remote submarine features there is no population living within 100 km of any of these volcanoes. The hazard is considered low to the nature of lava effusions at spreading ridges and with no permanent population the risk is therefore low.

Volcano Facts

Number of Holocene volcanoes	3
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	2
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate, rift-zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	All eruptions of VEI 0.
Number of Holocene eruptions	4 confirmed eruptions.
Number of historically active volcanoes	1
Number of historical eruptions	1

Number of volcanoes	Primary volcano type	Dominant rock type
3	Submarine	Basaltic (2), Unknown (1)

Table 242: The number of volcanoes, their volcano type classification and dominant rock type according to VOTW4.0.

Hazard, Uncertainty and Exposure Assessments

The eruptive record for these volcanoes prevents the determination of hazard through calculation of the VHI without large uncertainties. These volcanoes are therefore unclassified. Just Escanaba Segment and North Gorda Ridge have a Holocene eruption record, most recently with a 1996 VEI 0 eruption of North Gorda Ridge. Despite the hazard being unclassified, the absence of a local population means the risk here is low.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR	**North Gorda Ridge**						
	U- HR	Escanaba Segment						
	U- NHHR	Unnamed (331050)						
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 243: Identity of volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

One volcano has historical records of activity. This volcano, the submarine North Gorda Ridge volcano, does not have dedicated ground-based monitoring.

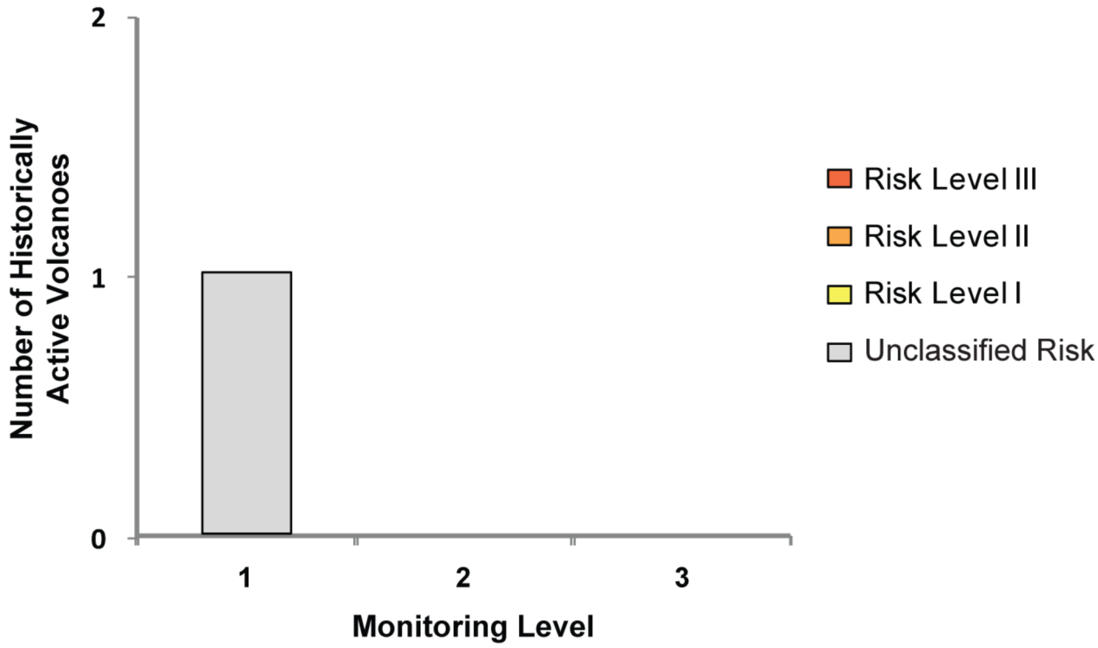


Figure 256: The monitoring and risk levels of the historically active volcanoes. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

[i] http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk

Region 14: Mexico and Central America

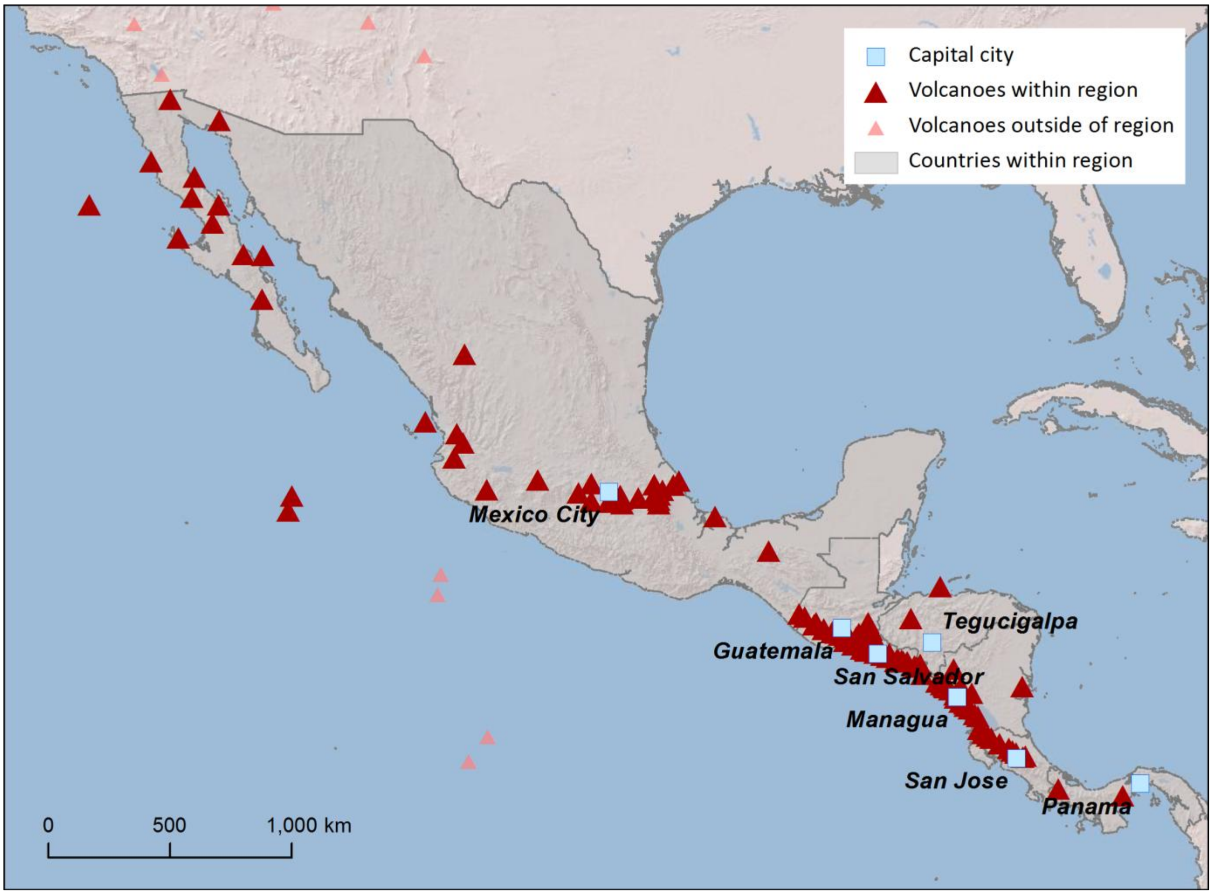


Figure 257: The distribution of Holocene volcanoes through the Melanesia and Australia region. The capital cities of the constituent countries are shown.

Description

Region 14: Mexico and Central America comprises volcanoes from Panama in the south to the Mexico-US border in the north. Seven countries are represented here.

Country	Number of volcanoes
Costa Rica	10
El Salvador	22
Guatemala	23
Honduras	4
Mexico	40
Nicaragua	19
Panama	2

*Table **244:** The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.*

118 Holocene volcanoes are located in Mexico and Central America with most of these volcanoes located in Mexico. Volcanism here is largely related to the subduction of the Cocos Plate beneath the Caribbean and North American Plates.

A range of volcano types are present in this region, though most (about 60%) are stratovolcanoes. The rock type through this region is dominantly andesitic, but ranges from basaltic to rhyolitic.

A range of activity styles and eruption sizes are recorded through the Holocene, with eruptions of VEI 0 to 6. About 73% of eruptions have been small, at VEI 0 – 2, however about 11% (70) of eruptions have been large explosive VEI ≥4 events. The only countries in this region with no Holocene record of producing such eruptions are Honduras and Panama, though pyroclastic flows are recorded in Panama. The largest Holocene eruption in this region was the VEI 6 Terra Blanca Joven (TBJ) eruption of Ilopango in El Salvdor in about 450 AD. This eruption produced widespread pyroclastic flows and devastated Mayan cities. The capital of El Salvador lies within 20 km of this volcano.

Thirty-seven volcanoes have historical records of 578 eruptions, 98% of which were recorded through direct observations. Just 203 eruptions were recorded before 1500 AD. 12% of historical events produced pyroclastic flows, and 7% generated lahars. 23% of eruptions produced lava flows.

Lives were lost in 4% of historical eruptions, accounting for over 40,000 fatalities. This region has a high population, with most volcanoes (64%) having high proximal populations and as such many are considered relatively high risk. However the hazard (VHI) is poorly constrained at many volcanoes here so about 80% of volcanoes are unclassified in hazard and risk.

Thirty-one of thirty-seven historically active volcanoes in this region are monitored using at least one dedicated seismometer, with active monitoring groups in many of this region’s countries.

Volcano facts

Number of Holocene volcanoes	118
Number of Pleistocene volcanoes with M≥4 eruptions	39
Number of volcanoes generating pyroclastic flows	35 (171 eruptions)
Number of volcanoes generating lahars	22 (52 eruptions)
Number of volcanoes generating lava flows	31 (162 eruptions)
Number of eruptions with fatalities	26
Number of fatalities attributed to eruptions	46,317
Largest recorded Pleistocene eruption	The largest eruption in this region during the Quaternary is recorded at 84 ka with the M7.8 eruption of Los Chocoyos Ash (H)

	from Atitlán in Guatemala.
Largest recorded Holocene eruption	The largest recorded Holocene eruption in this region is the 1500 BP M6.7 TBJ eruption of Ilopango.
Number of Holocene eruptions	781 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 6 and unknown.
Number of historically active volcanoes	37
Number of historical eruptions	578

Number of volcanoes	Primary volcano type	Dominant rock type
6	Caldera(s)	Basaltic (1), Dacitic (3), Rhyolitic (2)
68	Large cone(s)	Andesitic (44), Basaltic (18), Dacitic (5), Unknown (1)
4	Lava dome(s)	Andesitic (1), Dacitic (2), Rhyolitic (1)
8	Shield(s)	Andesitic (3), Basaltic (4), Trachytic / Andesitic (1)
33	Small cone(s)	Andesitic (7), Basaltic (20), Dacitic (1), Rhyolitic (2), Trachytic / Andesitic (1), Unknown (2)
1	Submarine	Unknown (1)

*Table **245**: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.*

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	50

*Table **246**: Average recurrence interval (years between eruptions) for small and large eruptions in Mexico and Central America.*

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 50 years.

Eruption Size

Eruptions are recorded through Mexico and Central America of VEI 0 to 6, representing a range of eruption styles from gentle effusive events to large explosive eruptions. VEI 2 events dominate the record, with about 50% of all Holocene eruptions classed as such. Nearly 11% of eruptions here are explosive at VEI≥4.

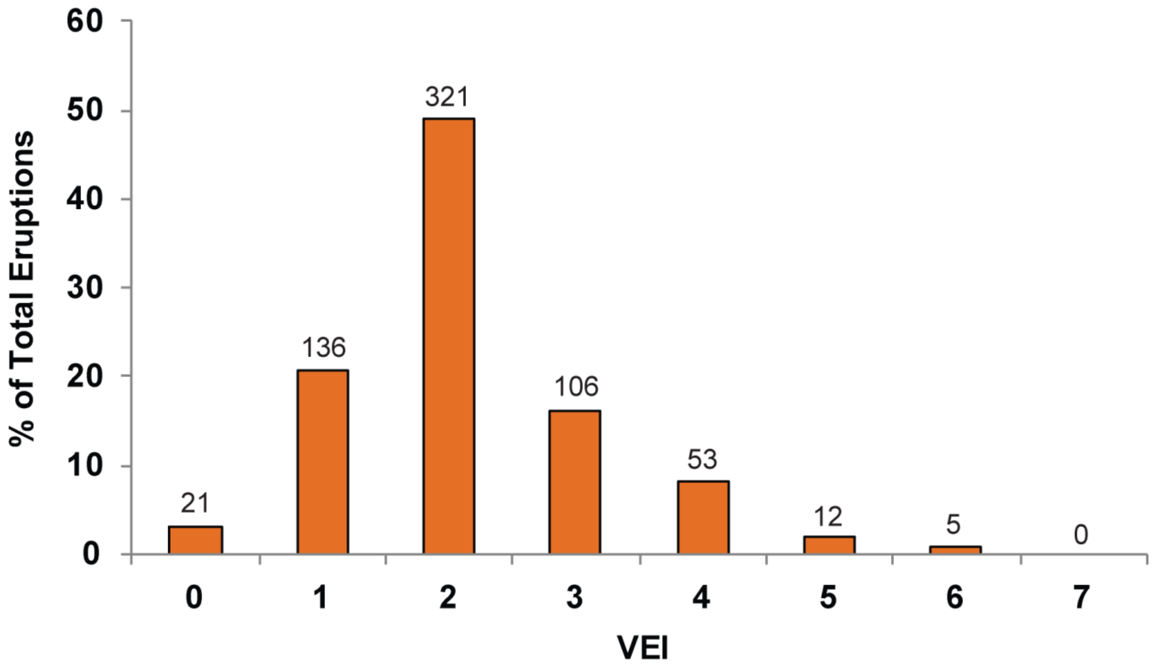


Figure 258: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 127 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	155,467,352
Gross Domestic Product (GDP) per capita (2005 PPP $)	2,579 – 13,766 (Mean 7,686)
Gross National Income (GNI) per capita (2005 PPP $)	2,551 – 13,519 (Mean 7,649)
Human Development Index (HDI) (2012)	0.581 – 0.78 (Medium to High, Mean 0.689 Medium)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	5,647,382 (3.63 %)
Number (percentage) of people living within 30 km of a Holocene volcano	36,638,320 (23.57 %)
Number (percentage) of people living within 100 km of a Holocene volcano	96,977,702 (62.38 %)

Infrastructure Exposure

Number of airports within 100 km of a volcano	29
Number of ports within 100 km of a volcano	43
Total length of roads within 100 km of a volcano (km)	34,152
Total length of railroads within 100 km of a volcano (km)	2,308

CLASSIFIED	**Hazard III**				Colima	Orizaba, Pico de; Fuego; Irazú; Turrialba	Santa María; Pacaya; Apoyeque	
	Hazard II			Rincón de la Vieja	San Cristóbal; Momotombo	Popocatépetl; Santa Ana; Telica; Concepción	Atitlán	Chichinautzin; Masaya
	Hazard I				Negro, Cerro; Arenal	San Miguel; Poás	Izalco	
UNCLASSIFIED	**U – HHR**	**Bárcena; Socorro**		**Cosigüina**	San Martín; **Chichón, El**; Conchagüita; **Pilas, Las**; **Miravalles**; Barú	Ceboruco; **Tacaná**	**Acatenango**	**Michoacán-Guanajuato**; Almolonga; **San Salvador;** Ilopango
	U- HR				Cumbres, Las	Malinche, La; Cofre de Perote; Tecuamburro; Barva	Zitácuaro-Valle de Bravo; Jocotitlán; Toluca, Nevado de; Naolinco Volcanic Field	**Nejapa-Miraflores**
	U- NHHR	Guadalupe; Isabel, Isla	Pinacate; San Luis, Isla; Jaraguay Volcanic Field; Coronado; San Borja Volcanic Field; Unnamed; Tres Vírgenes; Tortuga, Isla; Comondú-La Purísima	Utila Island; Maderas; Azul, Volcán; Orosí	San Quintín Volcanic Field; Sangangüey; Mascota Volcanic Field; Atlixcos, Los; Tigre, Isla el; Zacate Grande, Isla; Zapatera; Ciguatepe, Cerro el; Lajas, Las; Tenorio; Valle, El	Prieto, Cerro; Iztaccíhuatl; Humeros, Los; Moyuta; Tahual; Suchitán; Ipala; Quezaltepeque; Cinotepeque, Cerro; Taburete; Conchagua; **Rota**; **Mombacho**; **Platanar**	Papayo; Serdán-Oriental; Gloria, La; Tajumulco; Tolimán; Agua; Cuilapa-Barbarena; Jumaytepeque; Flores; Santiago, Cerro; Ixtepeque; Chiquimula Volcanic Field; San Diego; Singüil, Cerro; **Apaneca Range**; Guazapa; San Vicente; **Tecapa**; Usulután; Tigre, El; Chinameca; Aramuaca, Laguna; Yojoa, Lake; Granada; Estelí	Durango Volcanic Field; Chingo; Coatepeque Caldera; Apastepeque Field
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 247: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed “classified” (top). Those without sufficient data are “Unclassified” (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
11	7
35	6
30	5
23	4
6	3
9	2
4	1

Table 248: The number of volcanoes in Mexico and Central America classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
11	III
10	II
2	I
95	Unclassified

Table 249: The number of volcanoes in the Mexico and Central America region classified at each Risk Level.

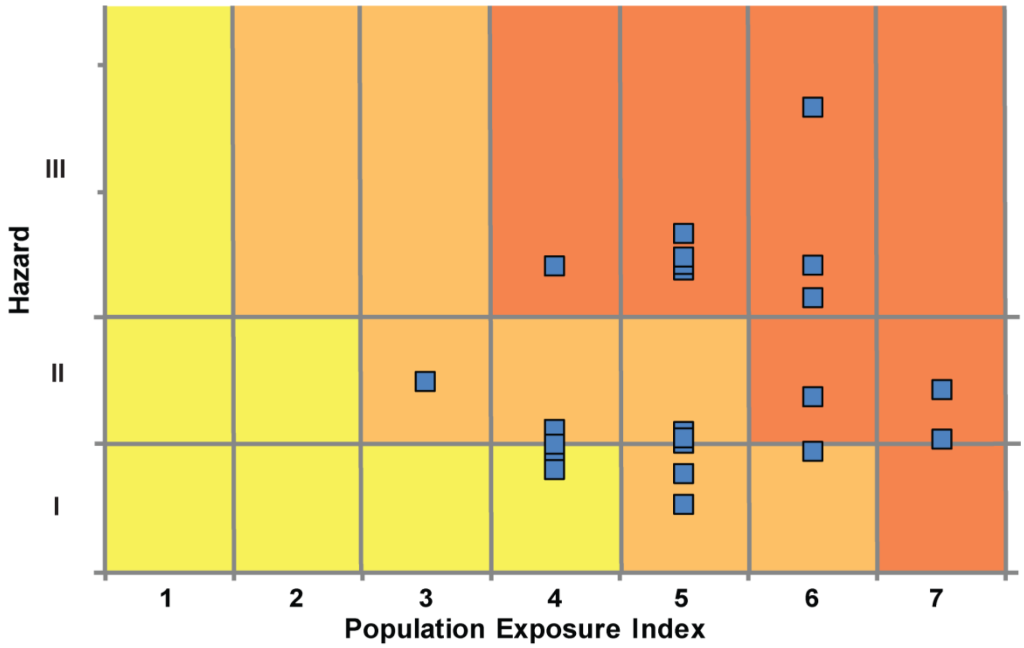


Figure 259: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

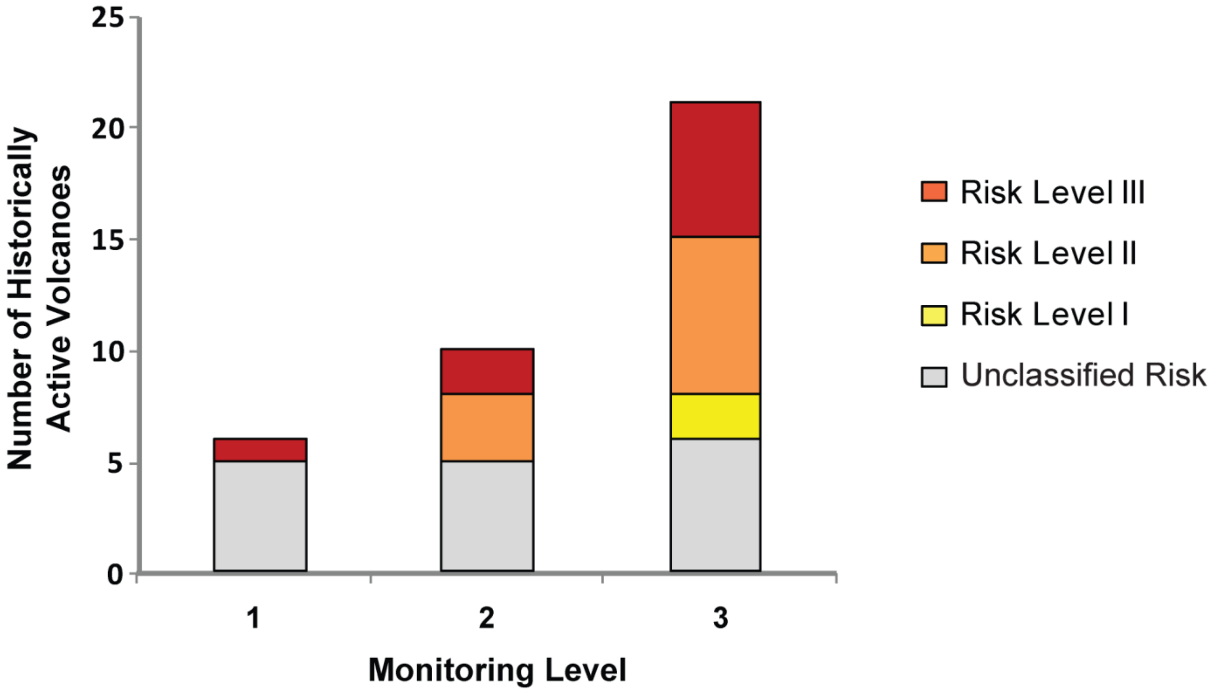


Figure 260: The monitoring and risk levels of the historically active volcanoes in Mexico and Central America. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Costa Rica

Description

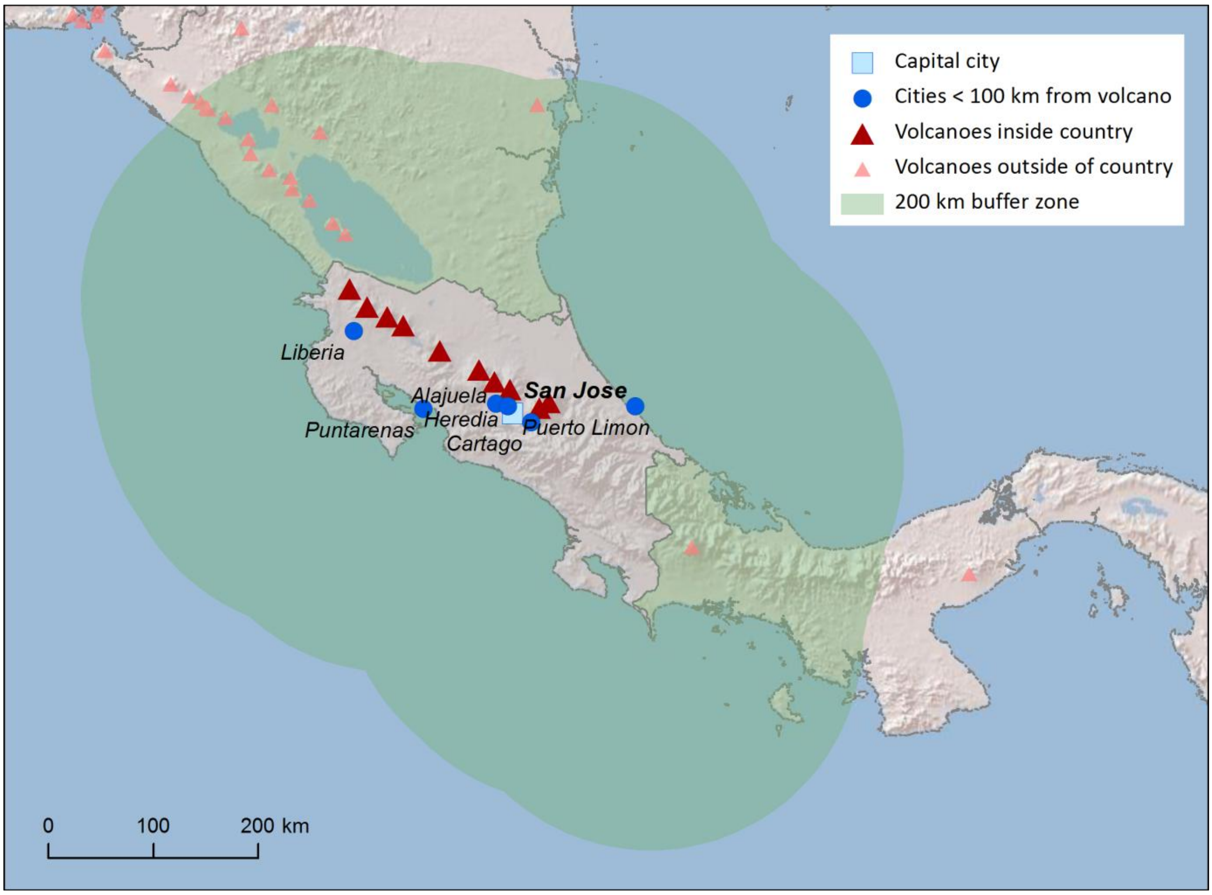


Figure 261: Location of Costa Rica's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Costa Rica.

Ten Holocene volcanoes are located in northern Costa Rica. Volcanism here is the result of the subduction of the Cocos Plate beneath the Caribbean Plate, forming a chain of andesitic stratovolcanoes and complex volcanoes about 60 km inland stretching from central Costa Rica to the border with Nicaragua.

151 confirmed eruptions are recorded in the Holocene from eight volcanoes. The remaining two volcanoes have suspected activity of Holocene age. Of these, most were recorded historically, with 103 recorded since 1500 AD from seven volcanoes. These eruptions are listed at VEI 0 to 3, indicating moderate explosive activity. VEI 4 eruptions have been recorded in the Holocene, and larger events exist in the Pleistocene record. Despite the moderate size of the eruptions, pyroclastic flows and lahars are recorded in 10 and 12 historical eruptions respectively. Lahars are a frequent feature in volcanism in the tropics due to rainfall, and secondary lahars can continue for years after the eruption.

The distribution of volcanoes throughout Costa Rica and neighbouring Panama and Nicaragua means that almost the entirety of the country and population lie within 100 km of one or more Holocene volcanoes.

The assessment of Hazard at the Holocene volcanoes of Costa Rica is associated with large uncertainties. However, almost all of the historically active volcanoes here are more fully understood and so have better constrained, and high, hazard levels. With moderate to large proximal populations at Costa Rican volcanoes the volcanic risk must be considered.

Irazú is one of Costa Rica's most active volcanoes, with frequent explosive eruptions documented since 1723. An eruption in 1963 – 1965, one of Irazú's largest at VEI 3, caused ash fall that led to significant disruption of San José and surrounding areas. Five major explosive eruptions have occurred at Turrialba during the past 3,500 years, with a series of pyroclastic flow-generating events in the 19th century.

In terms of fatalities, the most destructive eruption in Costa Rica's history is that of Arenal in August 1968. Situated towards the middle of Costa Rica's southeast to northwest trending line of volcanoes and roughly 70 km from the border with Nicaragua, Arenal is one of Costa Rica's most active volcanoes. The 1968 eruption initiated persistent activity which still continues; 78 people were killed in the first three days, mostly by pyroclastic flows but also by ballistic bombs (Alvarado et al. 2006). The village of Tabacon, 3.5 km northwest of the volcano, was almost totally obliterated. Other destructive eruptions include the 1963 – 1965 eruption of Irazú, which led to approximately fifty fatalities.

The Observatorio Sismológico y Vulcanológico Arenal-Miravalled (OSIVAM), part of the Costa Rican Institute of Electricity (ICE), is responsible for the monitoring of Costa Rica's volcanoes. They maintain networks of seismometers at all historically active volcanoes, and have additional dedicated ground-based monitoring at three of the volcanoes.

OSIVAM, the Universidad de Costa Rica, and Centro de Investigaciones en Ciencias Geologicas have a Volcano Alert Level system, comprising seven levels over three colour-codes. Green, phases 1 to 3, are used for dormant volcanoes and those with active fumaroles and seismicity to minor eruptive activity limited to the vicinity of the crater. Yellow, phases 1 to 2 are used for increases in the volcanic activity, where seismic data exceeds baseline activity and magmatic movements are suspected, with phreatic eruptions and indications that a magmatic eruption will occur within a week. Red, phases 1 to 2, indicate magmatic eruptions, with chance of increased hazard affecting the local region and beyond. OSIVAM release bulletins describing activity, and all are available to the public.

The research and monitoring OSIVAM conduct help to understand activity in Costa Rica, to generate hazard maps and to present information for decision making purposes to the National Emergency Commission.

See also:

Observatorio Sismologico y Vulcanologico Arenal-Miravalles (OSIVAM) website:
http://www.rsn.ucr.ac.cr/index.php/es/vulcanologia/informacion-general

Alvarado-Induni, G.E. and Chavarria-Aguilar, O.L. (2005) Costa Rica: Land of Volcanoes. EUNED, Costa Rica, pp.306.

Alvarado, G.E., Soto, G.J., Schmincke, H-U., Bolge, L.L. and Sumita, M. (2006) The 1968 andesitic lateral blast eruption at Arenal volcano, Costa Rica. Journal of Volcanology and Geothermal Research, 157, 9-33.

Volcano Facts

Number of Holocene volcanoes	10*
Number of Pleistocene volcanoes with M≥4 eruptions	4
Number of volcanoes generating pyroclastic flows	6
Number of volcanoes generating lahars	4+
Number of volcanoes generating lava flows	3
Number of fatalities caused by volcanic eruptions	>100
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M7.7 eruption of the Miembro Flujos La Ese from Miravalles in 580 ka.
Largest recorded Holocene eruption	19 eruptions of Arenal are recorded of VEI 4 during the Holocene.
Number of Holocene eruptions	151 confirmed eruptions. 18 uncertain and 8 discredited eruptions.
Recorded Holocene VEI range	0 – 4 and Unknown.
Number of historically active volcanoes	6-
Number of historic eruptions	102

*Further volcanoes may have had Holocene age activity as suggested by a young appearance of their morphology, however detailed dating has not yet been undertaken. In some cases, what are considered sub-features of volcanoes in VOTW4.0 can be described as separate volcanoes. For example Chato is considered in VOTW4.0 as a stratovolcano of Arenal.

+Further volcanoes have had lahars in the Holocene, which are not specifically recorded in VOTW.4.22.

-In VOTW4.22 Irazu, Poas, Arenal, Rincon de la Vieja, Turrialba and Miravalles have records of confirmed historical eruptions. However, the 1946 eruption of Miravalles is described as a non-volcanic hydrothermal explosion by Alvardo-Induni (2005).

Number of volcanoes	Primary volcano type	Dominant rock type
10	Large cone(s)	Andesitic (10)

Table 250: The number of volcanoes in Costa Rica, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	4,811,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	10,732
Gross National Income (GNI) per capita (2005 PPP $)	10,863
Human Development Index (HDI) (2012)	0.773 (High)

Population Exposure

Capital city	San José
Distance from capital city to nearest Holocene volcano	22.9 km
Total population (2011)	4,576,562
Number (percentage) of people living within 10 km of a Holocene volcano	144,235 (3.2%)
Number (percentage) of people living within 30 km of a Holocene volcano	3,424,754 (74.8%)
Number (percentage) of people living within 100 km of a Holocene volcano	4,707,288 (>100%)

Ten largest cities, as measured by population, and their populations (2011, data via data.un.org):

San Jose	284,054
Alajuela	254,886
Desamparados	208,411
San Carlos	163,745
Cartago	147,898
Perez Zeledon	134,534
Pococi	125,962
Heredia	123,616
Goicoechea	115,084
Puntarenas	115,019

Infrastructure Exposure

Number of airports within 100 km of a volcano	3
Number of ports within 100 km of a volcano	5
Total length of roads within 100 km of a volcano (km)	3,031
Total length of railroads within 100 km of a volcano (km)	0

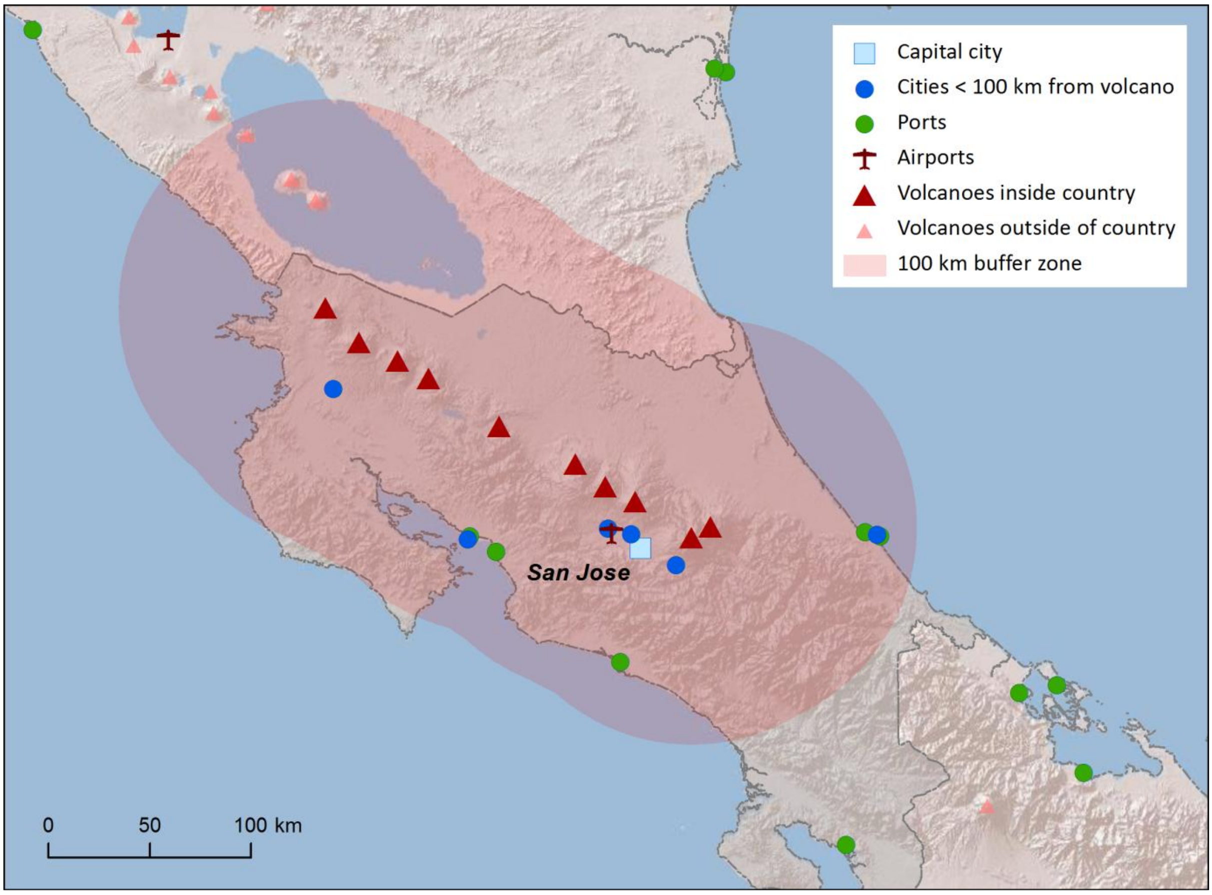


Figure 262: The location of Costa Rica's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The Holocene volcanoes in Costa Rica form a chain through the centre to the north-west of the country. Being a relatively narrow country, the 100 km radii of these volcanoes forms a continuous band of exposure throughout much of the country, with only the southernmost region bordering Panama lying outside of this zone. The 100 km radii also extend beyond Costa Rica's borders and into Nicaragua, exposing a significant area here. Whilst the area around the Panama border lies outside of the radii of the Costa Rican volcanoes, it falls within the 100 km radius of Barú in Panama. Six of the largest cities in Costa Rica lie within 100 km of the country's Holocene volcanoes, including the capital, San José. San José lies within 100 km of five historically active volcanoes. Much of the critical infrastructure in the country is exposed to the volcanic hazard, including ports, airports and an extensive road network.

Hazard, Uncertainty and Exposure Assessments

The data availability in the eruption records of Costa Rica's volcanoes is varied. Half of the volcanoes here have adequate data to allow the calculation of the VHI and the determination of a hazard level. These classified volcanoes are classed at Hazard Levels I, II and III. Irazú and Turrialba both have records of VEI 3 and 4 Holocene eruptions and explosive eruptions producing pyroclastic flows, and these are therefore scored most highly at Hazard Level III.

Five volcanoes here are unclassified as calculation of the VHI would be associated with large uncertainties due to the absence of sufficient information in the record. Indeed, three volcanoes have no confirmed Holocene eruptions. Barva and Miravalles both have a Holocene record, including post-1900 AD eruptions at the latter.

The PEI in Costa Rica ranges from moderate to high at PEI 3 to 5. Coupled with the Hazard Levels, this categorises the volcanoes here at Risk Levels I to III. Irazú and Turialba are classed at Risk Level III, with over 3 million people living within 100 km and a hazard classification of Level III.

CLASSIFIED	**Hazard III**					Irazú; Turrialba		
	Hazard II			Rincón de la Vieja	Arenal			
	Hazard I					Poás		
UNCLASSIFIED	**U – HHR**				**Miravalles**			
	U- HR					Barva		
	U- NHHR			Orosí	Tenorio	**Platanar**		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 251: Identity of Costa Rica's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Irazú	5	III
Turrialba	5	III
Poás	5	II
Arenal	4	II
Rincón de la Vieja	3	II

Table 252: Classified volcanoes of Costa Rica ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 3 volcanoes; Risk Level III – 2 volcanoes.

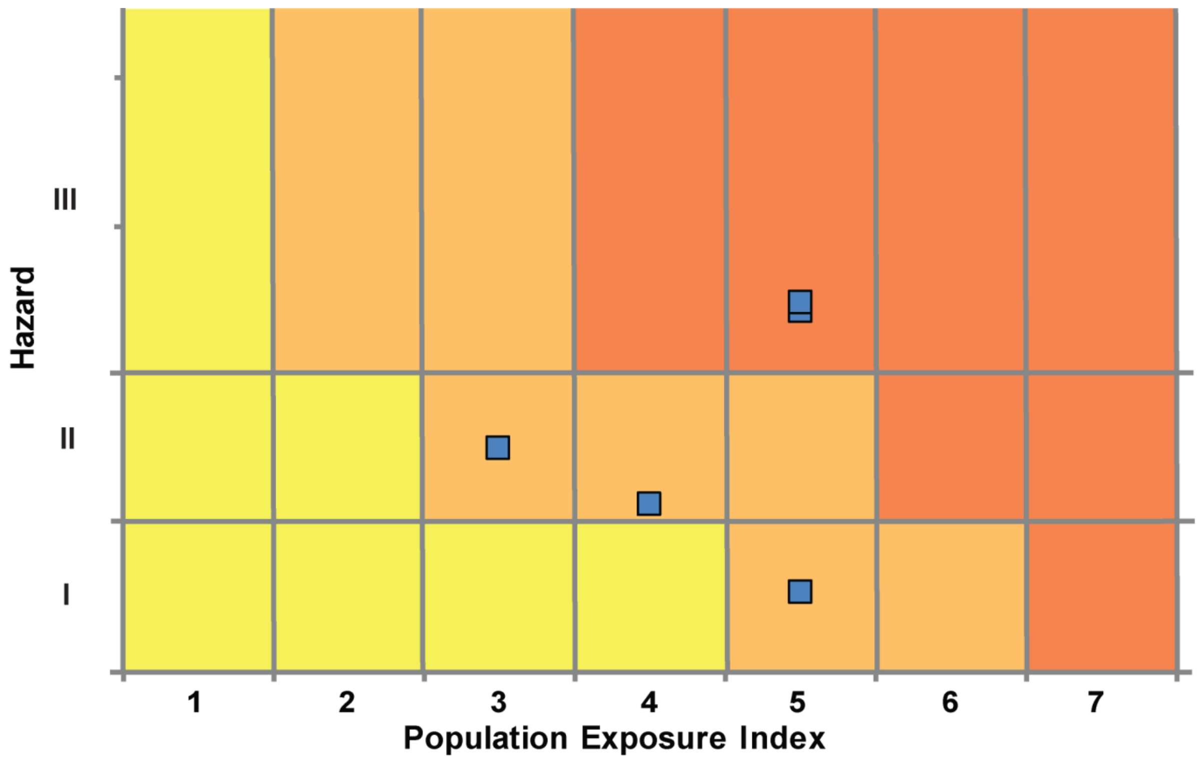


Figure 263: Distribution of Costa Rica's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Six volcanoes are recorded as having historical activity in Costa Rica. The Observatorio Sismológico y Vulcanológico Arenal-Miravalled (OSIVAM), part of the Costa Rican Institute of Electricity (ICE), is responsible for seismological and volcanological monitoring in northern Costa Rica. All historically active volcanoes have dedicated ground-based monitoring systems in place, all with seismic networks, and additional deformation and gas monitoring used at Arenal and Poás (Risk II) and Miravalles (Risk unclassified). The two Risk Level III volcanoes Irazú and Turrialba have regular visits by the observatory staff for further monitoring.

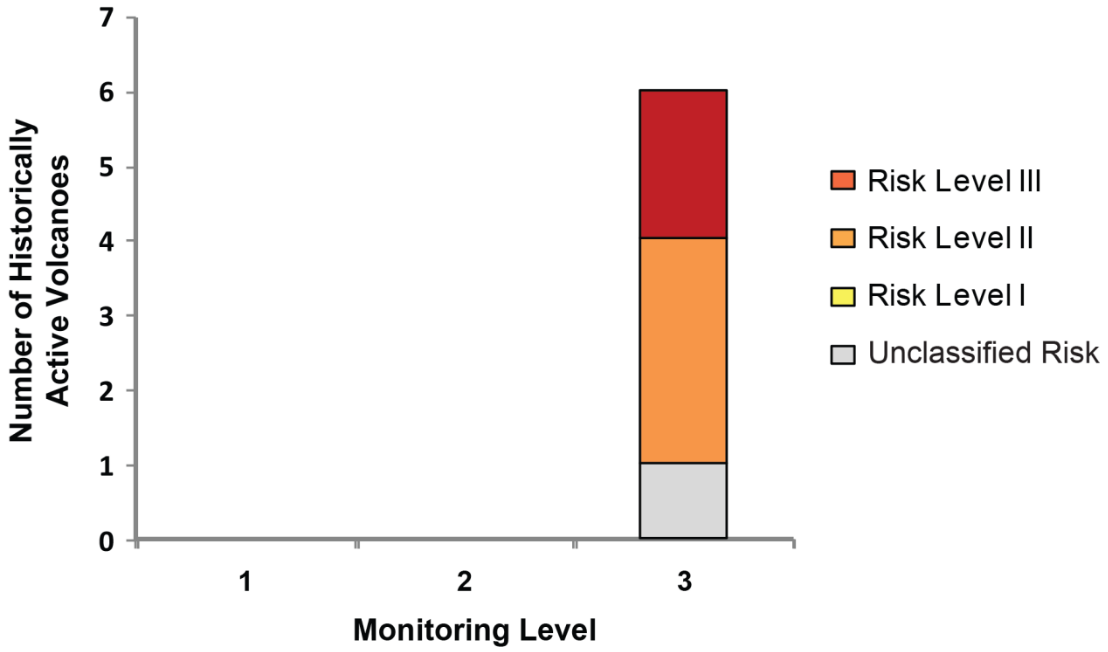


Figure 264: The monitoring and risk levels of the historically active volcanoes in Costa Rica. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

El Salvador

Description

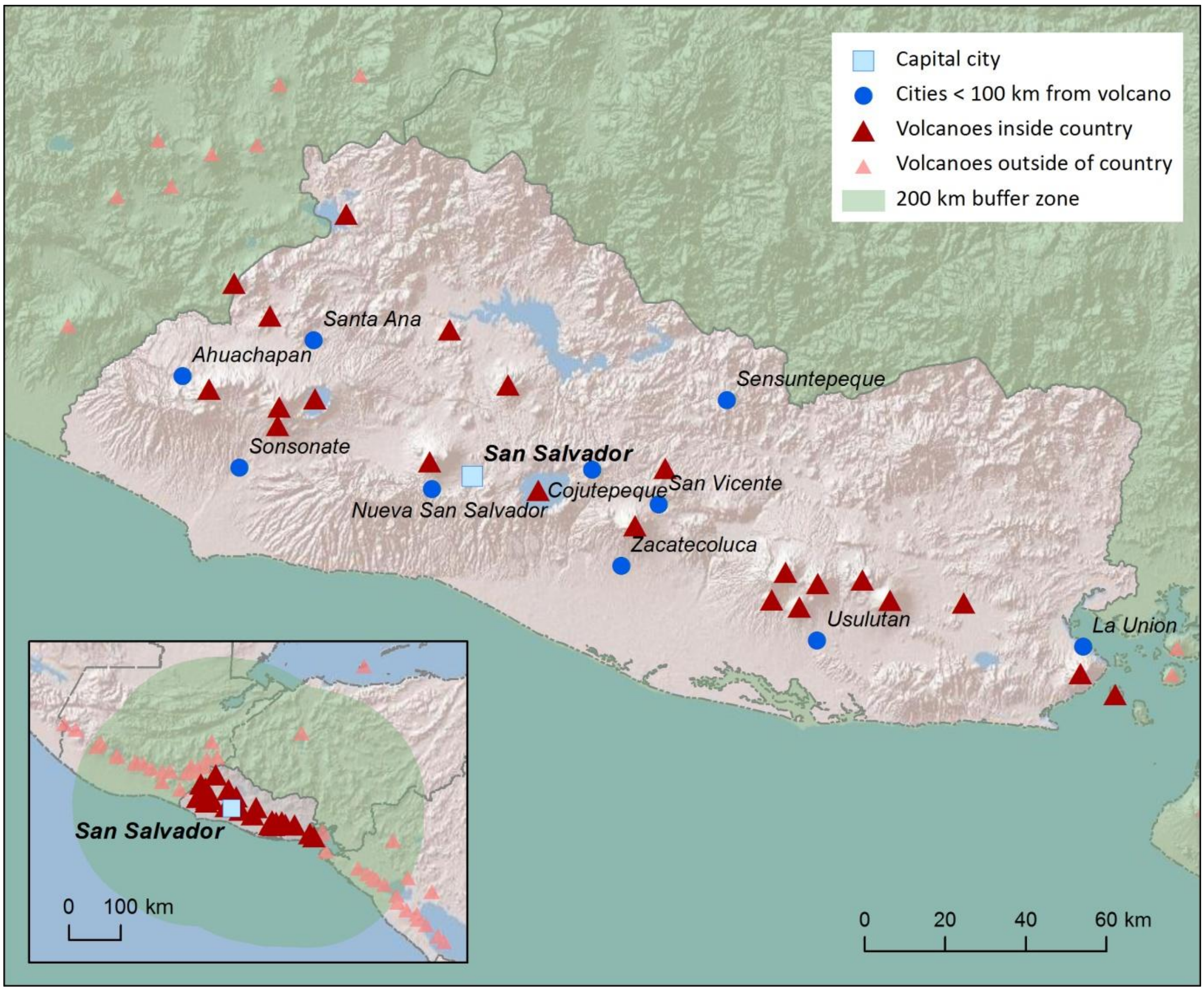


Figure 265: Location of El Salvador's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect El Salvador.

Twenty-two Holocene volcanoes are located throughout El Salvador, in a chain parallel to the coastline stretching from Guatemala in the north to the Gulf of Fonseca between El Salvador, Honduras and Nicaragua. Volcanism here is related to the subduction of the Cocos Plate beneath the Caribbean Plate.

The volcanoes of El Salvador are dominantly basaltic and andesitic stratovolcanoes, but there are also volcanic fields and more felsic calderas.

Six volcanoes have produced 102 eruptions during the Holocene, with the remaining volcanoes suspected of having activity of Holocene age. Eruptions have ranged in size from small VEI 0 events to large explosive VEI 6 events. Of these 102 eruptions, only three are recorded before 1500 AD, indicating that the eruption record is poorly known before historical times. All historical eruptions were small to moderate at VEI 0 – 3.

The assessment of hazard at most of the volcanoes of El Salvador is complicated by poorly constrained eruptive histories, with hazard scores assigned here with large associated uncertainties. Further work is required to more fully understand the age and size of El Salvador's eruptions.

The distribution of the volcanoes through El Salvador means that the entirety of the country falls within 100 km of one or more Holocene volcano, thus all infrastructure and the total population fall in this zone. The capital, San Salvador, lies within 20 km of two historically active volcanoes – Ilopango and San Salvador, both of which have produced VEI 3 eruptions during historic times and VEI 4-6 eruptions pre-1500 AD. The most frequently active volcano in El Salvador, Izalco, lies within 50 km of the capital. Major et al. (2004) suggest that even short (>4 km) debris flows or lahars at San Salvador, San Vicente and San Miguel volcanoes could "put hundreds to thousands of lives, property and infrastructure at risk" with areas within 10 km of volcanoes being inundated within minutes to tens of minutes.

Over twenty eruptions have resulted in property damage in El Salvador and six eruptions of Santa Ana, Izalco, San Salvador, Ilopango and Apaneca Range have resulted in the loss of about 30,000 lives. The largest loss of life resulted from the 450 AD eruption of Ilopango, which produced widespread pyroclastic flows.

The Servicio Geologico Nacional, part of the Ministerio de Medio Ambiente y Recursos Naturales, DGOA-MARN is responsible for monitoring the volcanoes of El Salvador. DGOA-MARN monitor historically active volcanoes with dedicated instrumentation networks. Continuous monitoring is undertaken to establish baseline data, which allows for anomalous behaviour to be identified. Various techniques are used, with a network of telemetered seismic stations being the principal technique. Additional geochemical, gas and hydrogeochemical, deformation and visual monitoring is also undertaken. DGOA-MARN collaborate with the Volcanological Research Group at the National University of El Salvador in geochemical monitoring of gases.

About 10% of personnel at DGOA-MARN have experience of responding to an eruption, which can be expected to be beneficial in future responses to eruptions. Set procedures have been developed which will be followed in the event of unrest or eruption, with an activity ladder of forewarning – warning – alert – emergency. DGOA-MARN would inform civil defence as unrest and eruption occurs. Resources are currently not available to respond to and extend monitoring to developing situations at currently unmonitored or unrecognised volcanoes. Volcanic risk could be reduced through additional resources and increase in monitoring capacity.

See also:

DGOA-MARN website: http://www.snet.gob.sv/ver/vulcanologia

Major, J.J., Schiling, S.P., Pullinger, C.R., and Demetrio Escobar, C. (2004) Debris-flow hazards at San Salvador, San Vicente, and San Miguel volcanoes, El Salvador. GSA Special Papers, v.375, 89-108.

Volcano Facts

Number of Holocene volcanoes	22, inclusive of one on the border with Guatemala
Number of Pleistocene volcanoes with M≥4 eruptions	5
Number of volcanoes generating pyroclastic flows	4
Number of volcanoes generating lahars	1 eruption of Santa Ana in 2005 resulted in lahars according to VOTW4.22. However, lahars and secondary have also occurred at San Miguel, San Salvador and San Vicente.
Number of volcanoes generating lava flows	4 - 5
Number of fatalities caused by volcanic eruptions	?30,383
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M7.1 Conacaste (CCT) eruption of Coatepeque Caldera at 51 ka.
Largest recorded Holocene eruption	The M6.7 TBJ eruption of Ilopango at 1.5 ka.
Number of Holocene eruptions	102 confirmed eruptions. 13 uncertain and 4 discredited eruptions.
Recorded Holocene VEI range	0 – 6 and unknown.
Number of historically active volcanoes	6
Number of historic eruptions	99

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
2	Caldera(s)	Dacitic (1), Rhyolitic (1)
14	Large cone(s)	Andesitic (7), Basaltic (7)
5	Small cone(s)	Basaltic (2), Dacitic (1), Unknown (2)

Table 253: The number of volcanoes in El Salvador, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	6,309,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	6,032
Gross National Income (GNI) per capita (2005 PPP $)	5,915
Human Development Index (HDI) (2012)	0.680 (Medium)

Population Exposure

Capital city	San Salvador
Distance from capital city to nearest Holocene volcano	12.3 km
Number (percentage) of people living within 10 km of a Holocene volcano	2,104,232 (34.7%)
Number (percentage) of people living within 30 km of a Holocene volcano	5,810,384 (95.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	6,309,000 (100%)

Ten largest cities, as measured by population, and populations:

San Salvador	525,990
San Miguel	247,119
Santa Ana	176,661
Santa Tecla	124,694
Sonsonate	59,468
Usulutan	51,910
Cojutepeque	48,411
Zacatecoluca	39,613
San Vicente	37,326
Ahuachapan	34,102
La Union	26,807

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	2,019
Total length of railroads within 100 km of a volcano (km)	0

The numerous Holocene volcanoes in El Salvador are distributed throughout the country. Being a relatively small country, measuring no more than about 250 km across, the country in its entirety lies within the 100 km radii of the Holocene volcanoes. All infrastructure in the country is therefore exposed to the volcanic hazard. The capital, San Salvador, lies within 100 km of 15 Holocene volcanoes in El Salvador, including two historically active volcanoes within 20 km. The radii also extend beyond the country's border into Guatemala, Honduras and Nicaragua, and indeed volcanoes in these neighbouring countries have 100 km radii which extend into El Salvador, including Cosiguina in Nicaragua and eleven volcanoes in Guatemala.

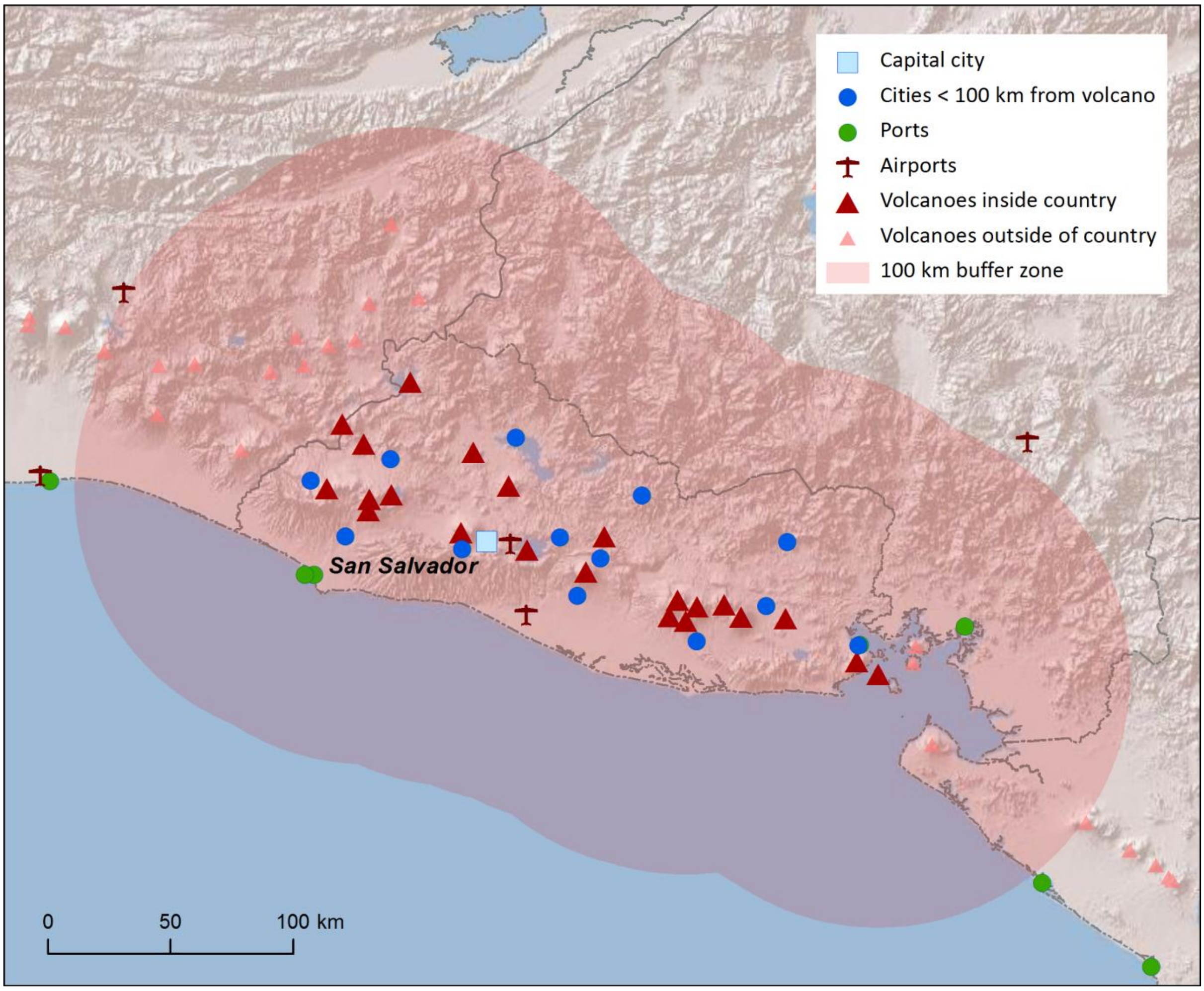


Figure 266: The location of El Salvador's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying amounts of information available in the eruption records of El Salvador's volcanoes. Just three volcanoes out of 22 have a detailed enough record to define hazard through the calculation of VHI, without large associated uncertainties. These three classified volcanoes are classed as Hazard Level I and II.

Of the unclassified volcanoes, 16 have no recorded confirmed Holocene eruptions. Three have historical records (post-1500 AD), including San Salvador and Ilopango which both have Holocene records of large VEI ≥4 eruptions.

The PEI ranges from moderate to very high in El Salvador with large proximal populations. The classified volcanoes Izalco, Santa Ana and San Miguel are all classed at Risk Level II, with high local populations. Although unclassified for hazard, five volcanoes (San Salvador, Ilopango, Chingo, Coatepeque Caldera and Apastepeque Field) would be classed at Risk Level III given their PEI of 7.

CLASSIFIED	**Hazard III**							
	Hazard II					Santa Ana		
	Hazard I					San Miguel	Izalco	
UNCLASSIFIED	**U – HHR**				Conchagüita			**San Salvador;** Ilopango
	U- HR							
	U- NHHR					Cinotepeque, Cerro; Taburete; Conchagua	San Diego; Singüil, Cerro; **Apaneca Range;** Guazapa; San Vicente; **Tecapa**; Usulután; Tigre, El; Chinameca; Aramuaca, Laguna	Chingo; Coatepeque Caldera; Apastepeque Field
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 254: Identity of El Salvador's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Izalco	6	II
Santa Ana	5	II
San Miguel	5	II

Table 255: Classified volcanoes of El Salvador ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 3 volcanoes; Risk Level III – 0 volcanoes.

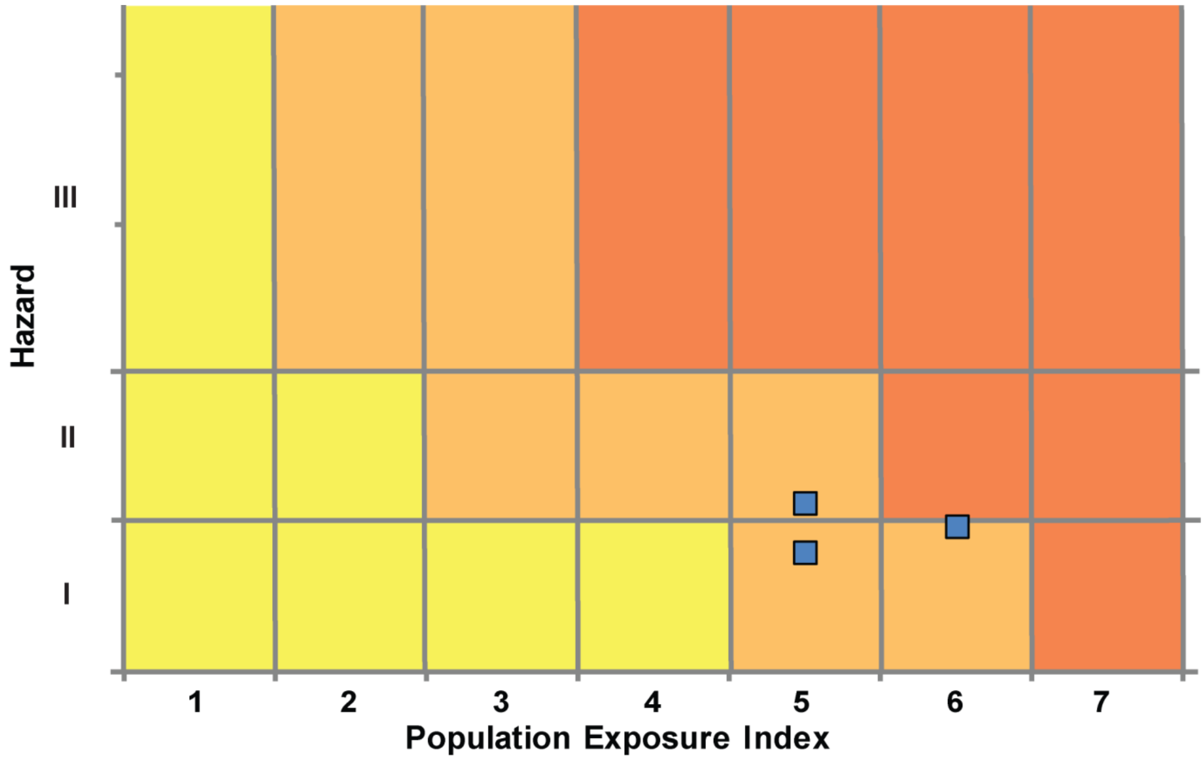


Figure 267: Distribution of El Salvador's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Six volcanoes have records of historical activity in El Salvador. The institution responsible for the monitoring of these volcanoes in DGOA-MARN the Servicio Geologico Nacional, part of the Ministerio de Medio Ambiente y Recursos Naturales. Seismic monitoring is undertaken at all volcanoes, with additional gas monitoring at San Miguel and San Salvador. Additional gas and deformation monitoring is undertaken at Santa Ana.

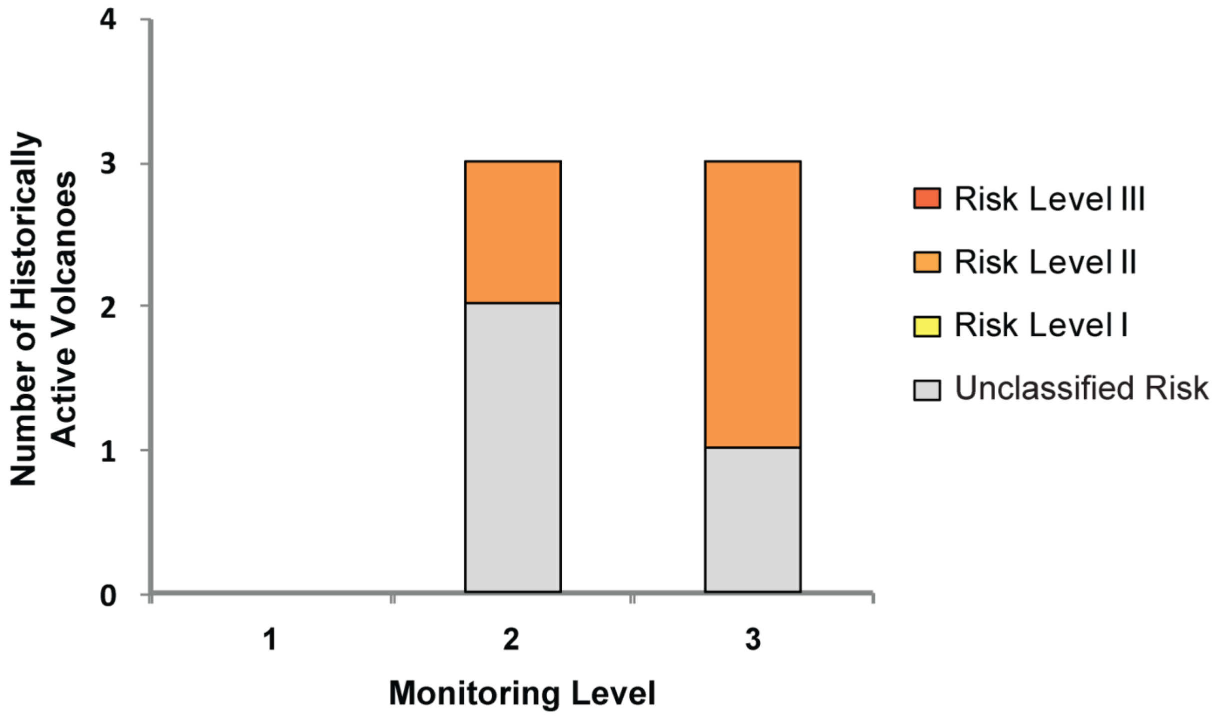


Figure 268: The monitoring and risk levels of the historically active volcanoes in El Salvador. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Guatemala

Description

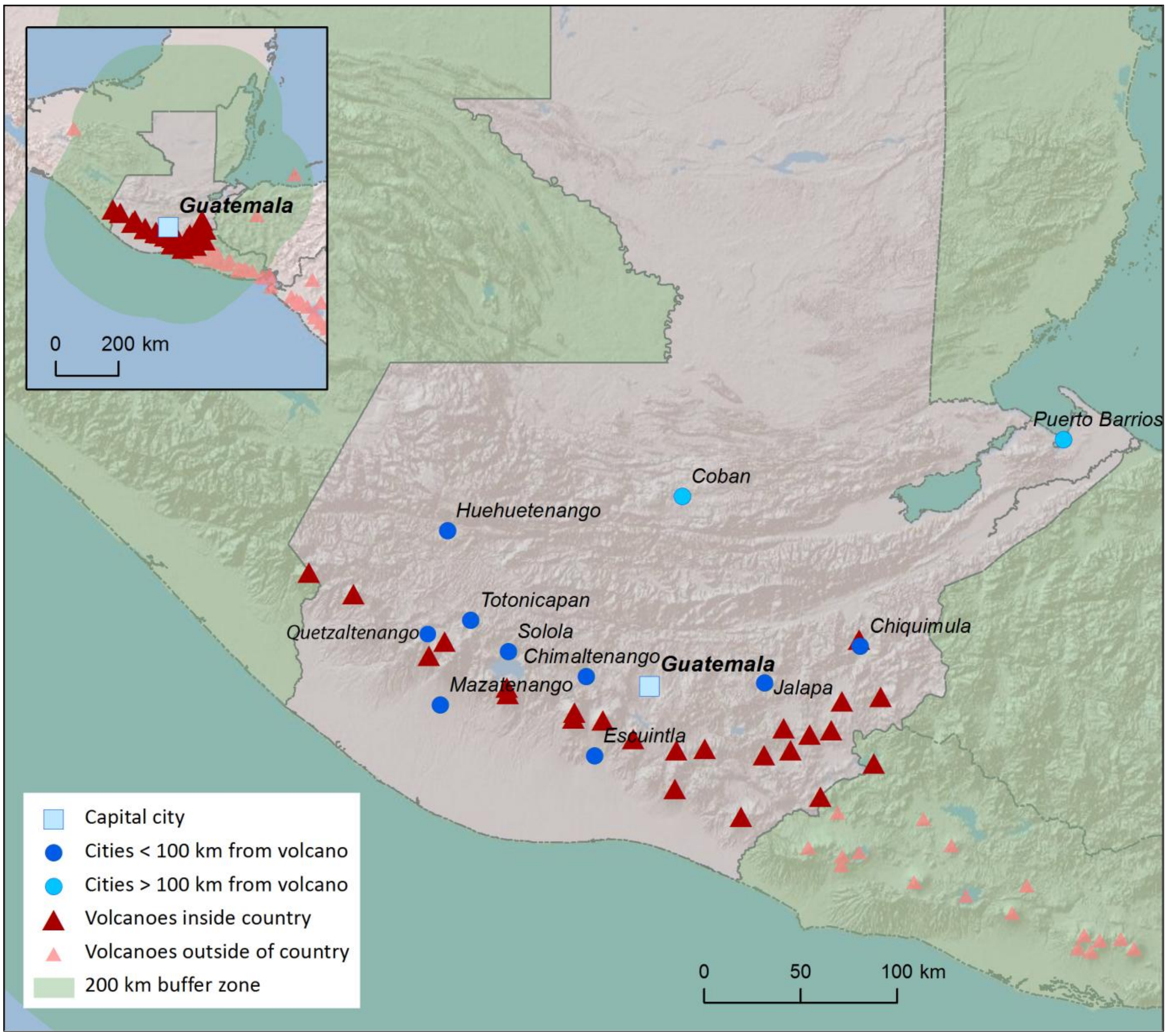


Figure 269: Location of Guatemala's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Guatemala.

Twenty-four Holocene volcanoes are located in Guatemala, dominantly in a chain parallel to the country's Pacific coastline stretching from El Salvador in the south to Mexico in the north. Volcanism here is due to the subduction of the Cocos Plate beneath the Caribbean Plate.

Most of the volcanoes in Guatemala (17) are stratovolcanoes most frequently of basaltic to andesitic composition. A number of volcanic fields and cinder cones are present here, dominantly situated in the south-east towards the border with El Salvador. Counting individual cones and vents, INSIVUMEH, the Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología states that 324 Quaternary volcanic vents are present throughout Guatemala from Bohnenberger (1969).

During the Holocene, 128 eruptions of VEI 1 – 6 are recorded at seven of Guatemala's volcanoes. The remaining volcanoes have suspected though unconfirmed eruptions. The Holocene VEI record indicates a range of eruption styles and sizes, from mild eruptions to large explosive events. 104 of these eruptions are historical, being recorded since 1500 AD suggesting the record is poorly known before historic times. Of the seven active volcanoes, all but Tecuamburro have records of producing pyroclastic flows, but only Santa Maria, Fuego and Tacana have a Holocene record of VEI≥4 eruptions. An eruption of Cerro Quemada at Almolonga in 1150 BP is classed at VEI 3 in VOTW4.22, but has a volume which might indicate VEI4 (caldera volume of 0.1km^3, Conway et al. 1992) and numerous VEI 3 eruptions are recorded at Pacaya. The largest Holocene eruption occurred at Santa Maria in 1902, with a VEI 6 eruption which devastated much of south-west Guatemala and resulted in about 10,000 fatalities through ash fall and secondary disease.

Eight eruptions at Santa Maria, Fuego and Pacaya have resulted in fatalities, and numerous evacuations have been ordered with a record of many eruptions resulting in property damage. Lahars in 1541 at Agua, during a non-eruptive phase, destroyed the then capital, Ciudad Vieja. The mobilisation of old tephra deposits during intense rainfall to form lahars can occur for years after eruptions, producing a long-term hazard.

A large population resides close to the volcanoes, with 95% of Guatemala's population living within 100 km of one or more Holocene volcanoes. Three large stratovolcanoes, Acatenango, Agua, and Fuego, overlook Guatemala's former capital, Antigua Guatemala, whilst much of the population of the present capital, Guatemala City, lives within 15 to 20 km of Pacaya. About 2 million live within the Pleistocene Amatitlan caldera, just north of Pacaya. The historically active Atitlán, Fuego and Acatenango are also located within about 70 km of the capital. Though with no recorded historical eruptions, but with a catastrophic historical lahar, Agua is also located within this distance. Further, Guatemala's second city and fourth largest population centre, Quetzaltenango, is situated approximately 10 km north-northeast of Santa María, and less than 5 km from the Cerro Quemado dome complex (part of the Almolonga caldera and volcanic field (Ewert and Harpel, 2004). Guatemala's volcanoes also threaten rural communities, as all have over 100,000 residents within 30 km of their summits.

INSIVUMEH, a government funded agency which is part of the Communications, Infrastructure and Housing Ministry, is responsible for monitoring of Guatemala's volcanoes and the provision of advice to the government regarding volcanic activity. INSIVUMEH run four Volcano Observatories: Santiaguito Observatory (OVSAN), Fuego Observatory (OVFUEGO I) in Panimache I and Sangre de Cristo (OVFUEGO II), and the Pacaya Observatory. Visual monitoring is undertaken and continuous seismic monitoring is in place with real-time telemetry of the data to the INSIVUMEH headquarters. The seismic equipment used to monitor volcanoes is part of the national seismic network. The resources are not available to respond to developing situations at previously unknown/inactive or un-monitored volcanoes.

A colour-coded alert scheme is used to communicate volcanic activity. INSIVUMEH communicate with the civil protection agency CONRED to recommend alert levels. These alert levels are communicated to the public via bulletins. If unrest increases at a volcano, INSIVUMEH communicate this to CONRED. Protocols are in place for increasing unrest and eruption, including the issuing of regular bulletins and communication with the Civil Aviation Authority and regional VAAC. INSIVUMEH are primarily responsible for the hazard evaluation, while CONRED and other civil authorities undertake risk assessments.

See also:

Bohnenberger, O.H. (1969) Los focus eruptivos Cuaternarios de Guatemala. Publicaciones Geologicas del ICAITI, 23-24.

Conway, F.M., Vallance, J.W., Rose, W.I., Johns, G.W. and Paniagua, S. (1992) Cerro Quemado, Guatemala: the volcanic history and hazards of an exogenous volcanic dome complex. Journal of Volcanology and Geothermal Research, 52:4, 303 – 308, 311-323.

Ewert, J.W. and Harpel, C.J. (2004) In Harm's Way: Population and Volcanic Risk. Geotimes, April 2004.

INSIVUMEH: http://www.insivumeh.gob.gt/

CONRED: http://www.conred.gob.gt/www/index.php

Volcano Facts

Number of Holocene volcanoes	24, inclusive of two on the border with El Salvador and one on the border with Mexico
Number of Pleistocene volcanoes with M≥4 eruptions	3 currently listed in LaMEVE: Fuego, Pacaya and Ayarza. There is also evidence of M≥4 eruptions at Tacaná, Santa Maria, Siete Orejas, Sabana Grande, Atitlan, Amatitlan and Tecuamburro.
Number of volcanoes generating pyroclastic flows	7
Number of volcanoes generating lahars	5*
Number of volcanoes generating lava flows	6*
Number of fatalities caused by volcanic eruptions	?>11,555
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M7.8 Los Chocoyos Ash (H) eruption of Atitlán at 84 ka.
Largest recorded Holocene eruption	The M6.3 eruption of Santa María in 1902 AD.
Number of Holocene eruptions	128 confirmed eruptions. 28 uncertain and 4 discredited eruptions.
Recorded Holocene VEI range	1 – 6 and unknown

Number of historically active volcanoes	7
Number of historic eruptions	104

*The number of volcanoes with Holocene age lahars and lava flows recorded in VOTW4.22 is thought to be an underestimate, with most Guatemala volcanoes suspected of producing lavas and lahars due to intense rainfall outside of eruptive activity.

Number of volcanoes	Primary volcano type	Dominant rock type
17	Large cone(s)	Andesitic (9), Basaltic (5), Dacitic (3)
1	Lava dome(s)	Rhyolitic (1)
6	Small cone(s)	Basaltic (6)

Table 256: The number of volcanoes in Guatemala, their volcano type classification and dominant rock type according to VOTW4.0.

The volcano types described here are the classifications in VOTW4.0. Lava domes are present at several volcanoes. For example Almolonga is listed as a stratovolcano, however much of the Holocene volcanism has been dominated by dome formation and destruction. The same applies to Santa Maria, which is listed as a stratovolcano, but has been dominated by dome forming activity for about a century and it is this lava dome activity which is the main cause of hazard.

Socio-Economic Facts

Total population (2012)	15,135,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,351
Gross National Income (GNI) per capita (2005 PPP $)	4,325
Human Development Index (HDI) (2012)	0.581 (Medium)

Population Exposure

Capital city	Guatemala City
Distance from capital city to nearest Holocene volcano	29.0 km*
Total population (2011)	13,824,463
Number (percentage) of people living within 10 km of a Holocene volcano	1,423,044 (10.3%)
Number (percentage) of people living within 30 km of a Holocene volcano	7,922,171 (57.3%)
Number (percentage) of people living within 100 km of a Holocene volcano	13,081,892 (94.6%)

*Villa Nueva and southern parts of Guatemala City lie within 15 to 20 km of the nearest volcano, Pacaya.

Ten largest cities, as measured by population, and populations:

Guatemala City	1,022,001 (UNDP data, 2001)
Mixco	452,134 (UNDP data, 2001)
Villa Nueva	390,329 (UNDP data, 2001)
Quetzaltenango	152,223 (UNDP data, 2001)
Escuintla	114,626 (UNDP data, 2001)
Chimaltenango	82,370
Huehuetenango	79,426
Totonicapan	69,734
Puerto Barrios	56,605
Coban	53,375

Infrastructure Exposure

Number of airports within 100 km of a volcano	4
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	2,921
Total length of railroads within 100 km of a volcano (km)	0

The numerous volcanoes in Guatemala are distributed through the south of the country, from the border with El Salvador to that with Mexico. With so many volcanoes in a relatively narrow stretch of land, the 100 km radii extends to encompass much of southern Guatemala, and also extend into El Salvador, Mexico and Honduras exposing infrastructure here. The 100 km radii of about 10 volcanoes in El Salvador also extend into Guatemala. Many of Guatemala's largest cities are located in the south of the country, and hence fall within 100 km of the Holocene volcanoes. Indeed eight of the most populous cities lie here in addition to the capital, Guatemala City. Much of the critical infrastructure in the country is therefore exposed to the volcanic hazard, including airports, ports and an extensive road network. Guatemala City lies within 70 km of several historically active volcanoes, including Atitlan, Acatenango, Fuego, Agua and Pacaya.

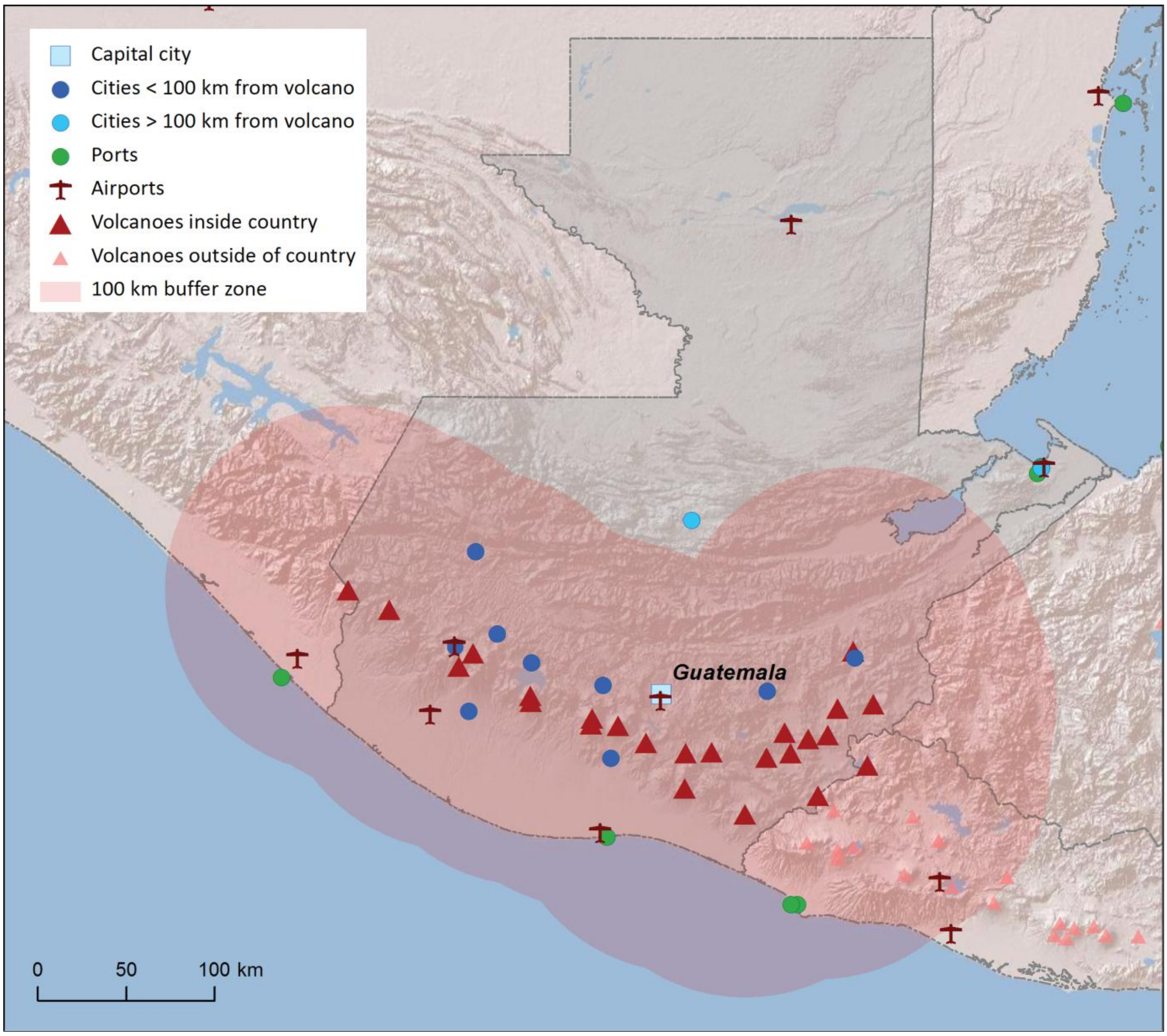


Figure 270: The location of Guatemala's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of Guatemala's volcanoes. Just four volcanoes out of 24 have sufficient detail to define the hazard through the calculation of the VHI. Three of these, Fuego, Santa Maria and Pacaya are classified at Hazard Level III, with records of explosive activity and pyroclastic flows and Holocene records of VEI ≥3 eruptions. Atitlan is classified as Hazard Level II, with a smaller percentage of eruptions with pyroclastic flows. All four of these volcanoes have high proximal populations, and PEIs of 5 and 6. These are therefore classified at Risk Level III.

Of the unclassified volcanoes, 16 have no recorded confirmed Holocene eruptions. Four have Holocene records, including historical events at Tacana, Almolonga and Acatenango. Eruptions since 1900 AD are recorded at the latter. With no classification of hazard, the risk levels cannot be determined, however these all have large local populations, with PEIs of 5 – 7, suggesting risk levels of II to III.

CLASSIFIED	**Hazard III**					Fuego	Santa María; Pacaya	
	Hazard II						Atitlán	
	Hazard I							
UNCLASSIFIED	**U – HHR**					Tacaná	**Acatenango**	Almolonga
	U- HR					Tecuamburro		
	U- NHHR					Moyuta; Tahual; Suchitán; Ipala; Quezaltepeque	Tajumulco; Tolimán; Agua; Cuilapa-Barbarena; Jumaytepeque; Flores; Santiago, Cerro; Ixtepeque; Chiquimula Volcanic Field; San Diego	Chingo
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 257: Identity of Guatemala's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	**Population Exposure Index**	**Risk Level**
Pacaya	6	III
Santa María	6	III
Atitlán	6	III
Fuego	5	III

Table 258: Classified volcanoes of Guatemala ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 4 volcanoes.

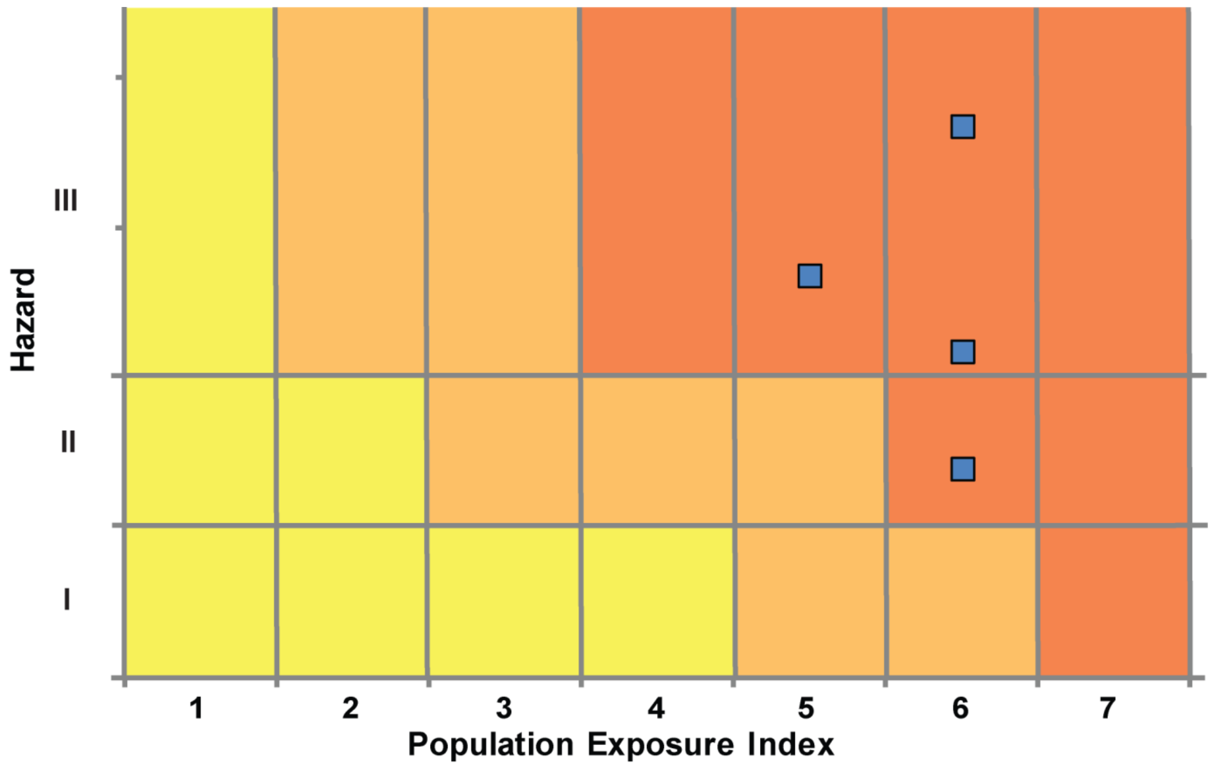


Figure 271: Distribution of Guatemala's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I – III.

National Capacity for Coping with Volcanic Risk

Seven volcanoes in Guatemala have recorded historical eruptions. These are classified as Risk Levels III (Atitlán, Fuego, Pacaya and Santa María) and Unclassified (Almolonga, Acatenango and Tacaná). The Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH) is responsible for monitoring these volcanoes. Monitoring is focussed on the Risk Level III volcano Santa Maria where seismic networks and geochemical monitoring is undertaken. Seismic monitoring is also undertaken at Fuego and Pacaya. A national seismic network is in place which may detect seismic activity at those volcanoes with no dedicated systems, if the seismic activity is very strong.

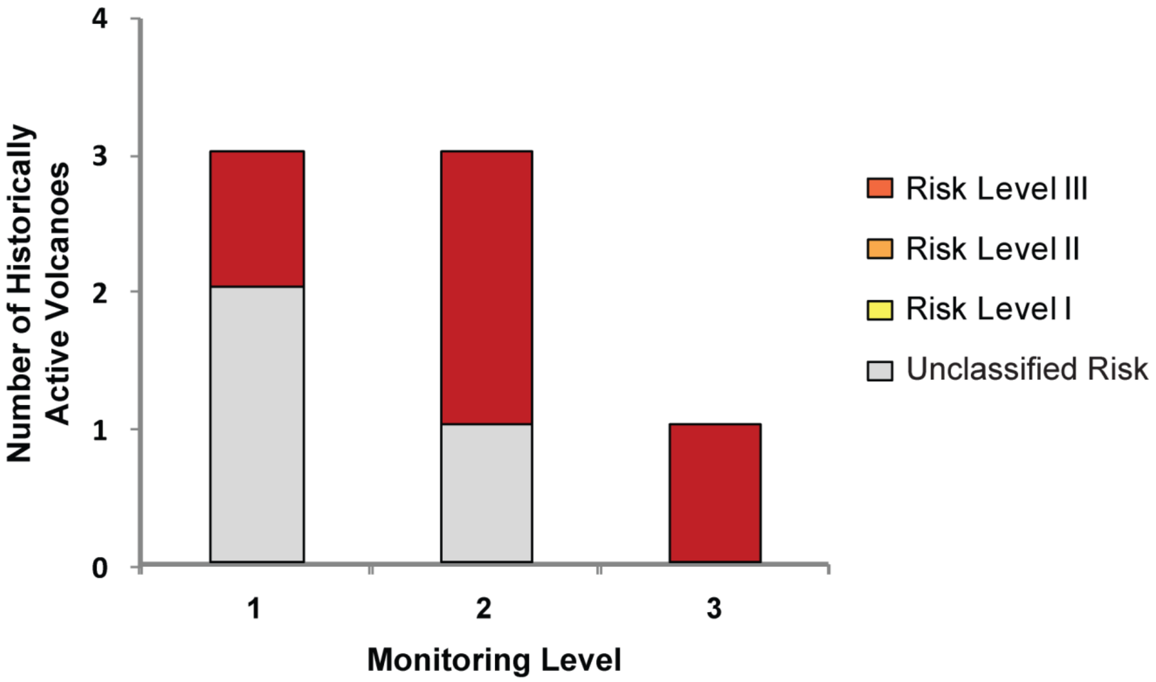


Figure 272: The monitoring and risk levels of the historically active volcanoes in Guatemala. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Honduras

Description

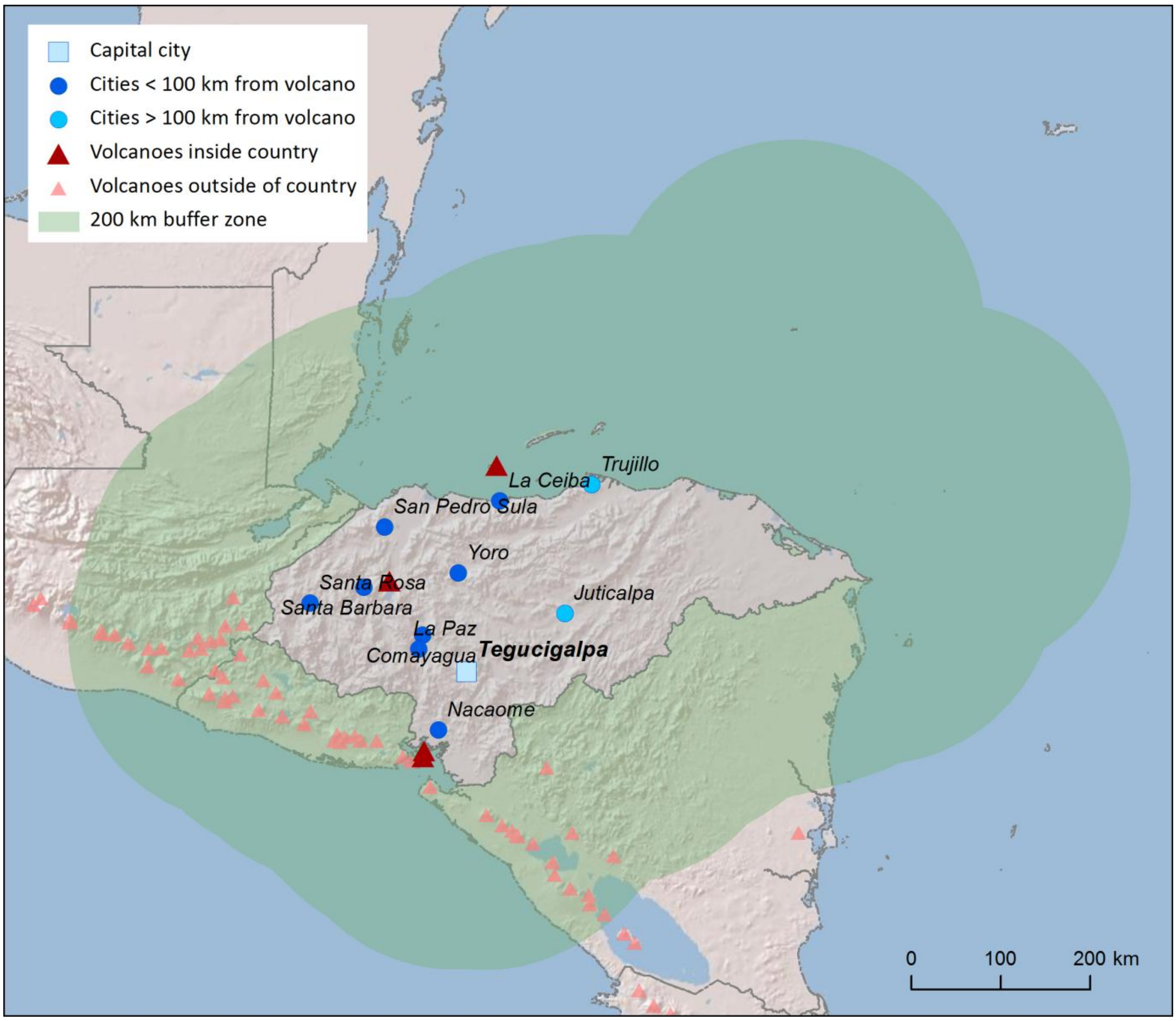


Figure 273: Location of Honduras' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Honduras.

Four Holocene volcanoes are located in Honduras, of these, only Lake Yojoa is situated on the mainland, in north-central Honduras. Utila Island volcano is situated in the Caribbean Sea of the northern coast of Honduras, whilst Isla el Tigre and Isla Zacate Grande lie off the southern coast in the Gulf of Fonseca. The country lies on the Caribbean plate, with the Cocos Plate subduction zone lying to the south.

No eruptions are recorded in the Holocene, however Holocene activity is suspected at Utila Island, Isla Zacate Grande and Isla el Tigre due to deposits of lavas and a satellite vent of this age. With deposits of suspected Holocene age, these volcanoes would benefit from further research to date the eruptions and develop an eruptive history. There is no Pleistocene record of large explosive eruptions or a historical record of unrest.

The volcanoes in Honduras are dominantly basaltic. Those in the Gulf of Fonseca are stratovolcanoes, whilst the more northerly volcanoes are small cones comprising a volcanic field and pyroclastic cones. Being basaltic centres, with suspected Holocene lavas effusive and localised moderately explosive activity may be characteristic here.

Despite the small number of the volcanoes, over 80% of the population in Honduras lives within 100 km of one or more Holocene volcanoes. This is due to the widespread distribution of the Honduran volcanoes and the proximity of volcanoes in neighbouring countries, with some southern Guatemalan and northern Nicaraguan volcanoes and many of the volcanoes in El Salvador having 100 km radii extending into Honduras. Similarly, the radii of the Honduran volcanoes extend into these countries. The extent of population exposure is also due to the location of many of the country's largest cities in these 100 km radii, including the capital, Tegucigalpa.

The Honduran volcanoes are unclassified in both hazard and risk due to the lack of a comprehensive eruptive history, meaning the understanding of the hazard at these volcanoes is limited and the Hazard Level assignment would be associated with considerable uncertainty.

At the time of the writing of this report there was no information available to suggest that ground-based monitoring is undertaken at the volcanoes in Honduras. With no historical activity or constrained Holocene activity, the hazard from neighbouring volcanoes may be greater than that within the borders of Honduras.

Volcano Facts

Number of Holocene volcanoes	4
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	-
Number of Holocene eruptions	0 confirmed. Suspected activity.
Recorded Holocene VEI range	-
Number of historically active volcanoes	-
Number of historic eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Basaltic (2)
2	Small cone(s)	Basaltic (2)

Table 259: The number of volcanoes in Honduras, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	7,960,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	3,566
Gross National Income (GNI) per capita (2005 PPP $)	3,426
Human Development Index (HDI) (2012)	0.632 (Medium)

Population Exposure

Capital city	Tegucigalpa
Distance from capital city to nearest Holocene volcano	96.4 km
Total population (2011)	8,143,564
Number (percentage) of people living within 10 km of a Holocene volcano	41,037 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	423,747 (5.2%)
Number (percentage) of people living within 100 km of a Holocene volcano	6,650,766 (81.7%)

Ten largest cities, as measured by population, and populations:

Tegucigalpa	850,848
San Pedro Sula	489,466
La Ceiba	130,218
Comayagua	58,784
Juticalpa	33,686
Santa Rosa	27,753
La Paz	17,555
Yoro	15,774
Santa Barbara	15,119
Nacaome	13,929

Infrastructure Exposure

Number of airports within 100 km of a volcano	5
Number of ports within 100 km of a volcano	7
Total length of roads within 100 km of a volcano (km)	3,924
Total length of railroads within 100 km of a volcano (km)	0

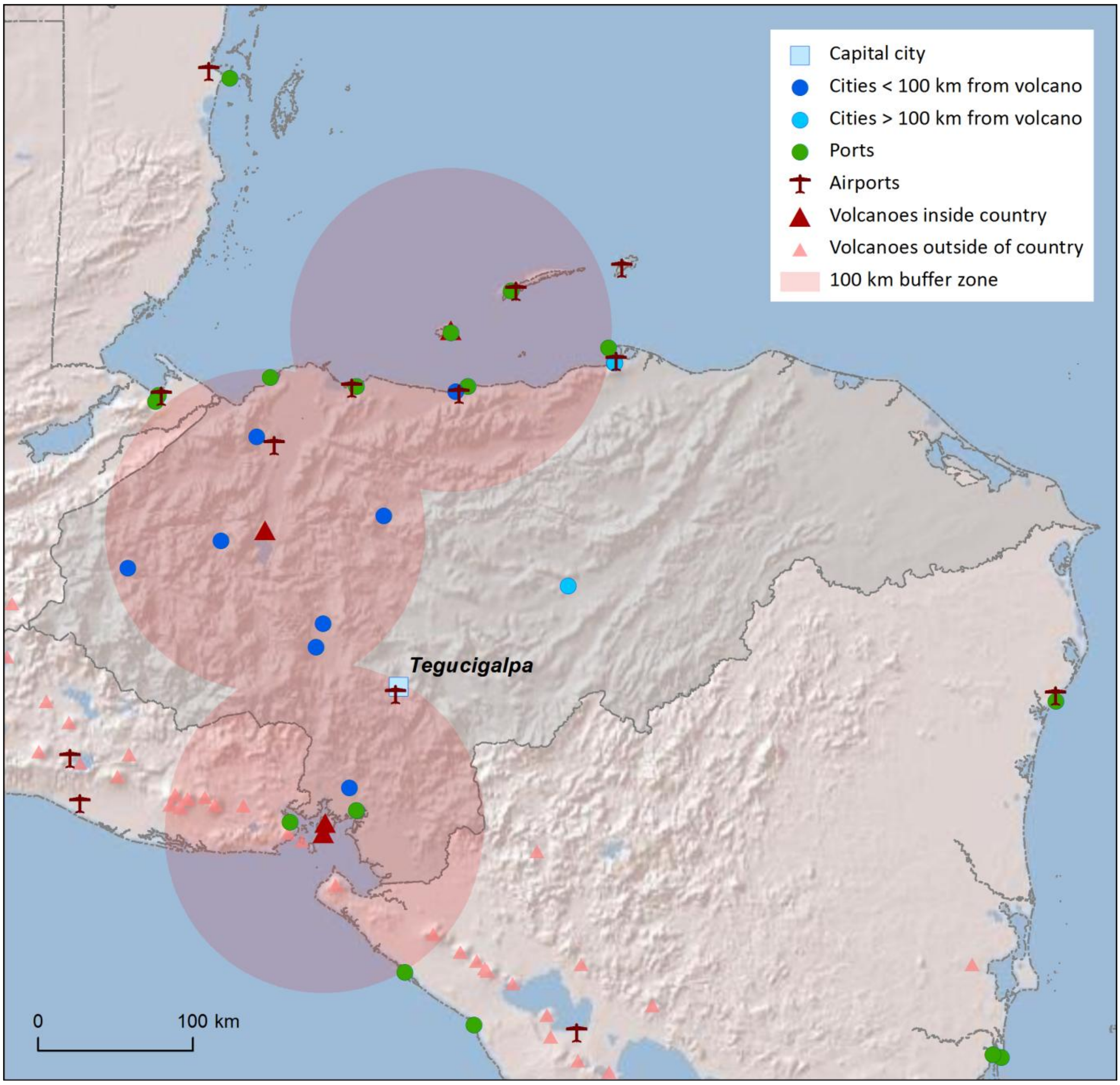


Figure 274: The location of Honduras' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The volcanoes of Honduras are widely distributed, from the Gulf of Fonseca in the Pacific Ocean, to a volcano in central mainland Honduras, to Utila Island in the Caribbean Sea. The 100 km radii of these volcanoes cover an extensive section of Honduras and extend into Guatemala, El Salvador and Nicaragua. Eight of the largest cities in Honduras lie within the 100 km radii of the Holocene volcanoes, as does the capital, Tegucigalpa. Much of the country's critical infrastructure is therefore exposed, including ports on the Caribbean Sea and Pacific Ocean, airports and an extensive road network. Tegucigalpa is not situated within 100 km of any historically active volcanoes.

Hazard, Uncertainty and Exposure Assessments

No volcanoes in Honduras have a record of confirmed Holocene eruptions. The absence of an extensive eruption record prevents assessment of hazard through the calculation of the VHI, and as such these volcanoes are unclassified.

The PEI ranges from moderate to high in Honduras, with Lake Yojoa having the highest PEI with over 120,000 living with 10 km. Without a hazard classification, the risk levels for Honduran volcanoes cannot be determined.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR			Utila Island	Tigre, Isla el; Zacate Grande, Isla		Yojoa, Lake	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 260: Identity of Honduras' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Honduras have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Honduras.

Mexico

Description

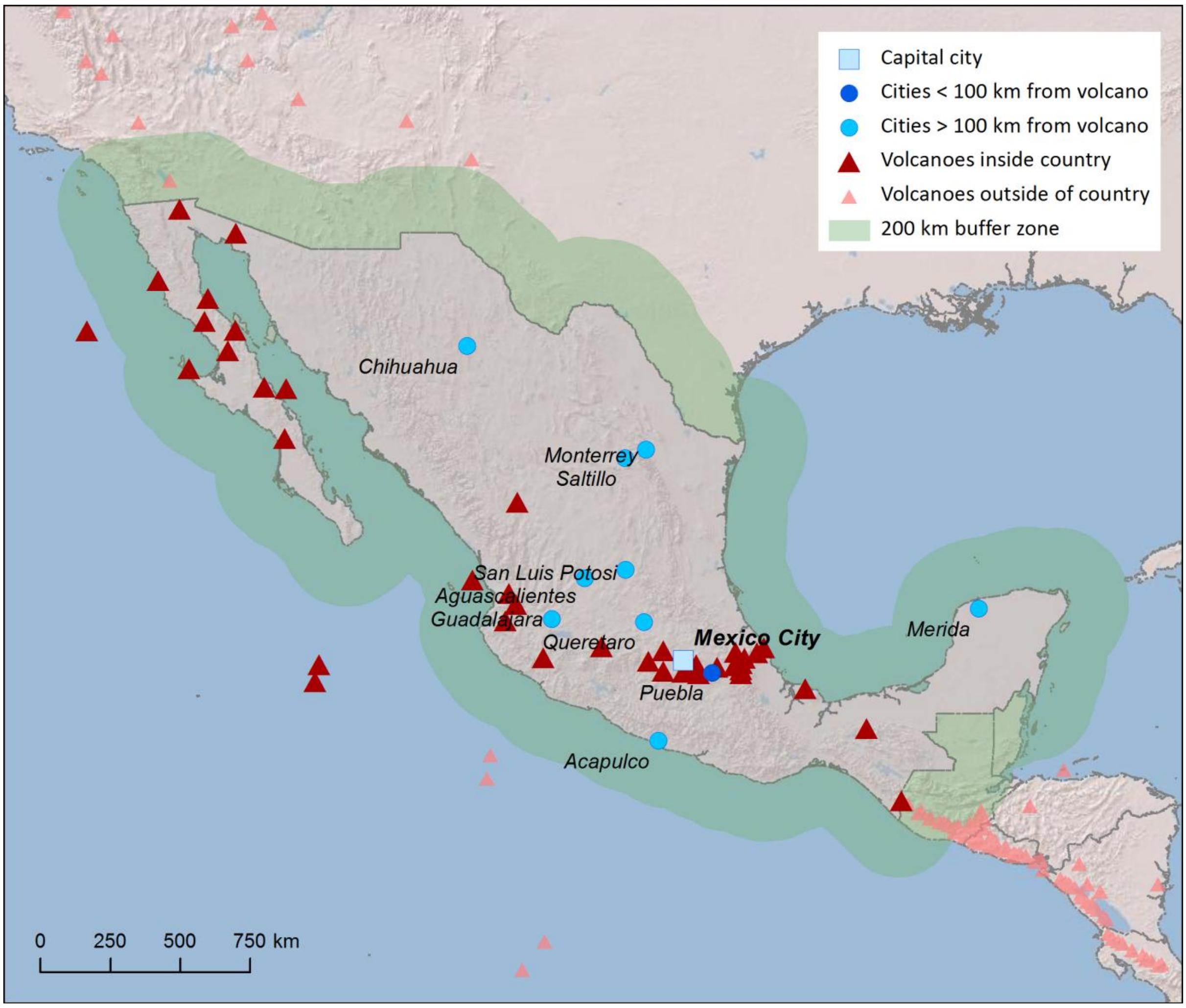


Figure 275: Location of Mexico's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Mexico.

Forty Holocene volcanoes are located in Mexico, including one on the border with Guatemala. Volcanoes are concentrated on the Baja California peninsula and across central Mexico, around the capital, Mexico City. Volcanism here is primarily due to the subduction of the Pacific and Cocos Plates beneath the North American Plate. This has given rise to the formation of dominantly andesitic volcanic centres, primarily comprising groups of cinder or tuff cones and stratovolcanoes, though a range of volcano types are present.

Mexico has an extensive Pleistocene record of large explosive eruptions, with 20 volcanoes recorded in LaMEVE with eruptions of VEI/M≥4. The largest recorded Pleistocene eruption was the M7.4 Xáltipan Ignimbrite from Los Humeros about 460,000 years ago. This ignimbrite covered about 3,500 square kilometres and formed the 15 x 21 km caldera.

Eighteen volcanoes have records of Holocene activity, with the remaining volcanoes having activity of suspected though unconfirmed Holocene age. 214 Holocene eruptions are recorded here, from

VEI 0 to 6. This size range demonstrates the range in activity in Mexico, from small events to very large explosive eruptions. About 12% of eruptions here are recorded at VEI ≥4. About 46% of all eruptions have records of producing pyroclastic flows. The largest Holocene eruption was that of the Jala Pumice from Ceboruco in about 930 AD. This produced voluminous rhyolitic pumice and formed a 4 km wide caldera. Most commonly, small eruptions of VEI 0 – 2 are recorded, with about 35% of the Holocene record comprising such events. About 20% of Holocene eruptions were VEI 3, being moderately explosive.

Of the Holocene record, about 50% of the eruptions have been recorded post-1500 AD, with 103 historic eruptions of VEI 0 – 5 from 10 volcanoes. About 10% of these (10 eruptions) were of VEI ≥4. Two VEI 5 eruptions have occurred historically, at Colima in 1913 and El Chichón in 1982. Pyroclastic flows and surges during the 1982 eruption devastated an area extending about 8km around the volcano.

In total, throughout Mexico, about 50% of the population live within 100 km of one or more Holocene volcanoes. The size of the local population varies at each volcano, with 13 volcanoes having a low PEI. 50% of the volcanoes here however have high local populations. Fatalities are recorded in about 8% of historical eruptions, with none recorded since 1996.

Monitoring of the historically active volcanoes in Mexico is undertaken by CENAPRED (National Center for Disaster Prevention), UNAM (Universidad Nacional Autónoma de México) and UCOL (Universidad de Colima).

CENAPRED creates, manages and evaluates public policies for risk reduction, coordinating risk information and early warning systems. CENAPRED and UNAM collaborate with joint research projects and shared expertise and also collaborate with the U.S. Geological Survey. CENAPRED and UNAM's main monitoring focus is on Popocatepetl, one of the most frequently active volcanoes in Mexico, located just 70 km from Mexico City. Popocatepetl has a complex monitoring system of visual, seismic, geodetic and geochemical instruments installed, with telemetered data CENAPRED for data processing. Upon detection of seismic unrest an alarm system is activated and duty staff are notified. The Scientific Technical Advisory Committee undertakes analysis of the data and makes recommendations based on the activity level. Government officials and civil protections are regularly updated and the public is informed. Hazard maps are available for flow and fall hazards.

The University of Colima runs the Observatorio Vulcanológico monitoring Colima, Mexico's most frequently active volcano. This observatory monitors activity at Colima through seismic, deformation, visual and geochemical instrumentation. All staff members have experience of responding to volcanic eruptions. Resources are limited with little current funding available to this institution. The Scientific Advisory Committee of Colima informs civil protection about the level of volcanic activity, however no formal alert system is used at Colima. The Protección Civil de Jalisco (Jalisco state) control the alert system there. Advice is provided to the public for what to do before, during and after eruptions, and hazard maps and evacuation routes are provided.

See also:

CENAPRED: http://www.cenapred.unam.mx/es/

Observatorio Vulcanológico, University of Colima: http://www.ucol.mx/volcan/index.php

Volcano Facts

Number of Holocene volcanoes	40, inclusive of one on the border with Guatemala
Number of Pleistocene volcanoes with M≥4 eruptions	20
Number of volcanoes generating pyroclastic flows	12
Number of volcanoes generating lahars	8
Number of volcanoes generating lava flows	13
Number of fatalities caused by volcanic eruptions	?>2,197
Tectonic setting	27 Subduction zone, 13 Rift zone
Largest recorded Pleistocene eruption	The M7.4 eruption of the Xáltipan Ignimbrite from Los Humeros at 460 ka.
Largest recorded Holocene eruption	The VEI 6 eruption of the Jala Pumice from Ceboruco in 930AD.
Number of Holocene eruptions	214 confirmed eruptions. 30 uncertain and 1 discredited eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	10
Number of historic eruptions	103

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
2	Caldera(s)	Dacitic (1), Rhyolitic (1)
13	Large cone(s)	Andesitic (11), Dacitic (1), Unknown (1)
3	Lava dome(s)	Andesitic (1), Dacitic (2)
6	Shield(s)	Andesitic (2), Basaltic (3), Trachytic / Andesitic (1)
15	Small cone(s)	Andesitic (7), Basaltic (5), Rhyolitic (2), Trachytic / Andesitic (1)
1	Submarine	Unknown (1)

Table 261: The number of volcanoes in Mexico, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	121,073,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	12,776
Gross National Income (GNI) per capita (2005 PPP $)	12,947
Human Development Index (HDI) (2012)	0.775 (High)

Population Exposure

Capital city	Mexico City
Distance from capital city to nearest Holocene volcano	46.7 km
Total population (2011)	113,724,226
Number (percentage) of people living within 10 km of a Holocene volcano	394,678 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	15,418,740 (13.6%)
Number (percentage) of people living within 100 km of a Holocene volcano	57,764,870 (50.8%)

Ten largest cities, as measured by population, and populations:

Mexico City	11,285,654
Guadalajara	1,640,589
Puebla	1,392,099
Monterrey	1,122,874
Merida	717,175
Chihuahua	708,267
San Luis Potosi	677,704
Aguascalientes	658,179
Acapulco	652,136
Saltillo	621,250

Infrastructure Exposure

Number of airports within 100 km of a volcano	13
Number of ports within 100 km of a volcano	10
Total length of roads within 100 km of a volcano (km)	17,530
Total length of railroads within 100 km of a volcano (km)	2,233

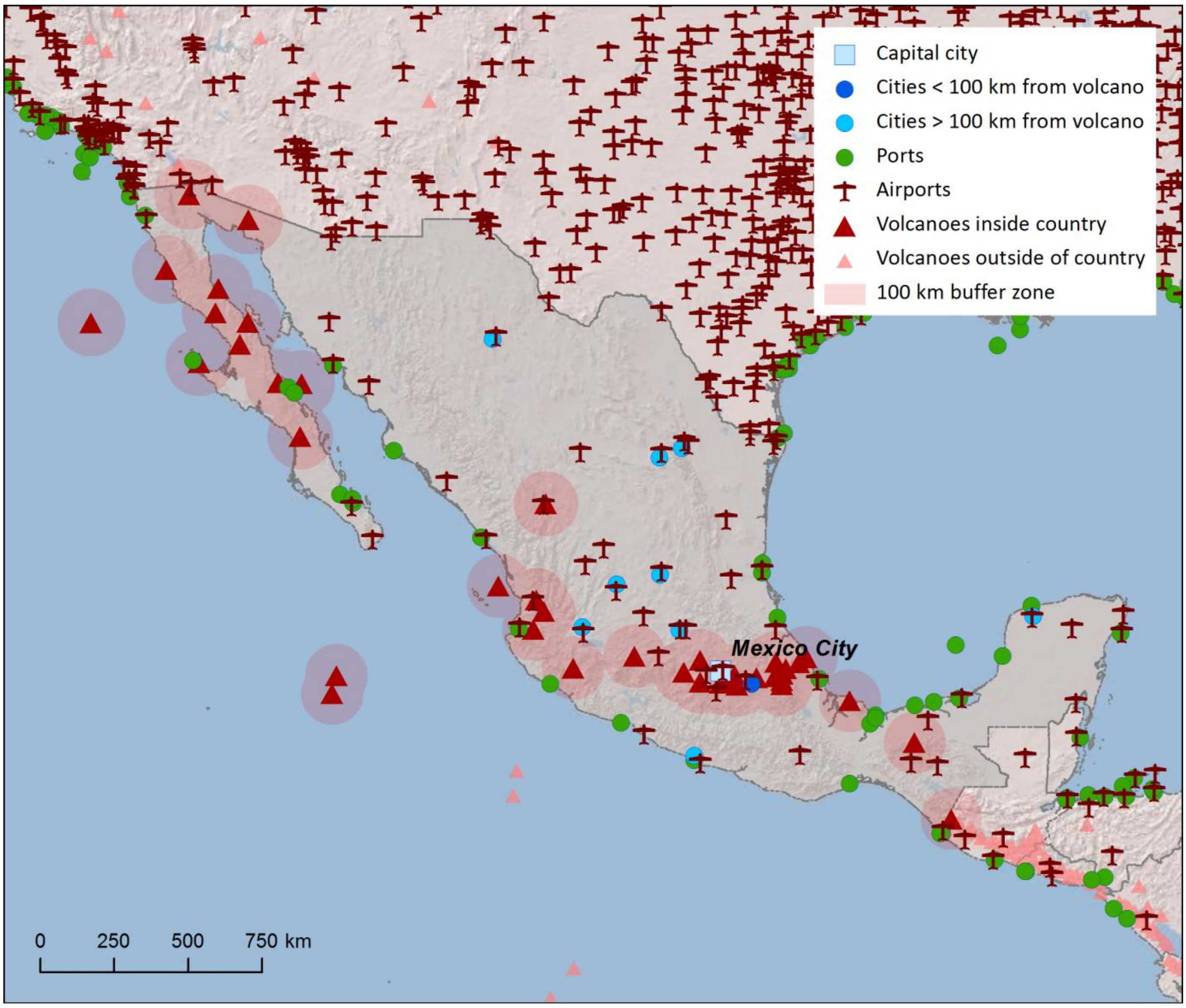


Figure 276: The location of Mexico's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The volcanoes in Mexico are distributed throughout the Baja California peninsula, across central Mexico and to the border with Guatemala. The 100 km radius of Tacaná, on the Mexico-Guatemala border extends into both countries, while the radius surrounding Pinacate in the north extends into Arizona in the USA. Four volcanoes in Guatemala and Salton Buttes in California, USA have 100 km which extend into southern and northern Mexico respectively, exposing infrastructure here. Two of the largest cities in Mexico lie within 100 km of the Holocene volcanoes, including Puebla and the capital, Mexico City, hence exposing significant critical infrastructure here. Mexico City lies within 100 km of the historically and frequently active Popocatépetl volcano. The distribution of the volcanoes throughout the country places numerous ports and airports under threat as well as a very extensive road and rail network.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of data in the eruption records of Mexico's volcanoes. Out of 40, just four have sufficient detail to define the hazard through the calculation of the VHI. These volcanoes are classified at Hazard Level II and III, with Holocene records of large explosive eruptions of VEI ≥4 and a particularly strong record of explosive eruptions accompanied by pyroclastic flows at Colima and Pico de Orizaba.

Of the unclassified volcanoes, 22 have no records of confirmed Holocene age eruptions. The remaining have a Holocene record, including historical events at seven volcanoes, with eruptions recorded since 1900 AD at five of these volcanoes. Five unclassified volcanoes have records of Holocene age large explosive VEI ≥4 eruptions.

The PEI ranges from low to very high in Mexico. The classified volcanoes all have moderate to very high PEIs and these are therefore classed at Risk Levels II and III. The risk levels for the unclassified volcanoes cannot be determined due to the absence of hazard data.

CLASSIFIED	**Hazard III**				Colima	Orizaba, Pico de		
	Hazard II					Popocatépetl		Chichinautzin
	Hazard I							
UNCLASSIFIED	**U – HHR**	**Bárcena; Socorro**			San Martín; **El Chichón**	Ceboruco; **Tacaná**		**Michoacán-Guanajuato**
	U- HR				Cumbres, Las	Malinche, La; Cofre de Perote	Zitácuaro-Valle de Bravo; Jocotitlán; Toluca, Nevado de; Naolinco Volcanic Field	
	U- NHHR	Guadalupe; Isabel, Isla	Pinacate; San Luis, Isla; Jaraguay Volcanic Field; Coronado; San Borja Volcanic Field; Unnamed; Tres Vírgenes; Tortuga, Isla; Comondú-La Purísima		San Quintín Volcanic Field; Sangangüey; Mascota Volcanic Field; Atlixcos, Los	Prieto, Cerro; Iztaccíhuatl; Humeros, Los	Papayo; Serdán-Oriental; Gloria, La	Durango Volcanic Field
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 262: Identity of Mexico's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Chichinautzin	7	III
Orizaba, Pico de	5	III
Popocatépetl	5	II
Colima	4	III

Table 263: Classified volcanoes of Mexico ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 1 volcano; Risk Level III – 3 volcanoes.

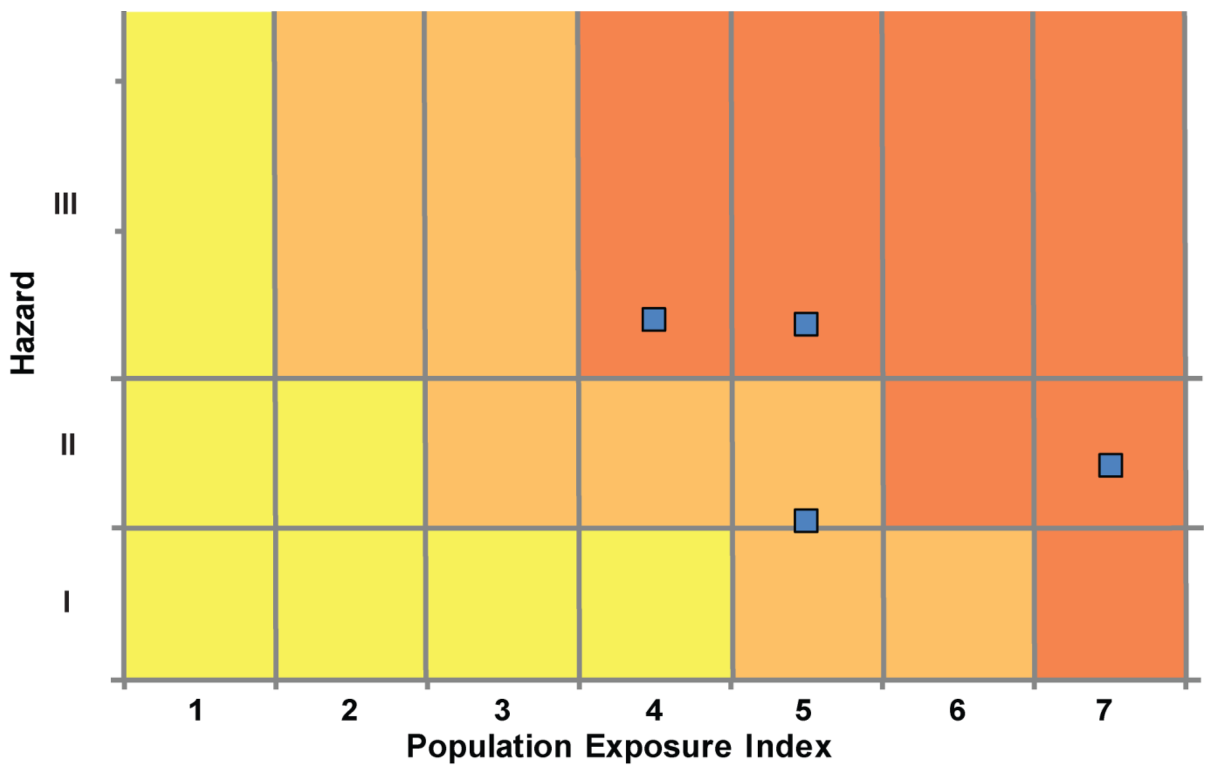


Figure 277: Distribution of Mexico's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Ten volcanoes in Mexico have records of historical activity. Seven of these are unclassified whilst three are at Risk Levels II and III. At the time of the writing of this report, no information available indicated dedicated ground-based monitoring at three volcanoes here (Bárcena, Socorro, Michoacán-Guanajuato). However, a national seismic network is in place. At seven historically active volcanoes, dedicated seismic monitoring and additional deformation and sometimes gas monitoring is used.

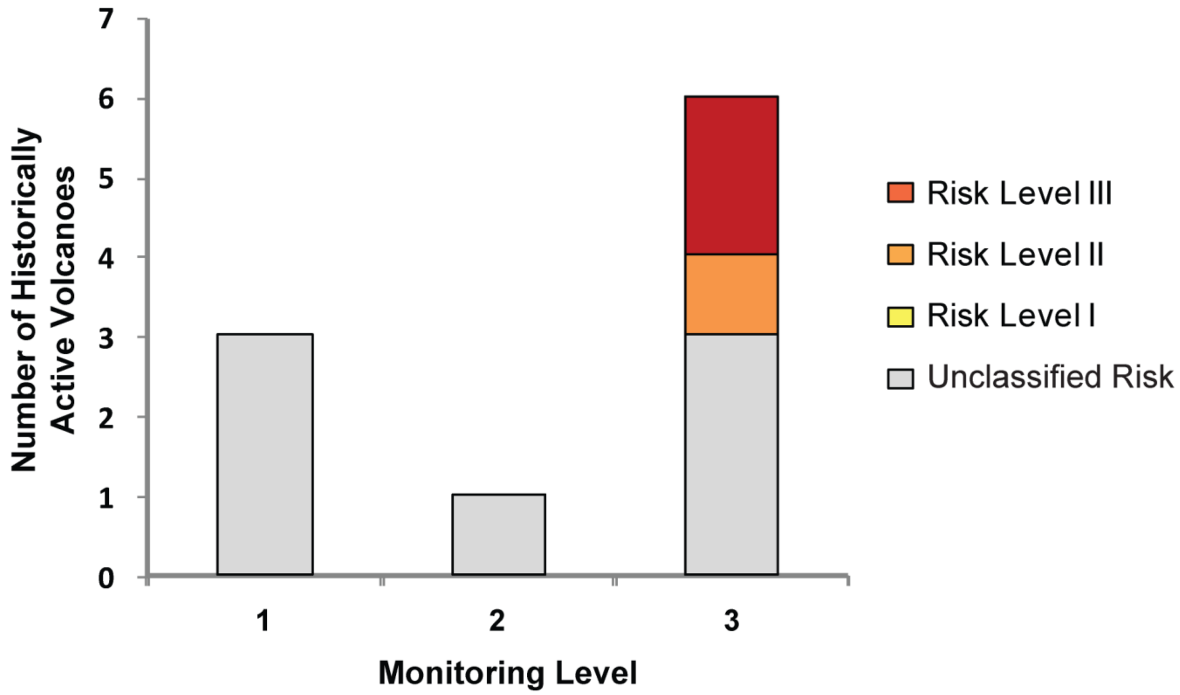


Figure 278 The monitoring and risk levels of the historically active volcanoes in Mexico. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Nicaragua

Description

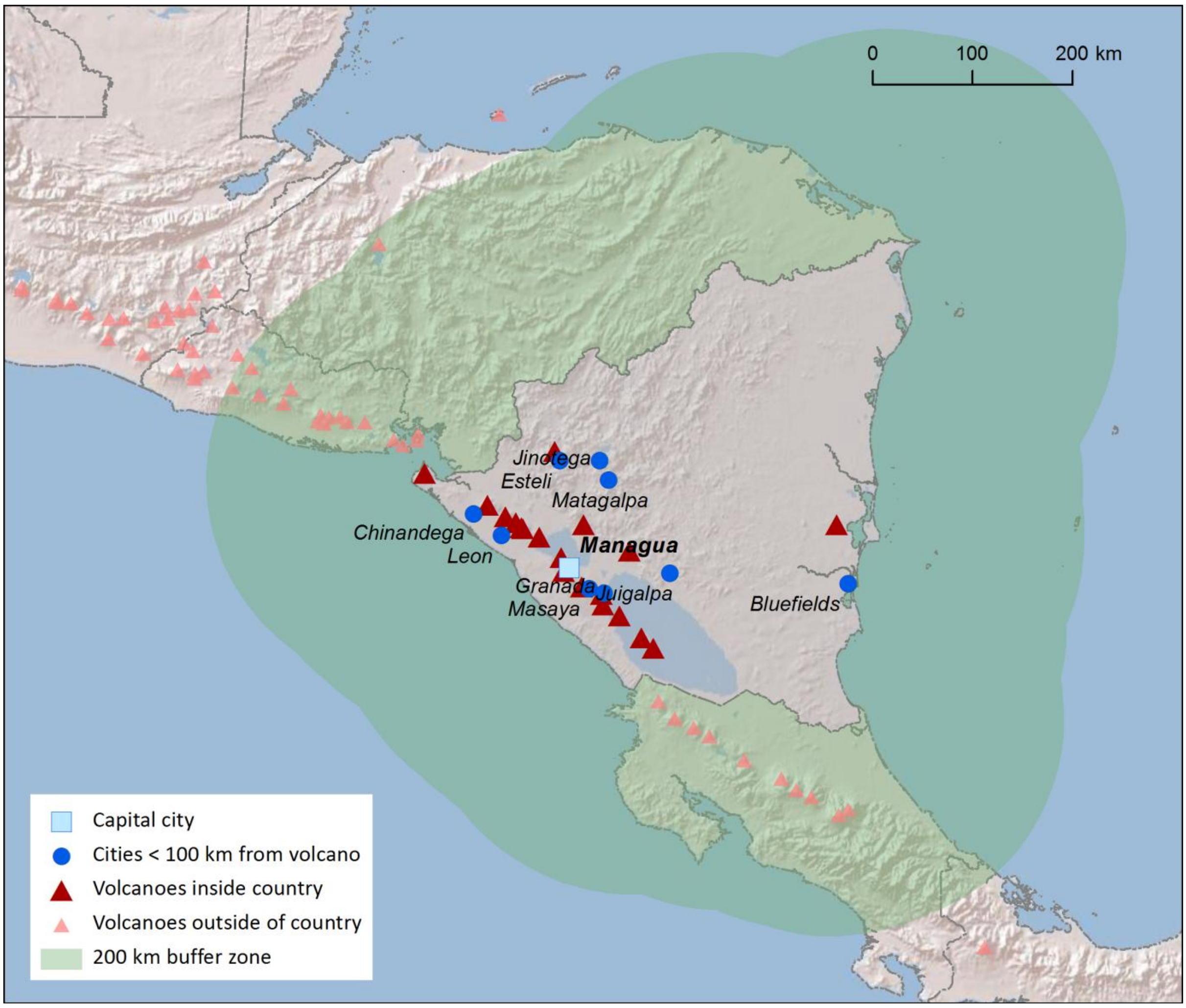


Figure 279: Location of Nicaragua's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Nicaragua.

Nineteen Holocene volcanoes are located in Nicaragua, dominantly in a chain near the west coast, from the border with Costa Rica in the south and the Gulf of Fonseca in the north. One, Volcán Azul (Blue volcano), lies near the Caribbean Sea coast. Volcanism in Nicaragua is due to the subduction of the Cocos Plate beneath the Caribbean Plate. A range of volcano types have developed throughout Nicaragua, though most volcanoes are dominantly basaltic and andesitic stratovolcanoes. A number of basaltic volcano fields comprising multiple cinder cones have also formed, and large calderas are also present.

191 confirmed eruptions are recorded during the Holocene, ranging in size from VEI 0 – 6 indicating a range in activity styles from mild events to very large explosive eruptions. Seven volcanoes have records of producing pyroclastic flows. The largest recorded Holocene eruption was the VEI 6 eruption of Masaya at about 6,000 years ago. This basaltic Plinian eruption produced ash fall and pyroclastic flows. Masaya has been one of the most frequently active volcanoes in Nicaragua in the

Holocene, with 34 recorded eruptions, but these have mainly been small to moderate events. The capital of Nicaragua, Managua, lies only about 20 km from this volcano and a large explosive eruption here could have devastating consequences.

Most of the eruptions recorded during the Holocene were recorded in historical times, since 1500 AD, with 172 eruptions recorded in this time from eight volcanoes. With a scarce eruption record prior to 1500 AD, the assessment of hazard at many of Nicaragua's volcanoes is difficult and associated with significant uncertainties. Further research documenting the Holocene eruption record would be beneficial in understanding volcanism here.

Despite high proximal populations surrounding most volcanoes in Nicaragua, with over 1.5 million people living within 10 km of one or more Holocene volcanoes throughout the country and most of the population living within 100 km of one or more Holocene volcanoes, just five eruptions have recorded about 2,000 fatalities. In 1992, a VEI 3 eruption of Cerro Negro produced widespread damage due to voluminous ash fall. Despite the evacuation of over 20,000 people, many roofs collapsed resulting in loss of life. In 1998 Volcán Casita, a cone of San Cristóbal, suffered a catastrophic landslide and lahar following Hurricane Mitch. Several villages were buried and several thousand lost their lives. Lahars in the tropics are relatively common-place with the high rainfall, and lahars can occur for many years after eruptions due to the remobilisation of ash.

The Instituto Nicaragüense de Estudios Territriales (INETER) is responsible for volcano monitoring in Nicaragua. All historically active volcanoes are seismically monitored, with additional deformation monitoring at five volcanoes. INETER analyse the data in near real-time and release monthly bulletins of volcanic activity and status online. INETER is a member of WOVO.

See also:

Instituto Nicaragüense de Estudios Territriales (INETER): http://www.ineter.gob.ni/

Volcano Facts

Number of Holocene volcanoes	19
Number of Pleistocene volcanoes with M≥4 eruptions	6
Number of volcanoes generating pyroclastic flows	7
Number of volcanoes generating lahars	5
Number of volcanoes generating lava flows	6-7
Number of fatalities caused by volcanic eruptions	?
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M6.4 eruption of the Upper Apoyo Tephra (UAT) from Apoyo at 29,468 BP.

Largest recorded Holocene eruption	The M6.3 San Antonio Tephra eruption from Masaya at 6 ka.
Number of Holocene eruptions	191 confirmed eruptions. 23 uncertain.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	8
Number of historic eruptions	172

Number of volcanoes	Primary volcano type	Dominant rock type
2	Caldera(s)	Basaltic (1), Dacitic (1)
10	Large cone(s)	Andesitic (6), Basaltic (4)
2	Shield(s)	Andesitic (1), Basaltic (1)
5	Small cone(s)	Basaltic (5)

Table 264: The number of volcanoes in Nicaragua, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	6,009,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	2,579
Gross National Income (GNI) per capita (2005 PPP $)	2,551
Human Development Index (HDI) (2012)	0.599 (Medium)

Population Exposure

Capital city	Managua
Distance from capital city to nearest Holocene volcano	6.4 km
Total population (2011)	5,666,301
Number (percentage) of people living within 10 km of a Holocene volcano	1,521,967 (26.9%)
Number (percentage) of people living within 30 km of a Holocene volcano	3,371,558 (59.5%)
Number (percentage) of people living within 100 km of a Holocene volcano	5,314,523 (93.8%)

Ten largest cities, as measured by population, and populations:

Managua	973,087
Leon	144,538
Masaya	130,113
Chinandega	126,387
Matagalpa	109,089
Esteli	96,422
Granada	89,409
Juigalpa	54,731
Jinotega	51,073
Bluefields	44,373

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	5
Total length of roads within 100 km of a volcano (km)	3,333
Total length of railroads within 100 km of a volcano (km)	0

With the exception of Volcán Azul in the east of the country, all volcanoes in Nicaragua are situated in the west, largely in a chain paralleling the coastline. With numerous volcanoes located here, a large expanse of the country lies within the 100 km radii of these volcanoes. These radii also extend into Costa Rica, Honduras and El Salvador. All ten of Nicaragua’s largest cities, including the capital, Managua, lie within 100 km of Holocene volcanoes, and hence much of the country’s critical infrastructure is exposed including ports, airports and an extensive road network. Managua lies within 100 km of seven historically active volcanoes.

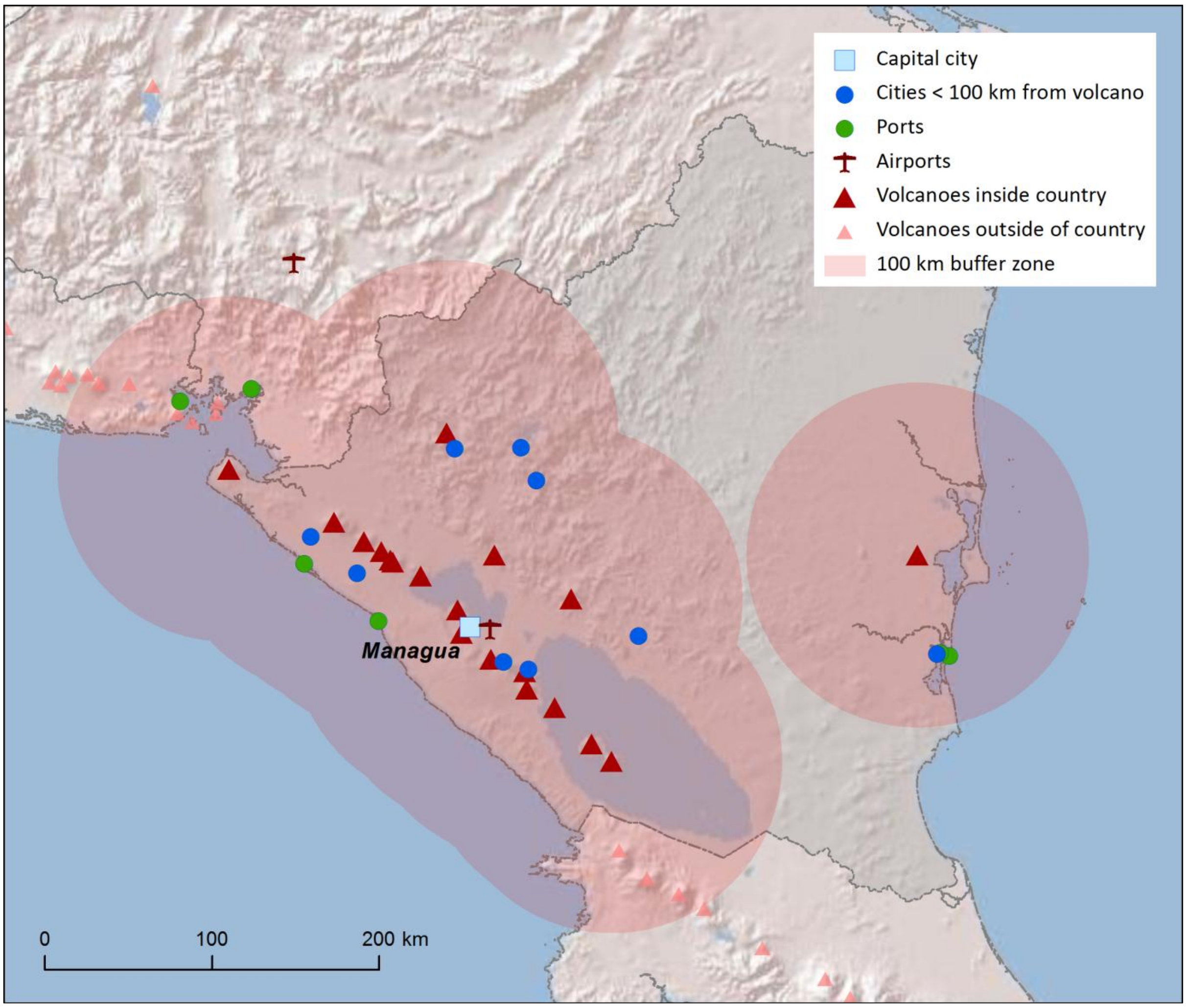


Figure 280: The location of Nicaragua's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of Nicaragua's volcanoes. About 40% of volcanoes have sufficient detail to define the hazard through the calculation of the VHI. These are classified across the hazard levels, with just one at Hazard Level III: Apoyeque. This volcano has a Holocene record of a VEI 6 eruption and all Holocene eruptions recorded here are large, explosive VEI ≥4 events.

Of the unclassified volcanoes, nine have no recorded confirmed Holocene eruptions. Three have Holocene records, including historical events at Cosigüina and Las Pílas. Eruptions since 1900 AD are recorded at the latter, and seismic unrest has been detected at the former. Unrest is also described at Nejapa-Miraflores, Rota and Mombacho.

The PEI ranges from moderate to very high in Nicaragua, with over half of the volcanoes here classed with a high local population and PEI of 5 to 7. The classified volcanoes are classed across all three Risk levels, with just Apoyeque and Masaya being Risk level III. Although unclassified in hazard, the very high PEI at Nejapa-Miraflores indicates that this would class as a Risk Level III.

CLASSIFIED	**Hazard III**						Apoyeque	
	Hazard II				San Cristóbal; Momotombo	Telica; Concepción		Masaya
	Hazard I				Negro, Cerro			
UNCLASSIFIED	**U – HHR**			**Cosigüina**	**Las Pilas**			
	U- HR							**Nejapa-Miraflores**
	U- NHHR			Maderas; Azul, Volcán	Zapatera; Ciguatepe, Cerro el; Lajas, Las	**Rota; Mombacho**	Granada; Estelí	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 265: Identity of Nicaragua's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Masaya	7	III
Apoyeque	6	III
Concepción	5	II
Telica	5	II
Momotombo	4	II
San Cristóbal	4	II
Negro, Cerro	4	I

Table 266: Classified volcanoes of Nicaragua ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 4 volcanoes; Risk Level III – 2 volcanoes.

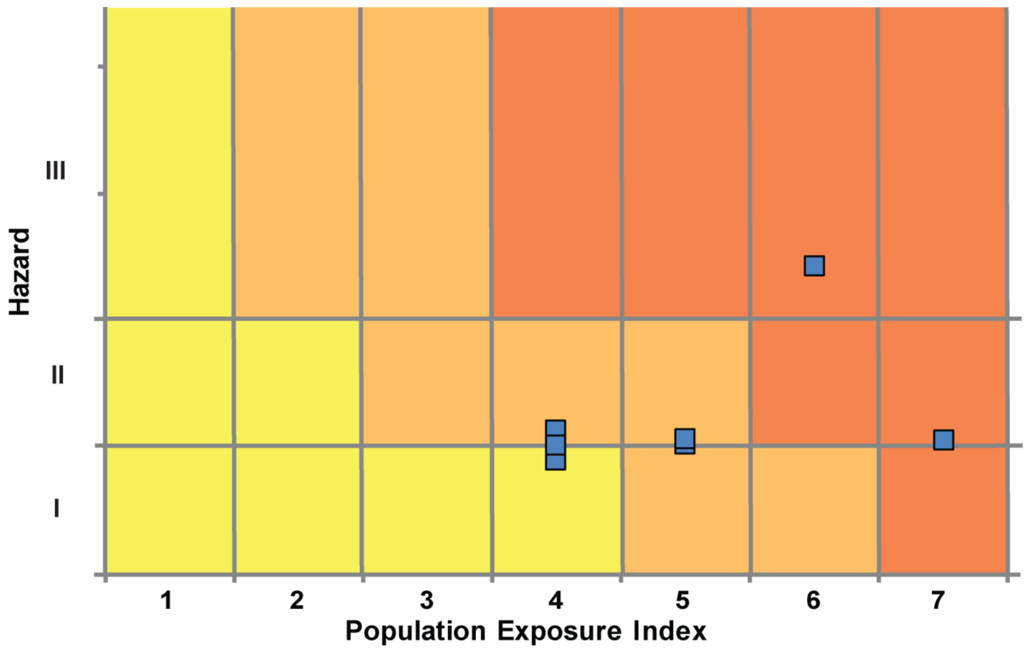


Figure 2811: Distribution of Nicaragua's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels: Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Eight volcanoes have recorded historical activity. The Instituto Nicaragüense de Estudios Territriales (INETER) is responsible for volcano monitoring. All historically active volcanoes have continuous seismic monitoring, with near real-time analysis. In addition to this, deformation monitoring is undertaken at San Cristóbal, Cerro Negro, Concepción, Cosigüina and the Risk Level III Masaya.

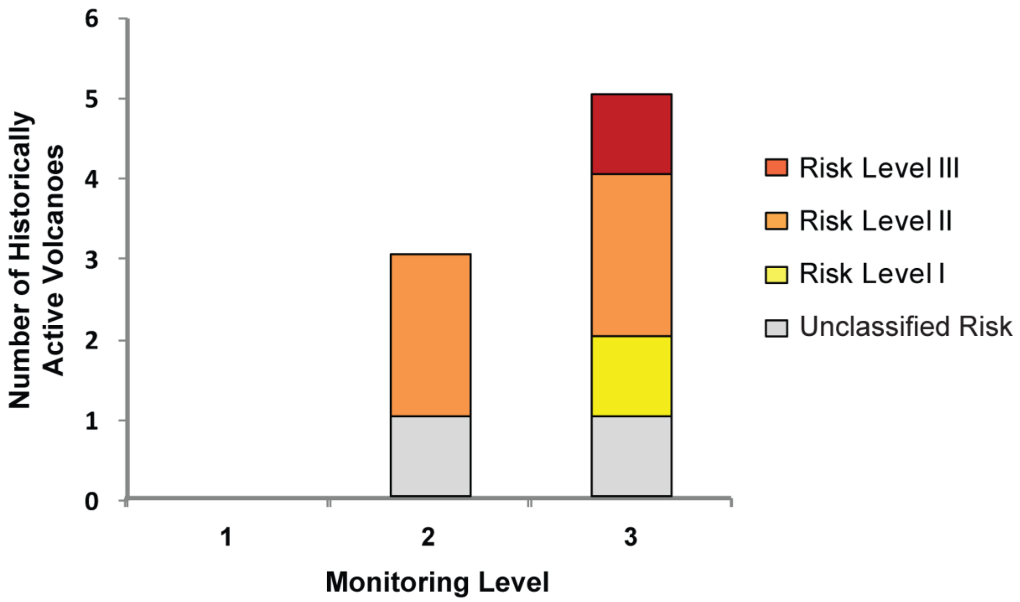


Figure 282: The monitoring and risk levels of the historically active volcanoes in Nicaragua. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Panama

Description

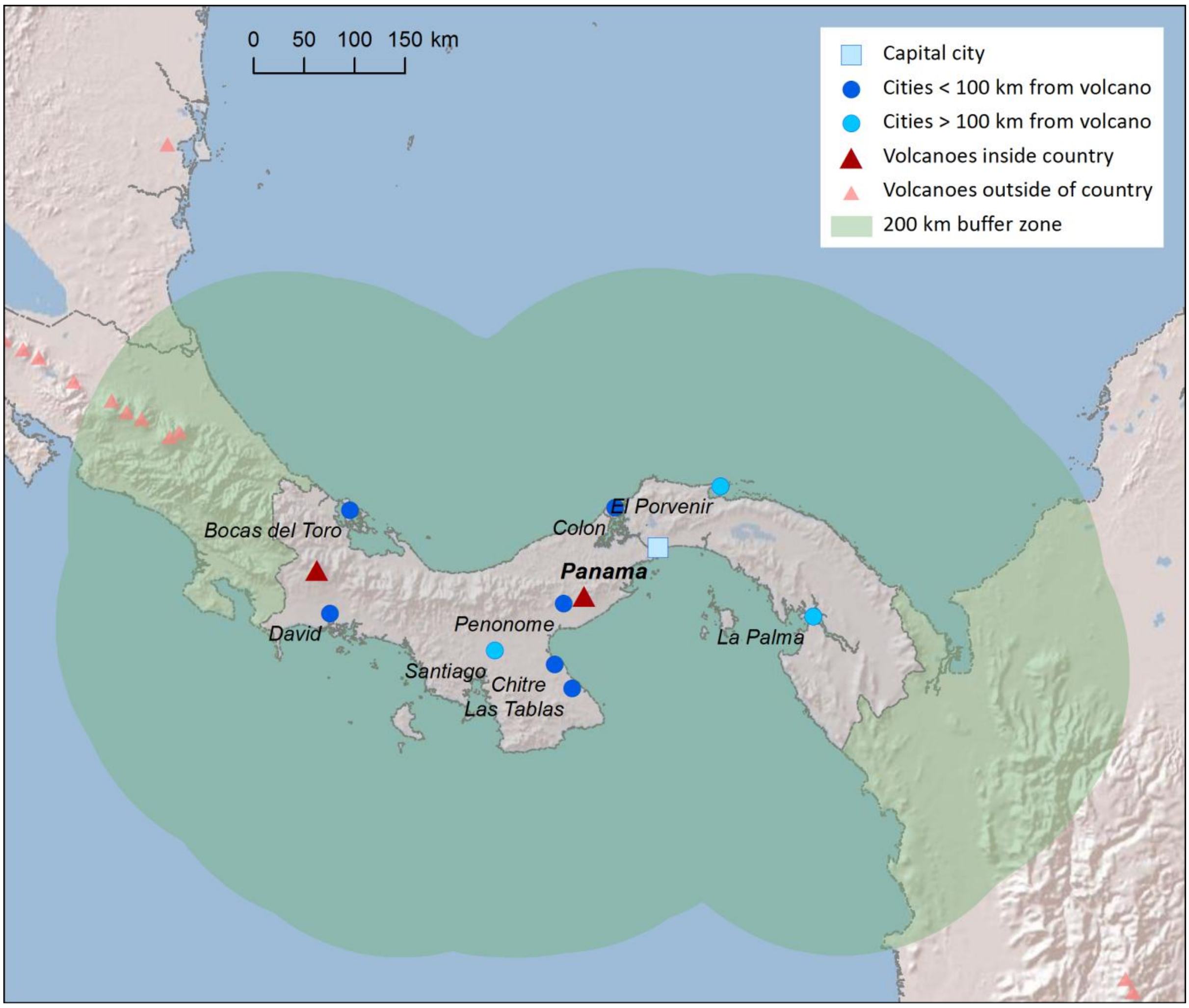


Figure 283: Location of Panama's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Panama.

Two Holocene volcanoes are situated in Panama. Barú lies in the west, close to the border with Costa Rica. El Valle lies in central Panama, around 80 km from the Panama Canal.

The volcanoes in Panama lie at the southern end of the Central American volcanic arc. Located on the Caribbean plate, several plates converge in this region with both the Caribbean and Nazca plates undergoing subduction.

Of the two Holocene volcanoes, neither has recorded historical activity, and only Barú has confirmed Holocene eruptions, with the most recent occurring in 710 AD. The size of the eruptions are unknown, however multiple pyroclastic surge deposits are identified suggesting a history of explosive eruptions at Barú. A record of Pleistocene activity at El Valle shows the occurrence of large magnitude explosive eruptions, with a magnitude 4 eruption here 56,000 years ago. Both volcanoes are large dominantly andesitic and dacitic Stratovolcanoes. This rock chemistry coupled with the explosive deposits suggests dominantly explosive activity in Panama with the potential for future eruptions of a similar style, producing pyroclastic density currents, ash fall and lahars.

Nearly 93% of the population of Panama lives within 100 km of the Holocene volcanoes, as many of the largest cities in the country lie within this distance. Indeed, the capital, Panama City lies at around 80 km from El Valle. Despite the large proportion of the population being exposed, the population within 10 km is moderate, and the volcanoes here are classed at PEI 4. A Holocene record of property damage exists at Barú. Barú has the potential to affect neighbouring Costa Rica, whilst some of the southernmost volcanoes in Costa Rica lie within 200 km of Panama.

Ash fall has been deposited more than 100 km downwind in prehistoric eruptions of Barú and dome collapses and subsequent hot PDCs have been channelled westwards. The town of Volcán is built on the deposits of these flows. Sherrod et al. (2008) describes these flows as constrained to 15 km from the summit dome. Large lahar plains extend to the south, and the city of David, the second most populous in Panama is located on this plain.

Barú is monitored by a seismic network maintained by the Institute of Geosciences at the University of Panama.

See also:

Sherrod, D.R., Vallance, J.W., Tabia Espinosa, A., and McGeehin, J.P. (2008) Volcan Baru; eruptive history and volcano-hazards assessment: US Geological Survey Open-File Report 2007-1401. 33p http://pubs.usgs.gov/of/2007/1401/

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The 56 ka M4.0 El Hato Ignimbrite and El Valle de Antón caldera formation of El Valle.
Largest recorded Holocene eruption	All Holocene eruptions are of unknown VEI.
Number of Holocene eruptions	5 confirmed eruptions.
Recorded Holocene VEI range	Unknown
Number of historically active volcanoes	-
Number of historic eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Andesitic (1), Dacitic (1)

Table 267: The number of volcanoes in Panama, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	3,808,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	13,766
Gross National Income (GNI) per capita (2005 PPP $)	13,519
Human Development Index (HDI) (2012)	0.780 (High)

Population Exposure

Capital city	Panama City
Distance from capital city to nearest Holocene volcano	82.6 km
Total population (2011)	3,460,462
Number (percentage) of people living within 10 km of a Holocene volcano	18,189 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	266,966 (7.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	3,203,311 (92.6%)

Largest cities, as measured by population, and populations:

Panama	408,168
David	82,859
Colon	76,643
Santiago	45,355
Chitre	43,966
Penonome	12,394
Las Tablas	8,570
La Palma	1,845
Bocas del Toro	<50,000

Infrastructure Exposure

Number of airports within 100 km of a volcano	4
Number of ports within 100 km of a volcano	12
Total length of roads within 100 km of a volcano (km)	1,394
Total length of railroads within 100 km of a volcano (km)	75

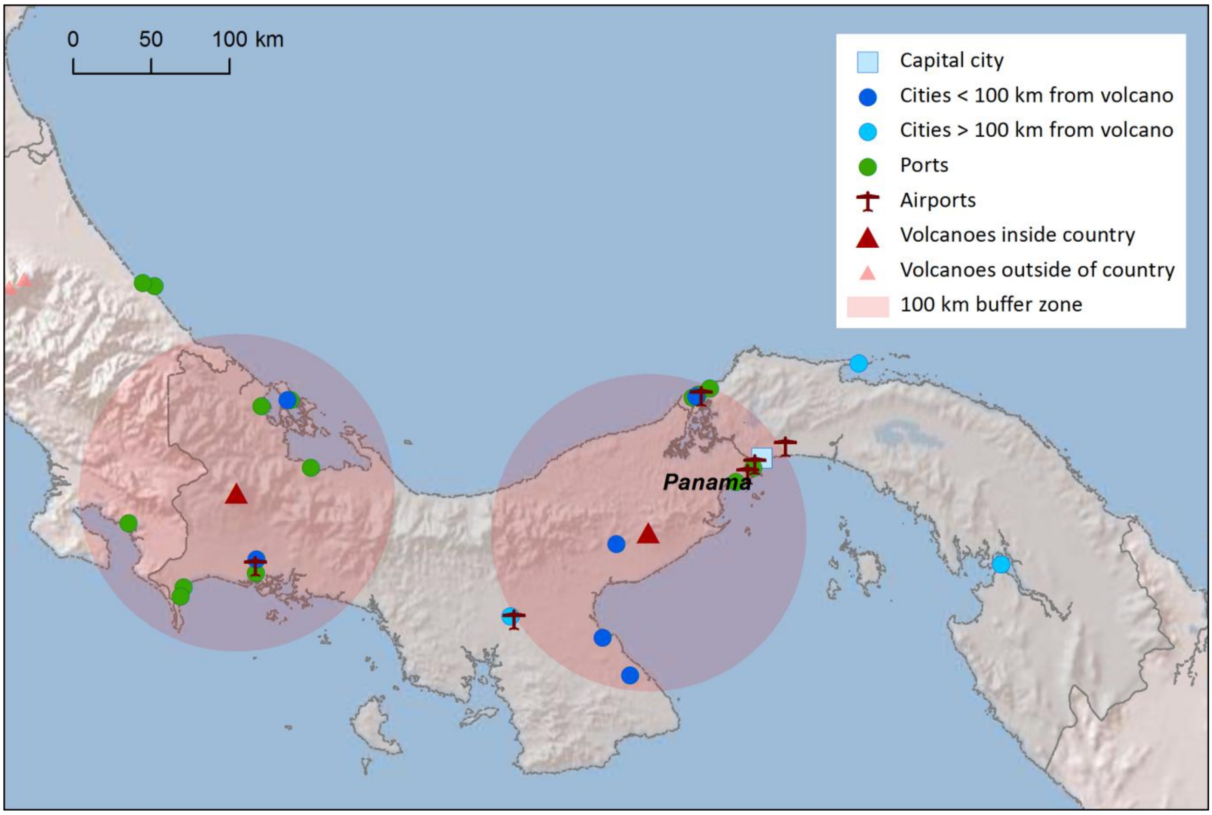


Figure 284: The location of Panama's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The two volcanoes in Panama are located in the centre and west of the country. The 100 km radius of the western volcano, Barú, extends across the border into Costa Rica, exposing infrastructure here as well as encompassing a number of ports and two of Panama's largest cities. The 100 km radius of El Valle volcano, encompasses several of Panama's largest cities, including the capital, Panama City, and crucially the Panama Canal, hence considerable critical infrastructure is exposed here.

Hazard, Uncertainty and Exposure Assessments

Neither volcano in Panama have a sufficiently extensive record for assessment of the hazard through the calculation of the VHI. Indeed, El Valle has no confirmed Holocene eruptions. Five Holocene eruptions are known at Barú, however the VEI is unknown. These volcanoes are therefore unclassified.

Both volcanoes in Panama have a moderate proximal population and are classed at PEI 4.

CLASSIFIED	Hazard III							
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR				Barú			
	U- HR							
	U- NHHR				El Valle			
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 268: Identity of Panama's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

A network of seismometers dedicated to the monitoring of Barú volcano has been installed and is managed by the University of Panama. El Valle has no historical eruption record and no dedicated ground-based monitoring.

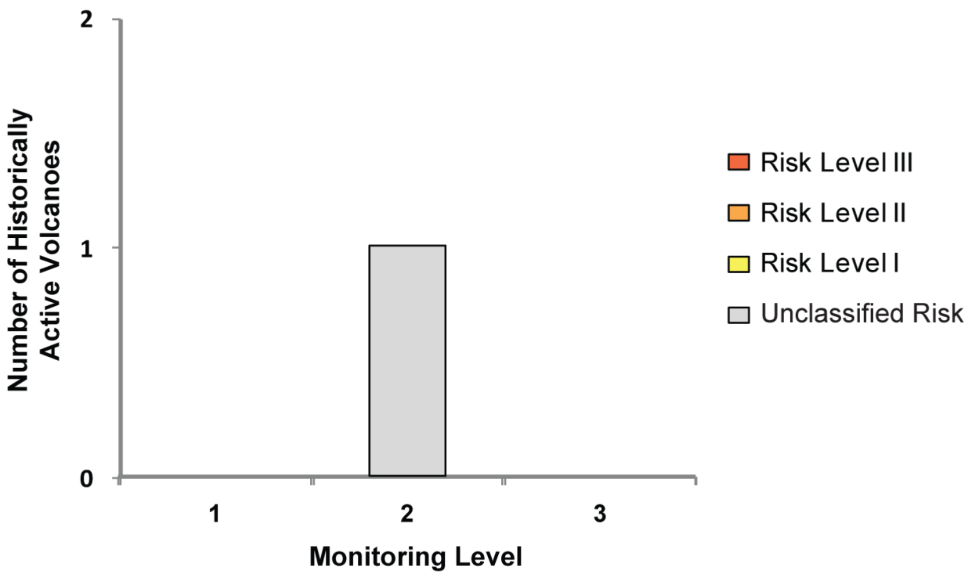


Figure 285: The monitoring and risk levels of the historically active volcanoes in Panama. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 15: South America

Figure 286: The distribution of Holocene volcanoes through the South America region. The capital cities of the constituent countries are shown.

Description

Region 15: South America comprises volcanoes throughout South America, from Colombia in the north to the tip of Chile in the south, and west to include the Galapagos Islands and Chilean islands in the Pacific Ocean. Six countries are represented here. All are included in this regional discussion, and individual profiles are provided.

Country	Number of volcanoes
Argentina	41
Bolivia	12
Chile	105
Colombia	15
Ecuador	35
Peru	17

Table 269: The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

197 Holocene volcanoes are located in South America. Most of these volcanoes are in Chile. Volcanism here is largely related to the subduction of the Nazca Plate beneath the South American Plate.

A range of volcano types are present, though most are stratovolcanoes. The rock composition varies from basaltic to rhyolitic, but is most commonly andesitic.

Along with ranges of volcano morphologies and rock types, a range of activity styles and eruption magnitudes are recorded throughout the Holocene, with eruptions ranging from VEI 0 to 6. About 72% of eruptions have been small, at VEI 0 to 2, however about 12% of eruptions have been large explosive VEI ≥4 events. The only countries in this region with no Holocene record of VEI ≥4 eruptions are Argentina and Bolivia, though pyroclastic flows are recorded in eruptions at volcanoes on the border of Chile-Argentina and Chile-Bolivia. Four VEI 6 eruptions are recorded here. The two most recent were the 1280 eruption of Quilotoa in Ecuador in which pyroclastic flows and lahars reached the Pacific, and the 1600 eruption of Huaynaputina, Peru, in which pyroclastic flows reached 13 km and lahars reached 120 km.

Seventy-six volcanoes have historical records of 672 eruptions, 95% of which were recorded through direct observations. Areas where the population is sparse have fewer observed events and therefore a less comprehensive record. 12% of historical events have included the production of pyroclastic flows and 15% resulted in lahars. 20% of historical eruptions produced lava flows. Many of South America's volcanoes are ice-capped, and as such lahars and explosive eruptions may be frequent.

Lives have been lost in 5% of historical eruptions. The eruption of Nevado del Ruiz in Colombia in 1985 resulted in the greatest loss of life, with over 20,000 fatalities due to lahars. These were produced during a moderate VEI 3 eruption, which led to the melting of the summit ice-cap. Most volcanoes (72%) have low proximal populations, and as such are considered relatively low risk. However, the hazard is poorly constrained at many volcanoes here, with no hazard and risk classification at about 80% of the region's volcanoes. Eight Risk Level III volcanoes are located in this region, all in Ecuador and Colombia.

Most historically active volcanoes are monitored in this region, with an apparent concentration of monitoring at the Risk Level II and III volcanoes. Chile, Colombia, Ecuador and Peru all have specific monitoring institutions.

Volcano facts

Number of Holocene volcanoes	197
Number of Pleistocene volcanoes with M≥4 eruptions	38
Number of volcanoes generating pyroclastic flows	45 (217 eruptions)
Number of volcanoes generating lahars	32 (126 eruptions)
Number of volcanoes generating lava flows	49 (194 eruptions)
Number of eruptions with fatalities	34
Number of fatalities attributed to eruptions	33,230
Largest recorded Pleistocene eruption	The 2.2 Ma M8 Cerro Galán Ignimbrite from Cerro Galán is the largest recorded Quaternary explosive eruption in this region.
Largest recorded Holocene eruption	The largest recorded Holocene eruption in LaMEVE in this region in the 800 BP Quilotoa eruption at M6.4.
Number of Holocene eruptions	976 confirmed Holocene eruptions
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	76
Number of historical eruptions	672

Number of volcanoes	Primary volcano type	Dominant rock type
13	Caldera(s)	Andesitic (5), Dacitic (5), Rhyolitic (3)
129	Large cone(s)	Andesitic (87), Basaltic (15), Dacitic (21), Trachytic/Andesitic (1), Unknown (5)
7	Lava dome(s)	Andesitic (1), Dacitic (4), Rhyolitic (1), Unknown (1)
18	Shield(s)	Andesitic (1), Basaltic (17)
28	Small cone(s)	Andesitic (13), Basaltic (11), Dacitic (1), Unknown (3)
1	Subglacial	Dacitic (1)
1	Submarine	Unknown (1)

Table 270: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	1
Large (> VEI 3)	50

Table 271: Average recurrence interval (years between eruptions) for small and large eruptions in South America.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 50 years.

Eruption Size

Eruptions are recorded through South America of VEI 0 to 6, representing a range of eruption styles from gentle effusive events to large explosive eruptions. VEI 2 events dominate the record, with over 50% of all Holocene eruptions classed as such. 12% of eruptions here are explosive at VEI≥4.

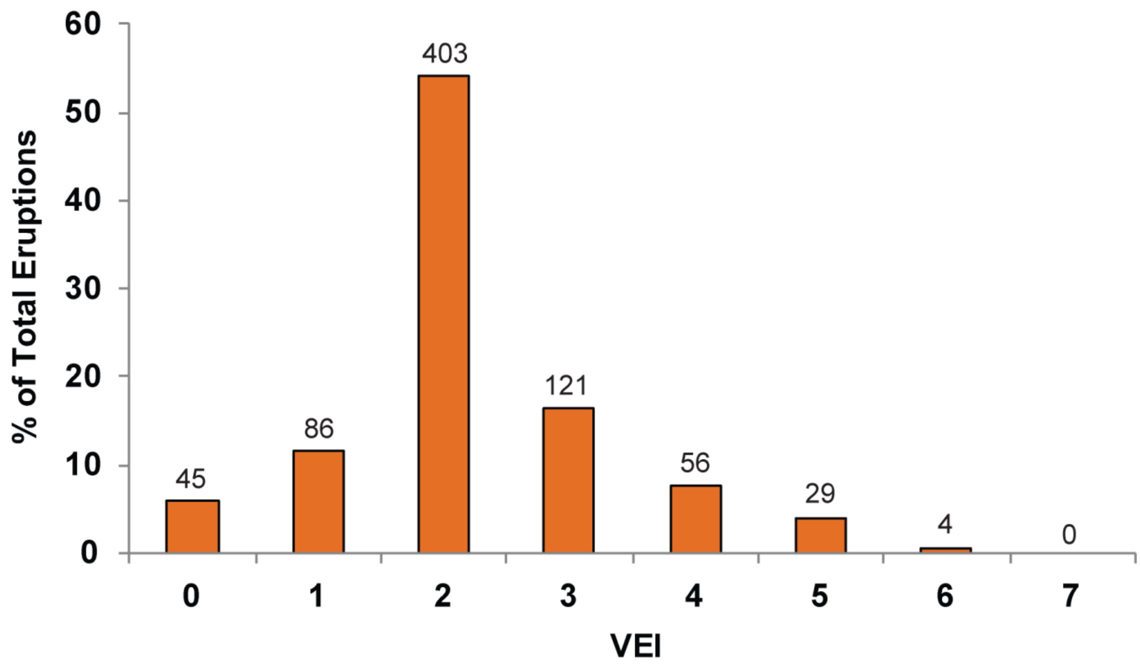


Figure 287: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 232 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	361,188,771
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,499 – 15,501
	(Mean 10,129)
Gross National Income (GNI) per capita (2005 PPP $)	4,444 – 15,347

	(Mean 10,060)
Human Development Index (HDI) (2012)	0.675 – 0.819 (Medium to Very High, Mean 0.746 High)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	1,252,806 (0.35 %)
Number (percentage) of people living within 30 km of a Holocene volcano	8,997,260 (2.49 %)
Number (percentage) of people living within 100 km of a Holocene volcano	35,346,223 (9.79 %)

Infrastructure Exposure

Number of airports within 100 km of a volcano	20
Number of ports within 100 km of a volcano	10
Total length of roads within 100 km of a volcano (km)	30,039
Total length of railroads within 100 km of a volcano (km)	3,118

CLASSIFIED	**Hazard III**		Azul, Cerro; Puyehue-Cordón Caulle; Osorno	Reventador; Sangay; Calbuco	Bravo, Cerro; Cayambe; Cotopaxi; Tungurahua	Nevado del Ruiz; Guagua Pichincha	Galeras; Atacazo	
	Hazard II		Fernandina; Yucamane; Láscar; Planchón-Peteroa; Chillán, Nevados de; Antuco; Copahue; Lonquimay; Llaima	Sabancaya; Ubinas; Villarrica	Tolima, Nevado del			
	Hazard I		Wolf; Negra, Sierra; Azul, Cerro; Guallatiri; Isluga; San Pedro; Huequi; Lautaro	Maipo	Puracé; Misti, El; Tupungatito; San José			
UNCLASSIFIED	**U – HHR**	Robinson Crusoe	Sumaco; Darwin; **Alcedo**; **Pinta**; **Marchena**; **Santiago**; Ticsani; **Irruputuncu**; Olca-Paruma; Putana; Llullaillaco; **Tinguiririca**; **Descabezado Grande**; Tromen; **Callaqui**; Quetrupillan; Huanquihue Group; **Mocho-Choshuenco**; Puntiagudo-Cordón Cenizos; Minchinmávida; Mentolat; **Hudson, Cerro**; **Arenales**; **Viedma**; **Reclus**; **Burney, Monte**; Fueguino	**Huaynaputina**; **Carrán-Los Venados**; **Chaitén**	**Huila, Nevado del**; **Doña Juana**; **Cumbal**; **Negro de Mayasquer, Cerro**; Antisana	Chacana		
	U- HR	Aliso	Ecuador; Taapaca; Parinacota; Socompa; **Ojos del Salado, Nevados**; Infiernillo; Longaví, Nevado de; Lanín; Antillanca Group; Cayutué-La Viguería; **Yanteles**; Corcovado; **Melimoyu**; Macá; Aguilera; Pali-Aike Volcanic Field	Soche; Huambo; Sollipulli; Caburgua-Huelemolle	Romeral; Chachimbiro; Chimborazo; Quimsachata; Andahua-Orcopampa	Santa Isabel; Machín; Azufral; Quilotoa	Cuicocha; Imbabura	Pululagua
	U-NHHR	San Félix; Unnamed; Blanca, Laguna	Genovesa; Auquihuato, Cerro; Sara Sara; Coropuna; Tutupaca; Casiri, Nevados; Tacora; Tambo Quemado; Tata Sabaya; Jayu Khota, Laguna; Nuevo Mundo; Pampa Luxsar; **Ollagüe**; Azufre, Cerro del; Sairecabur; Licancabur; Guayaques; Purico Complex; Colachi; Acamarachi; Overo, Cerro; **Chiliques**; Cordón de Puntas Negras; Miñiques; Tujle, Cerro; Caichinque; Tilocalar; Negrillar, El; Pular; Negrillar, La; Escorial; **Lastarria**; Cordón del Azufre; Bayo Gorbea, Cerro; Nevada, Sierra; Falso Azufre; Incahuasi, Nevado de; Solo, El; Copiapó; Tuzgle; Aracar; Unnamed; Antofagasta; Cóndor, El; Peinado; **Robledo**; Tipas; Palomo; Atuel, Caldera del; Risco Plateado; Calabozos; Maule, Laguna del; San Pedro-Pellado; Blancas, Lomas; Resago; Payún Matru; Domuyo; Cochiquito Volcanic Group; Puesto Cortaderas; Trolon; Mariñaqui, Laguna; **Tolguaca**; Tralihue; Pantojo, Cerro; Tronador; **Cuernos del Diablo**; Yate; Hornopirén; Apagado; Crater Basalt Volcanic Field; Palena Volcanic Group; Puyuhuapi; Cay; Río Murta	Petacas; Santa Cruz; San Cristóbal; Easter Island	Sotará; Illiniza; Chachani, Nevado; Nicholson, Cerro	Mojanda	Licto	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 272: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
1	7
5	6
8	5
23	4
18	3
137	2
5	1

Table 273: The number of volcanoes in South America classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
8	III
10	II
22	I
157	Unclassified

Table 274: The number of volcanoes in the South America region classified at each Risk Level.

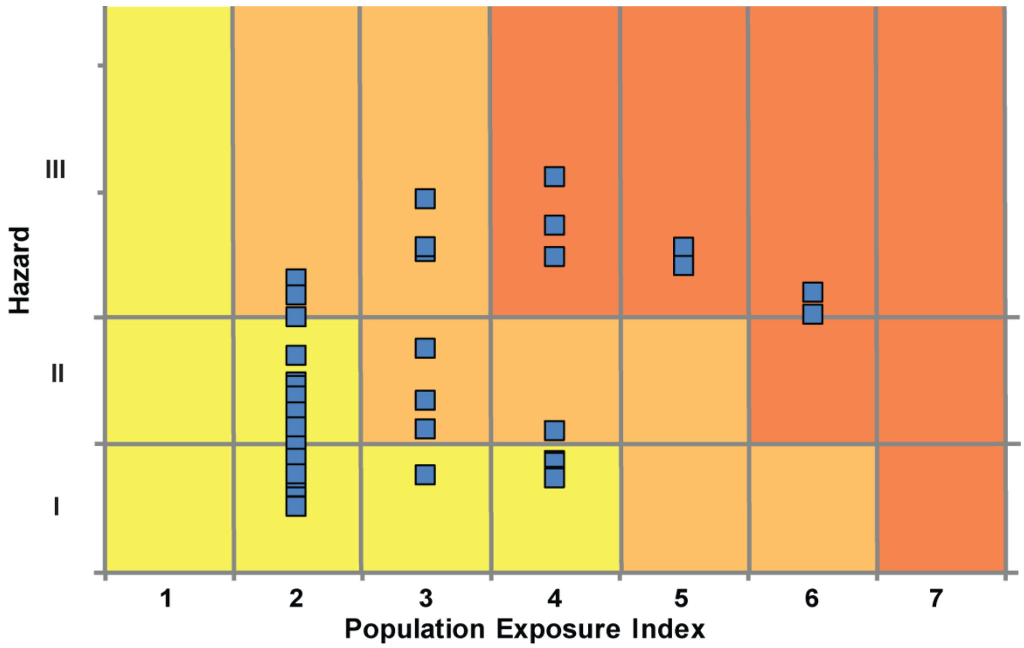


Figure 288: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

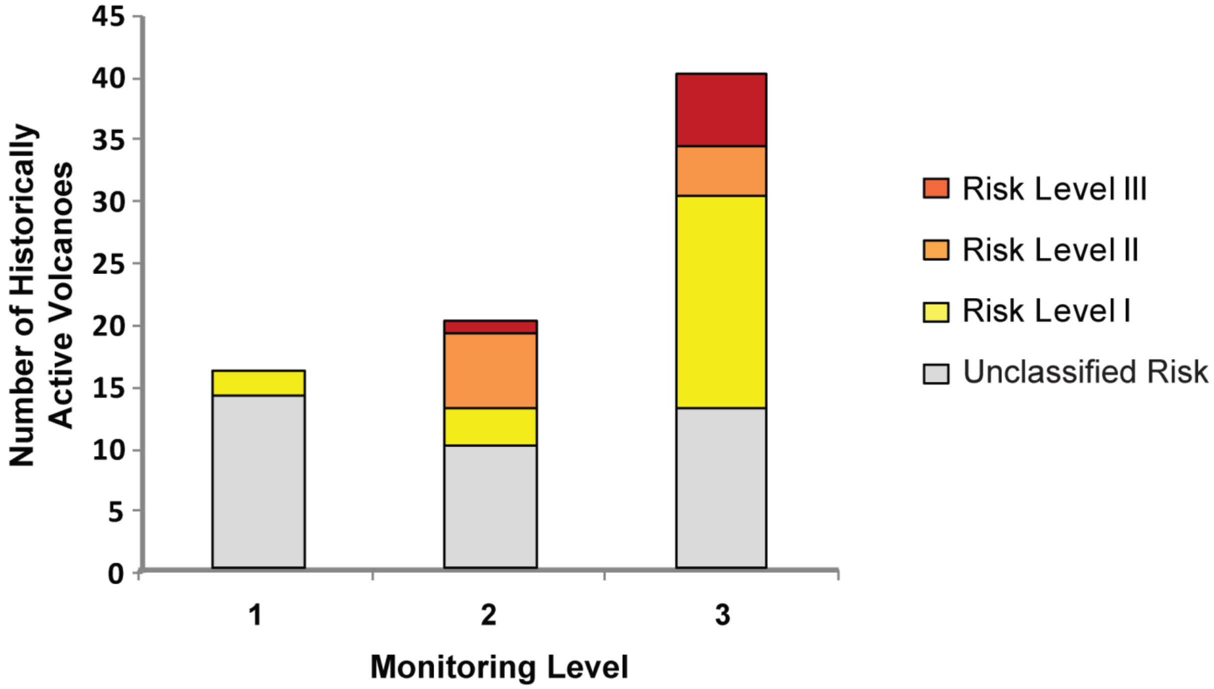


Figure 2892: The monitoring and risk levels of the historically active volcanoes in South America. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers

Argentina

Description

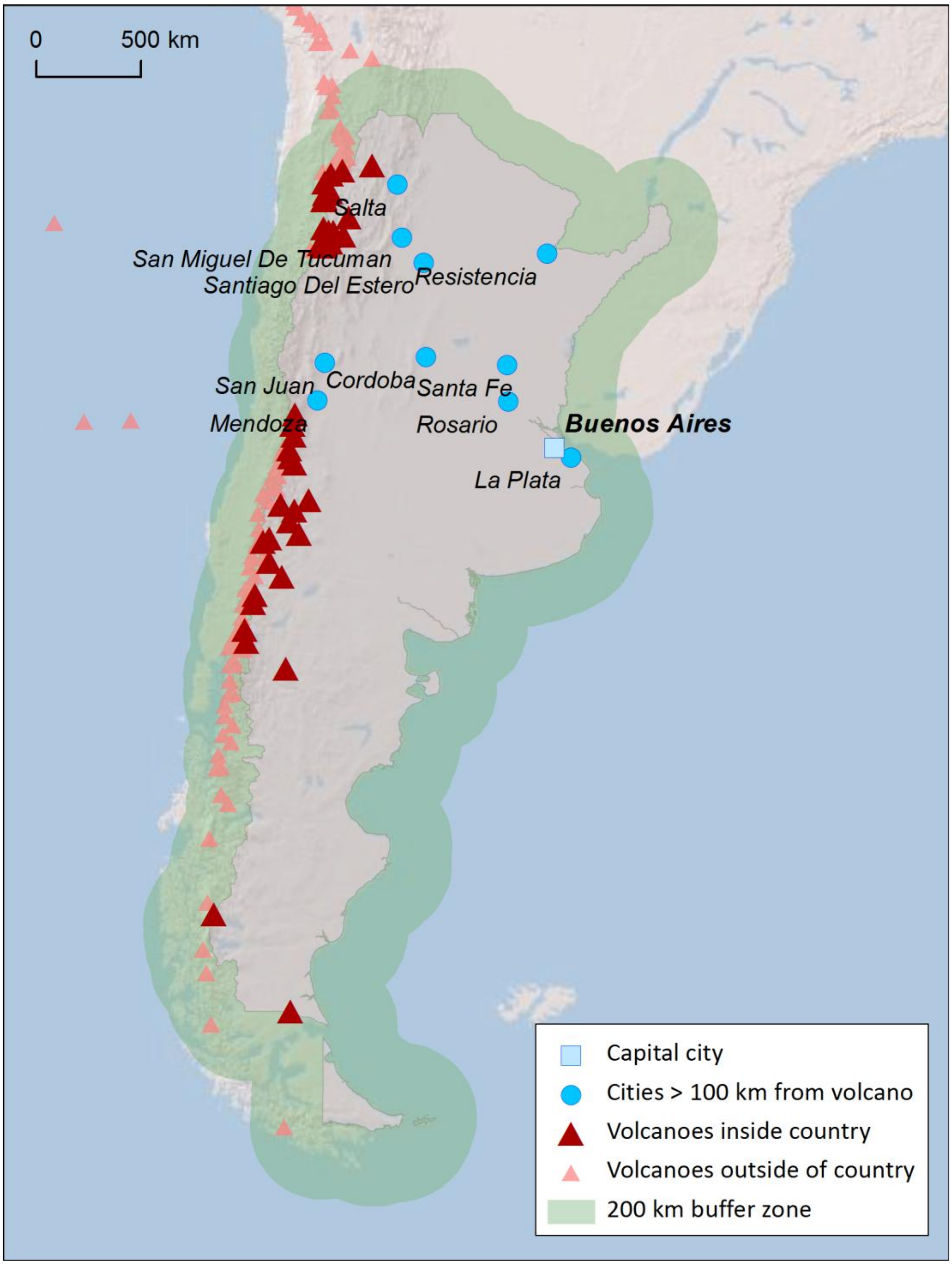


Figure 290: Location of Argentina's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Argentina.

Forty-one volcanoes are recorded in Argentina, including 19 on the border with Chile. Most of these volcanoes are located in the Andes, in western Argentina, dominantly in the centre and north of the country. Volcanism here is largely due to the subduction of the Nazca Plate beneath the South

American Plate. A range of volcano types are present here, though most are stratovolcanoes of dominantly andesitic composition.

Large explosive Pleistocene activity in recorded in Argentina, and 61 eruptions of Holocene age are recorded from 13 volcanoes. The remaining Holocene volcanoes have activity that is suspected to have occurred in the last 10,000 years. Of these Holocene eruptions, 47 are of historical age, occurring at 8 volcanoes. These eruptions ranged in size from VEI 0 to 3, indicating a prevalence of mild to moderate activity. Just one eruption, that of Copahue in 2000, has a recorded historical pyroclastic flow. During this event pyroclastic flows, scoria and ash fall occurred and evacuations were ordered with damage occurring to property.

Many of the most populous cities in Argentina are located far to the east of the volcanic chain, and the elevation of much of the Andes means that local populations are small. Indeed, less than 2,000 people live within 10 km of a Holocene volcano in the whole of Argentina, and less than 2% of the total population live within 100 km of one or more volcanoes (under 700,000). Although the hazard classification at many of Argentina's volcanoes is complicated by large uncertainties, the small local populations mean that these volcanoes are considered relatively low risk to proximal populations. However, the dominant wind direction is such that ash will commonly be distributed west to east across much of Argentina from eruptions in the far west of the country.

The Chilean volcanoes beyond the border are also very important to the hazard consideration in Argentina. Explosive eruptions of these volcanoes can produce ash clouds with ash dispersal throughout Argentina. Indeed, the dominant wind direction here is west to east, leading to ash fall in Argentina in most Chilean eruptions (Viramonte et al. 2001). There are many examples of this (Figure 290). For example, the 2008 eruption of Chaitén produced ash fall beyond the Argentine coast (Folch et al. 2008, Durant et al. 2012) and the 2011 eruption of Cordón Caulle resulted in significant ash fall across three Argentine provinces (Río Negro, Neugués and Chubut) (Collini et al. 2012). Both eruptions had negative impacts on farming (livestock) and agriculture, water transportation networks and air and ground transportation networks (Collini et al. 2012). See the profile for Chile for further discussion of the Chilean volcanoes.

Ash remobilisation can occur for years after an eruption due to wind and rain, and this can cause issues even in times of inactivity at the volcanoes, therefore ash distribution throughout the country must be understood, both from Argentine and Chilean volcanoes.

Authorities in Argentina, especially SEGEMAR (Servicio Geologico y Minero Argentino) and the Argentine Spacial Agency (CONAE) collaborate with the Servicio Nacional de Geologia y Mineria (SERNAGEOMIN) in Chile for monitoring of the border volcanoes. Seismic and deformation monitoring is in place as are cameras for visual observations. Alerts are released and evacuations ordered as unrest and eruption occurs. SERNAGEOMIN also monitor most volcanoes within Chile, releasing alerts which can be used in ash forecasts for Argentina.

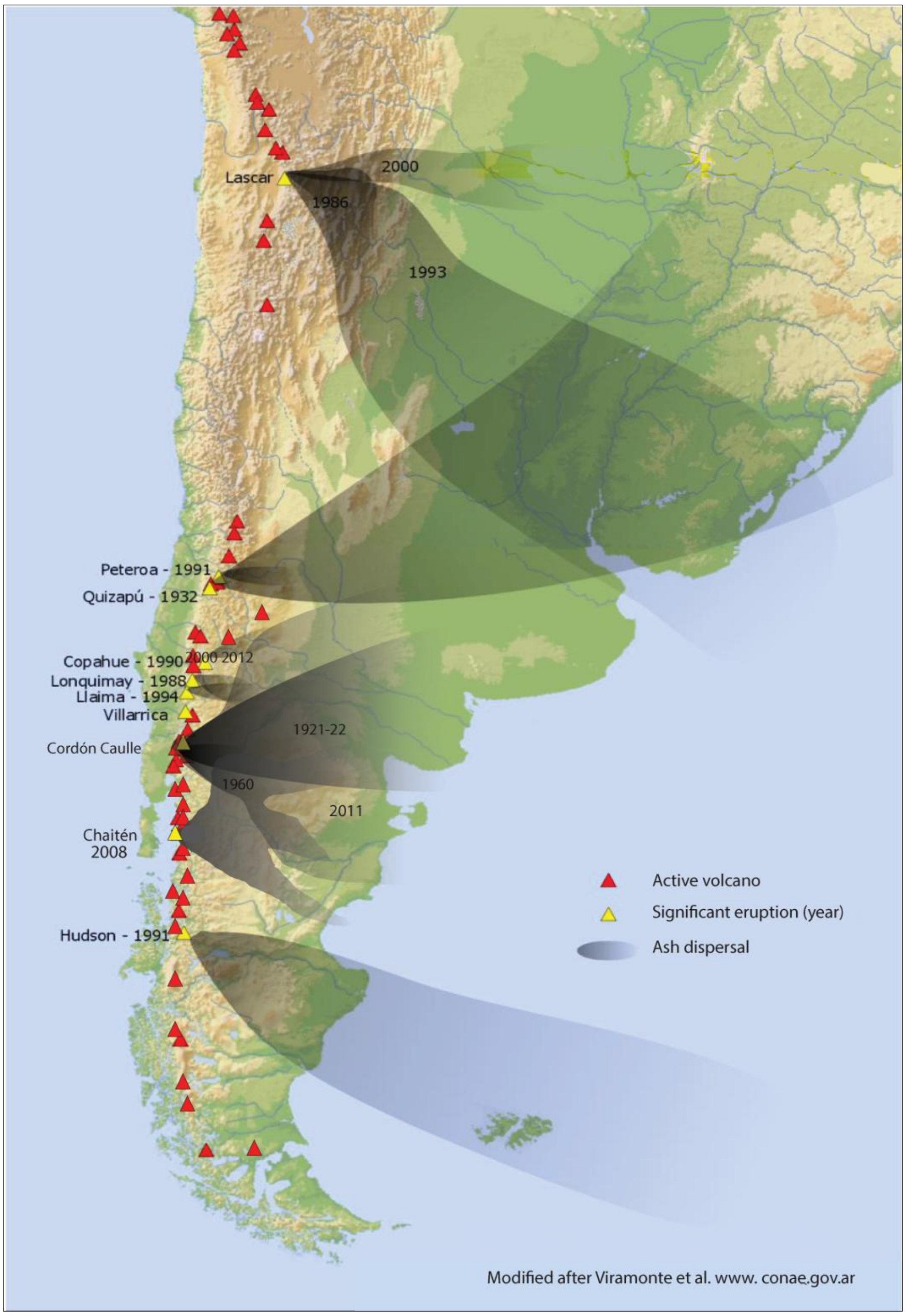


Figure 291: The active volcanoes of the southern Andes and ash dispersal across Argentina from recent eruptions of Chilean volcanoes. Modified after Viramonte et al. 2001.

References:

Collini, E., Soledad Osores, M., Folch, A. Viramonte, J.G., Villarosa, G. And Salmuni, G. (2012) Volcanic ash forecast during the June 2011 Cordon Caulle eruption. Natural Hazards, 66:2, 389-412.

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Folch, A., Jorba, O., & J. Viramonte. 2008. Volcanic Ash Forecast- Application to the May 2008 Chaitén Eruption. Natural Hazard and Earth System Sciences. 8: 927-940

Viramonte José G.,. Peralta Carlos M, Garrido Daniel, y Felpeto Alicia (2001). Uso de sensores remotos para la mitigación de efectos causados por erupciones volcánicas : Elaboración de mapas de Riesgo volcánico y alertas para la aeronavegación: Un caso de estudio. www.conae.gov.ar/WEB_Emergencias/Links_del_Cuerpo_Principal/Volcanes/Informe%20Riesgo%20Volcanico.htm

Volcano Facts

Number of Holocene volcanoes	41, inclusive of 19 on the border with Chile
Number of Pleistocene volcanoes with M≥4 eruptions	6, inclusive of 3 on the border with Chile
Number of volcanoes generating pyroclastic flows	4
Number of volcanoes generating lahars	2
Number of volcanoes generating lava flows	6
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	37 subduction zone, 4 intra-plate
Largest recorded Pleistocene eruption	The M8 eruption of the Cerro Galán Ignimbrite from Cerro Galán at 2.2 Ma.
Largest recorded Holocene eruption	The VEI 3 1751 AD eruption of Tromen volcano.
Number of Holocene eruptions	61 confirmed eruptions. 14 uncertain and 2 discredited eruptions.
Recorded Holocene VEI range	0 – 3 and unknown.
Number of historically active volcanoes	8
Number of historic eruptions	47

Number of volcanoes	Primary volcano type	Dominant rock type
3	Caldera(s)	Andesitic (2), Rhyolitic (1)
28	Large cone(s)	Andesitic (13), Basaltic (4), Dacitic (7), Unknown (4)
1	Lava dome(s)	Dacitic (1)
1	Shield(s)	Basaltic (1)
7	Small cone(s)	Andesitic (3), Basaltic (4)
1	Subglacial	Dacitic (1)

Table 275: The number of volcanoes in Argentina, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	41,117,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	15,501
Gross National Income (GNI) per capita (2005 PPP $)	15,347
Human Development Index (HDI) (2012)	0.811 (Very High)

Population Exposure

Capital city	Buenos Aires
Distance from capital city to nearest Holocene volcano	974.1 km
Total population (2011)	41,769,726
Number (percentage) of people living within 10 km of a Holocene volcano	1,809 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	26,905 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	618,387 (1.5%)

Ten largest cities, as measured by population, and populations:

Buenos Aires	13,076,300
Cordoba	1,428,214
Rosario	1,173,533
Mendoza	876,884
San Miguel De Tucuman	781,023
La Plata	694,167

Salta	512,686
Santa Fe	468,632
San Juan	447,048
Resistencia	387,158

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	4,638
Total length of railroads within 100 km of a volcano (km)	278

Volcanoes in Argentina occur along the western border of the country, on the border with Chile. Volcanoes here are located in three main groups, in the north, centre and south. Many of the border volcanoes here have 100 km radii which extend into Chile, and likewise the radii of Chilean volcanoes extend into western Argentina. The capital, Buenos Aires, lies in the east of the country at nearly 1000 km distance to the nearest Holocene volcano, and most of the largest cities in the country lie far east of the volcanic chain. Only the southernmost Palei-Aike volcano is located near the coast exposing ports and an airport here. An extensive road and rail network lies within the radii of the volcanoes throughout the country.

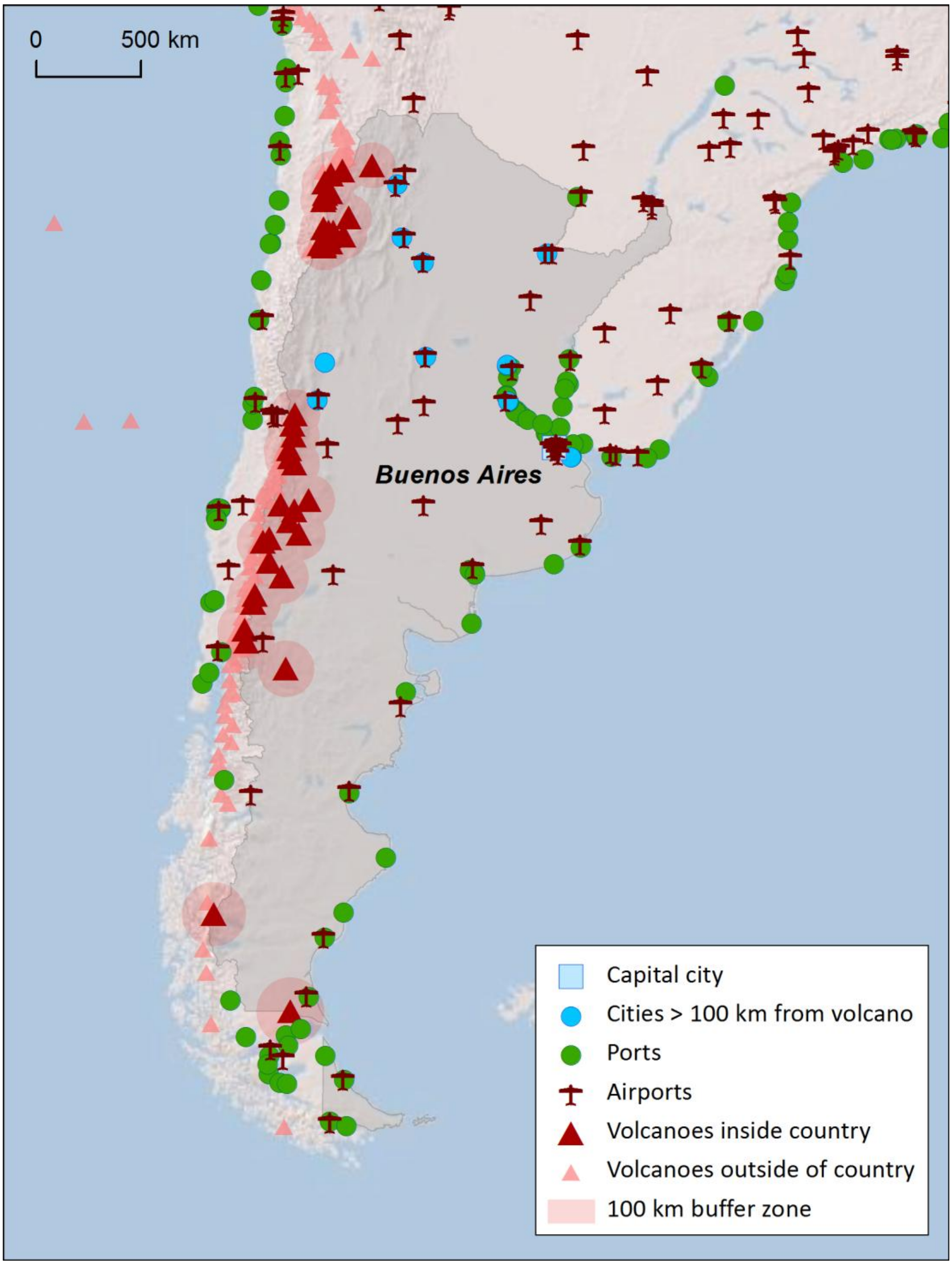

Figure 292: The location of Argentina's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of Argentina's volcanoes. Just four out of 41 have sufficient detail to define the hazard through the calculation of the VHI. These are classified at Hazard Levels I and II.

Of the unclassified volcanoes, 28 have no confirmed eruptions in the Holocene record. Nine have a Holocene record, including historical events at Llullaillaco, Tromen, Huanquihue Group and Viedma. The latter has recorded eruptions since 1900 AD. Unrest has been recorded at a further three unclassified volcanoes.

The PEI in Argentina is classed as low to moderate, with most volcanoes having a PEI of 2. All classified volcanoes here are classed at Risk Level I. Given the low population, all unclassified volcanoes would be classed at Risk Levels I and II, were the hazard known.

		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7
CLASSIFIED	**Hazard III**							
	Hazard II		Copahue					
	Hazard I			Maipo	Tupungatito; San José			
UNCLASSIFIED	**U – HHR**		Llullaillaco; Tromen; Huanquihue Group; **Viedma**					
	U- HR		Socompa; **Nevados Ojos del Salado**; Infiernillo; Lanín; Pali-Aike Volcanic Field					
	U- NHHR	Blanca, Laguna	Escorial; **Lastarria**; Cordón del Azufre; Bayo Gorbea, Cerro; Nevada, Sierra; Falso Azufre; Incahuasi, Nevado de; Solo, El; Tuzgle; Aracar; Unnamed; Antofagasta; Cóndor, El; Peinado; **Robledo**; Tipas; Atuel, Caldera del; Risco Plateado; Payún Matru; Domuyo; Cochiquito Volcanic Group; Puesto Cortaderas; Trolon; Tralihue; Pantojo, Cerro; Tronador; Crater Basalt Volcanic Field					

*Table 276: Identity of Argentina's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
San José	4	I
Tupungatito	4	I
Maipo	3	I
Copahue	2	I

Table 277: Classified volcanoes of Argentina ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 4 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

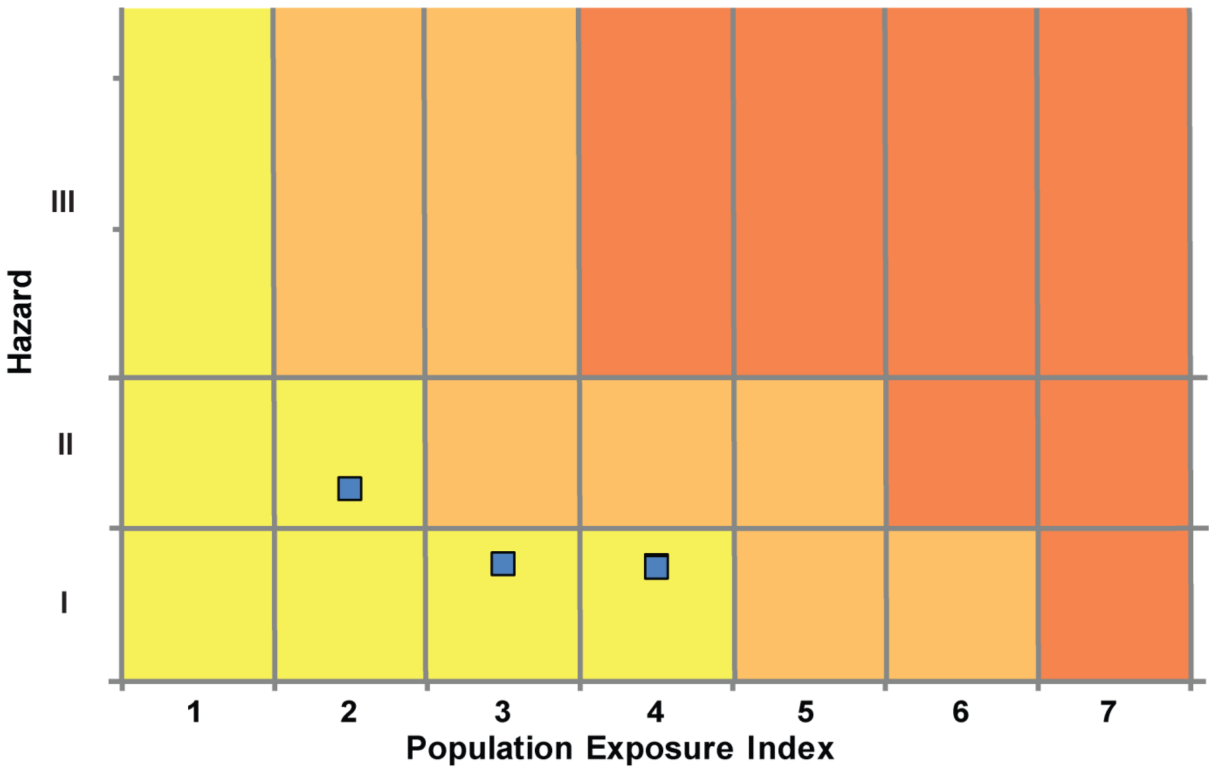

Figure 293: Distribution of Argentina's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Eight volcanoes in Argentina, inclusive of those on the border with Chile, have records of historical activity. Four are classified at Risk Level I (Tupungatito, San José, Maipo, Copahue) and four are unclassified with a PEI of 2 (Llullaillaco, Tromen, Huanquihue Group and Viedma). At the time of the writing of this report no information is available to indicate that dedicated ground-based monitoring is in place the four unclassified volcanoes. However, SERNAGEOMIN in Chile operate monitoring systems at four of the border volcanoes, with seismic and deformation monitoring at Copahue, Maipo, Tupungatito and San José.

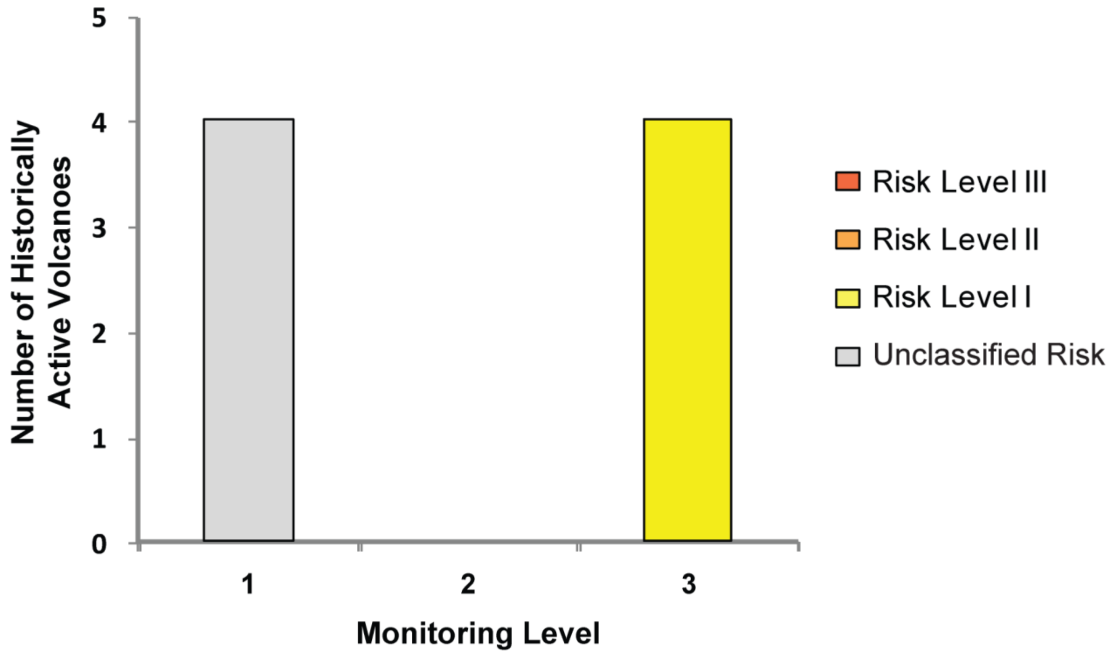

Figure 294: The monitoring and risk levels of the historically active volcanoes in Argentina. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Bolivia

Description

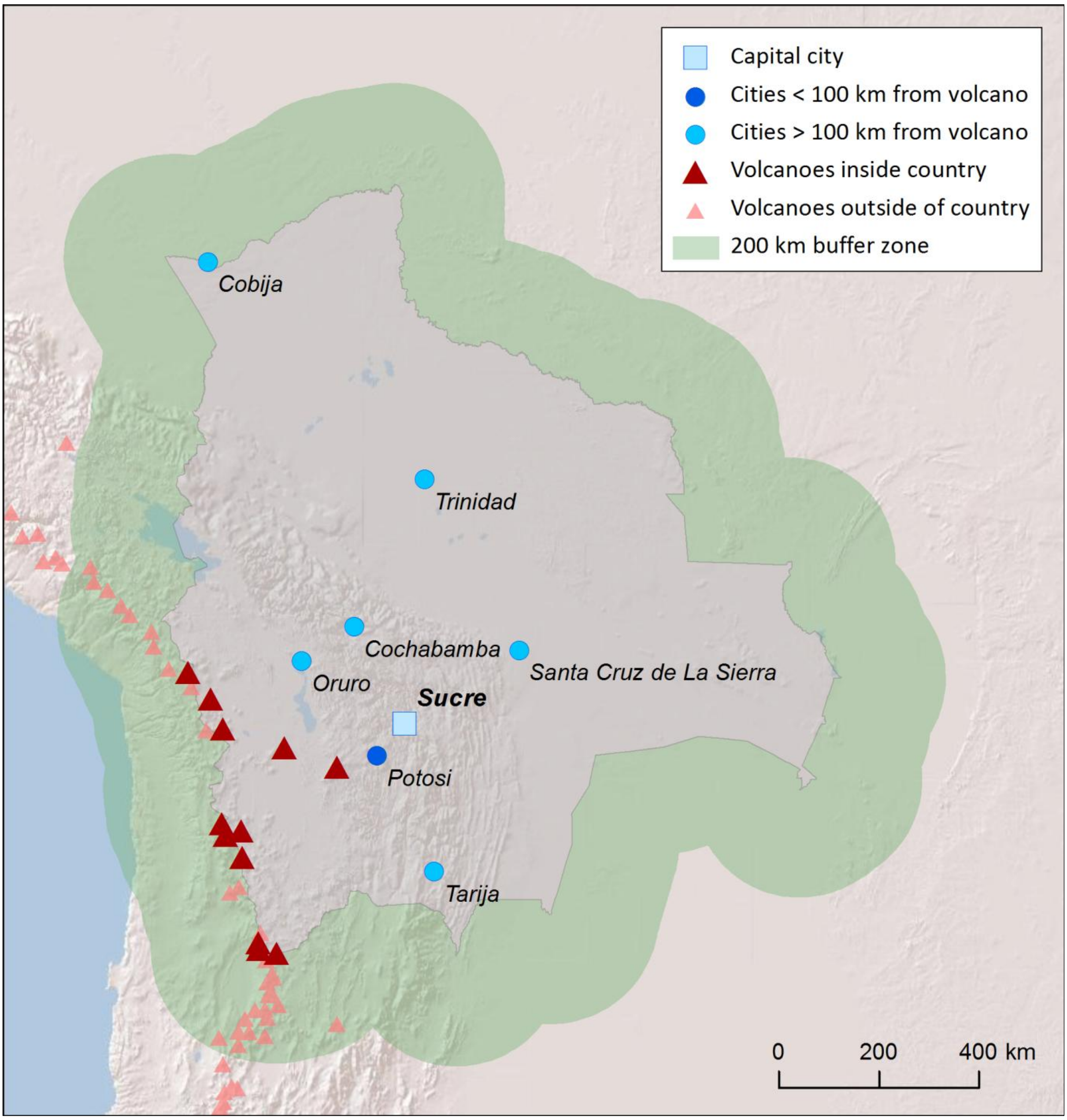

Figure 2953: Location of Bolivia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Bolivia.

Twelve Holocene volcanoes are located in Bolivia, including seven on the border with Chile. Volcanism here is largely due to the subduction of the Nazca Plate beneath the South American Plate. A variety of volcano forms have developed here, with stratovolcanoes being the most common. The composition varies from basaltic to rhyolitic, though andesitic compositions are most common.

Very large explosive eruptions are recorded back into the Pleistocene, but the Holocene record is sparse, with just seven confirmed eruptions. Two of these were recorded historically, in 1865 at

Olca-Paruma, and in 1995 and Irruputuncu. This latter eruption is the largest recorded in the Holocene, at just VEI 2.

The sparse nature of the eruptive record suggests that the hazard (the VHI) is poorly constrained however the volcanoes of Bolivia are remote, with the most populous cities located to the east. Only a small number of people live in close proximity to Holocene volcanoes in Bolivia, with about 3,000 in total within 10 km, and less than 500,000 within 100 km of these volcanoes. As such, current understanding suggests that these volcanoes are of relatively low risk.

There is no official monitoring institution in Bolivia, however SERNAGEOMIN in Chile monitors the border volcanoes. Two part-time scientists at the Universidad Mayor de San Andres undertaken volcanic research in Bolivia, and they advise that there are no current response protocols in place for developing unrest or eruption, largely due to the remote nature of the volcanoes. They suggest that infrastructure is at risk, with highways (the Oruro-Pisiga and Patacamaya-Tambo Quemado highway), railways (the Arica line) and an electricity generating station near Nuevo Mundo highlighted as being exposed.

Volcano Facts

Number of Holocene volcanoes	12, inclusive of 7 on the border with Chile
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M7.2 eruption of Laguna Colorado, at 1.9 Ma.
Largest recorded Holocene eruption	The VEI 2 eruption of Irruputuncu in 1995 AD.
Number of Holocene eruptions	7 confirmed eruptions. 2 uncertain eruptions.
Recorded Holocene VEI range	0 – 2
Number of historically active volcanoes	2
Number of historic eruptions	2

Number of volcanoes	Primary volcano type	Dominant rock type
1	Caldera(s)	Rhyolitic (1)
7	Large cone(s)	Andesitic (7)
2	Lava dome(s)	Dacitic (2)
2	Small cone(s)	Andesitic (1), Basaltic (1)

Table 278: The number of volcanoes in Bolivia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	10,523,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,499
Gross National Income (GNI) per capita (2005 PPP $)	4,444
Human Development Index (HDI) (2012)	0.675 (Medium)

Population Exposure

Capital city	Sucre
Distance from capital city to nearest Holocene volcano	152.1 km
Total population (2011)	10,118,683
Number (percentage) of people living within 10 km of a Holocene volcano	3,098 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	29,479 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	465,904 (4.6%)

Largest cities, as measured by population, and populations:

Santa Cruz de La Sierra	1,364,389
Cochabamba	900,414
La Paz	812,799
Sucre	224,838
Oruro	208,684
Tarija	159,269
Potosi	141,251
Trinidad	84,259
Cobija	26,585

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	908
Total length of railroads within 100 km of a volcano (km)	282

The volcanoes are situated in a chain along much of the western border of Bolivia and Chile. The 100 km radii of these volcanoes fully encompasses this border, and extends into Chile, Peru and Argentina. Similarly, the border volcanoes in these countries have 100 km radii which extend into Bolivia. The capital, Sucre, lies at over 150 km from the nearest Holocene volcano. The volcanoes in Bolivia are relatively remote, but with numerous small settlements and an extensive road network lying within their 100 km radii.

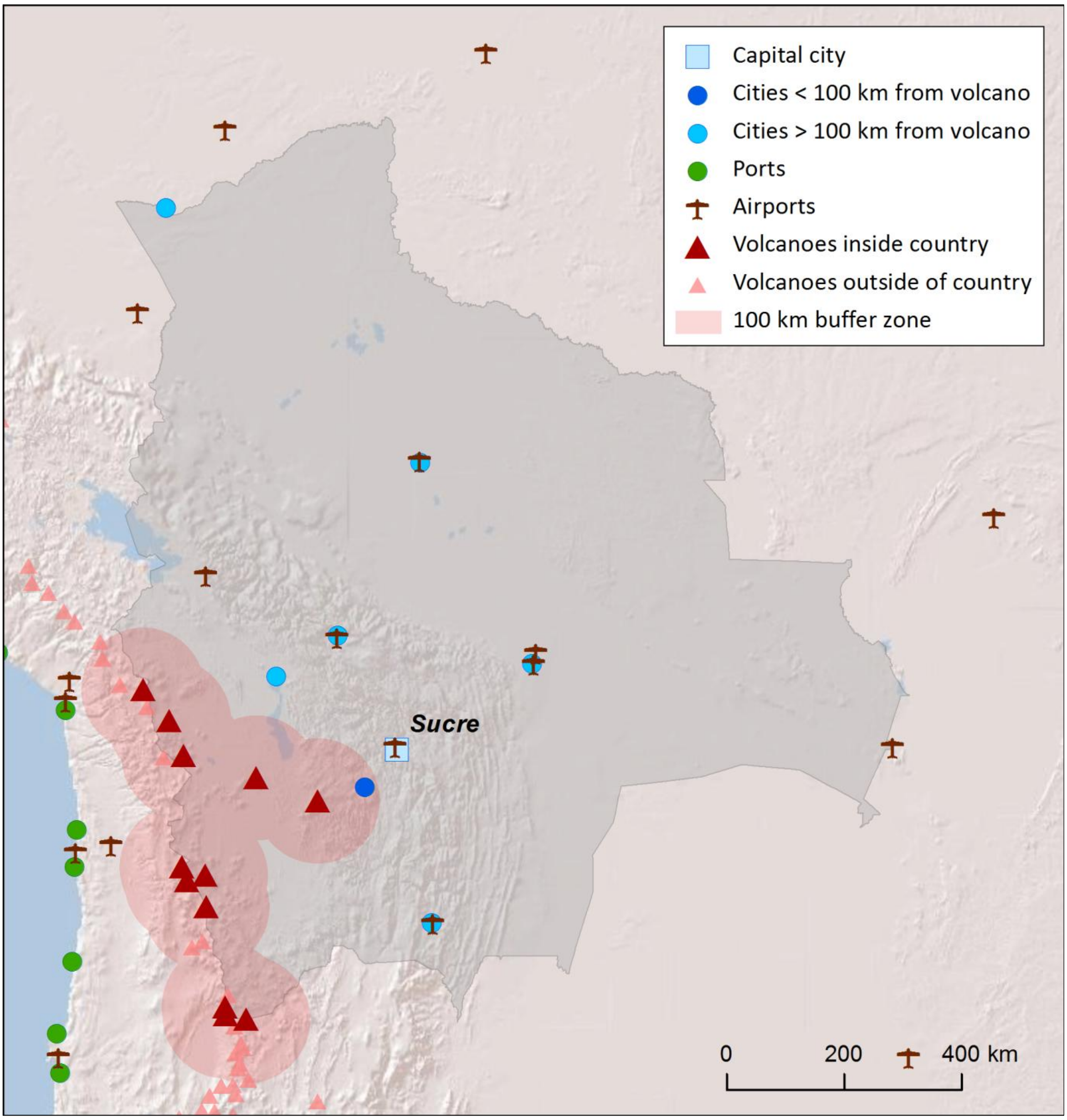

Figure 296: The location of Bolivia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The eruption records for Bolivia's volcanoes lack sufficient detail to determine hazard levels through the calculation of the VHI. These volcanoes are therefore unclassified. Indeed, of the twelve volcanoes here, just three have a confirmed Holocene record of eruptions, including historical activity at Irruputuncu and Olca-Paruma. Eruptions and unrest have been recorded at these two volcanoes since 1900 AD respectively.

The PEI at all Bolivian volcanoes is low at PEI 2. The absence of a hazard classification prevents determination of risk levels, however this low local populations suggests risk levels of I and II.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		**Irruputuncu**; **Olca-Paruma**					
	U- HR		Parinacota					
	U- NHHR		Tambo Quemado; Tata Sabaya; Jayu Khota, Laguna; Nuevo Mundo; Pampa Luxsar; **Ollagüe**; Sairecabur; Licancabur; Guayaques					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 279: Identity of Bolivia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Two volcanoes on the Bolivia-Chile border have historical records of activity. Monitoring undertaken by SERNAGEOMIN in Chile is described at both these volcanoes, however the details are unknown.

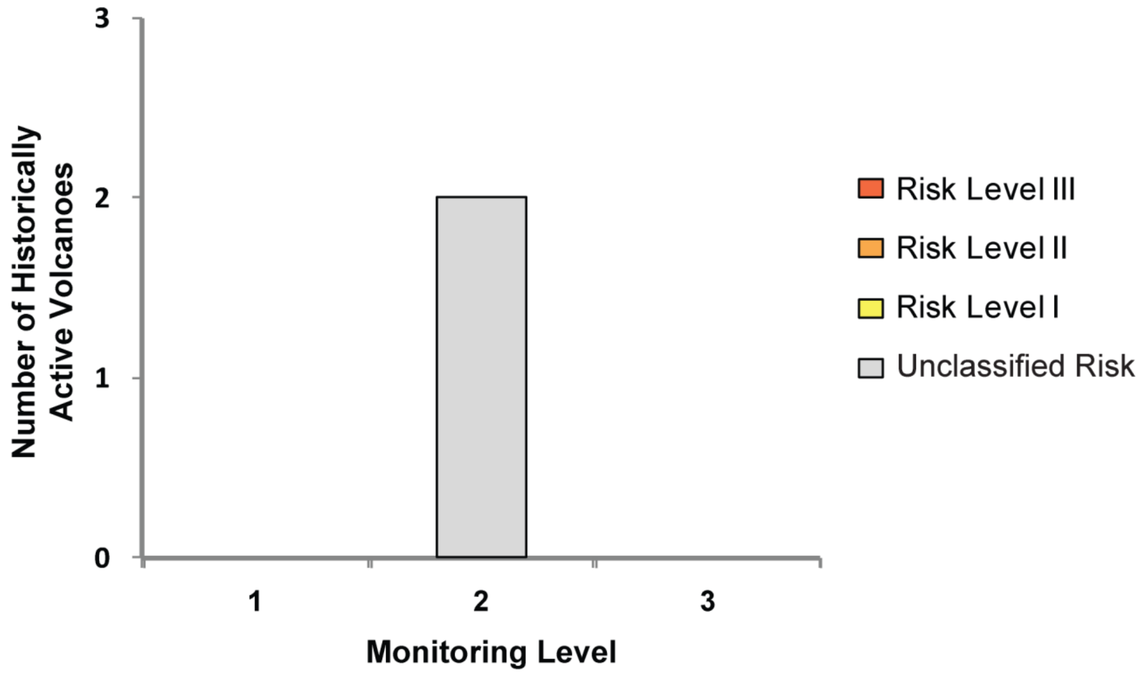

Figure 297: The monitoring and risk levels of the historically active volcanoes in Bolivia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Chile

Description

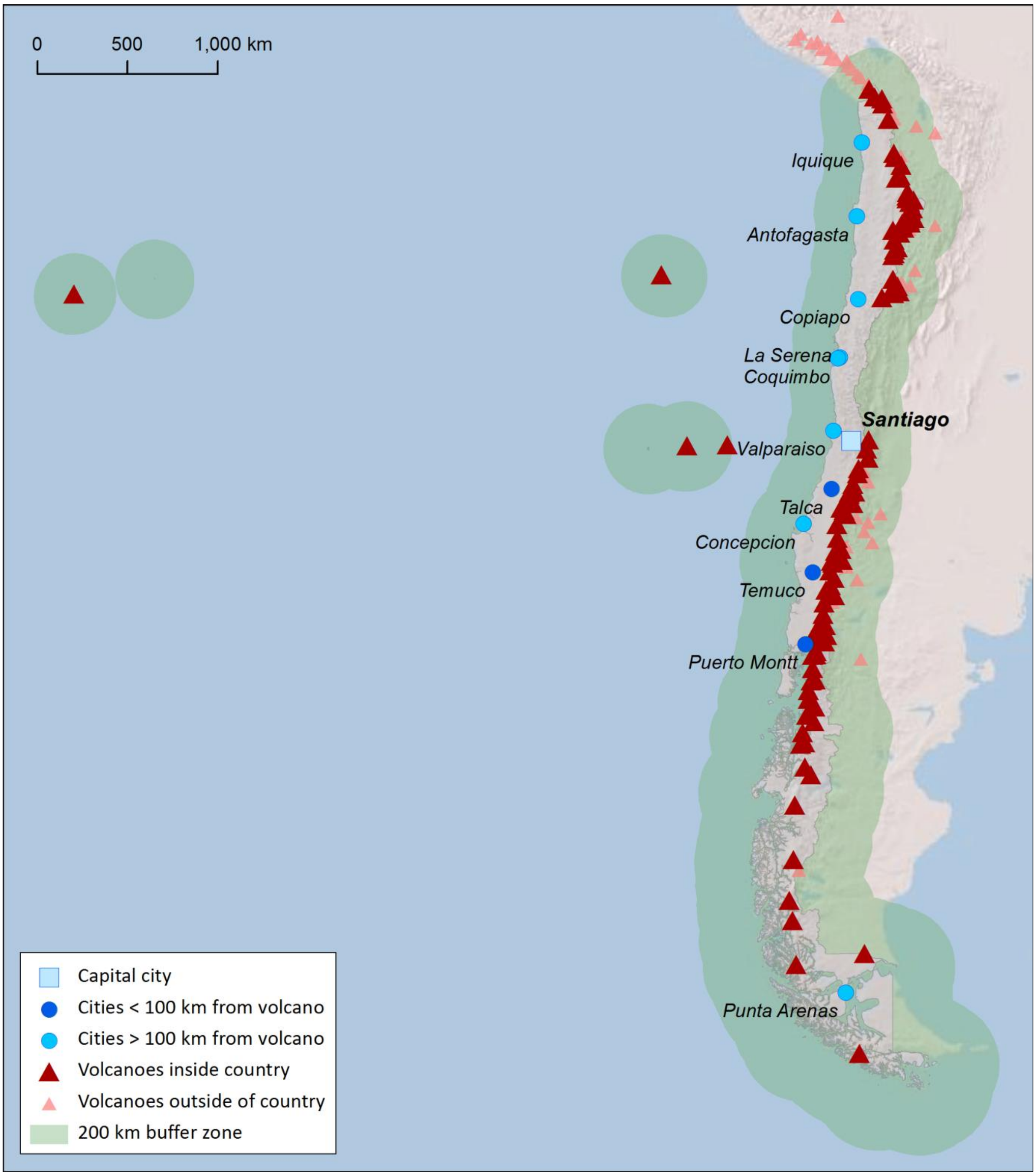

Figure 2984: Location of Chile's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Chile.

105 volcanoes are located in Chile, including nearly 30 on the borders within Argentina, Bolivia and Peru. Several groups of volcanoes are present, with scattered remote volcanoes in the very far south, a large concentration of volcanic centres south of Santiago and north of Copiapo, and Chilean islands in the Pacific Ocean. Volcanism through Chile is primarily due to the subduction of the Nazca Plate beneath the South American Plate and intra-plate processes in the Pacific.

A range of volcano types are present throughout Chile, though stratovolcanoes are most common with about three quarters of volcanoes here being classified as such. The rock type also varies, from basaltic to rhyolitic, however andesitic compositions are most common.

Large explosive Pleistocene activity is recorded in Chile at 20 volcanoes. The largest Pleistocene eruptions were of magnitude 7.4, with three eruptions of this size at Calabozos caldera about 150,000, 300,000 and 800,000 years ago. Holocene activity has occurred here and hot springs are still active within the caldera.

Holocene activity in Chile has included 476 confirmed eruptions from 56 volcanoes. The remaining volcanoes have activity of suspected Holocene age. Holocene activity has comprised a range of activity styles and sizes, with eruptions from VEI 0 to 6, though only about 5% of these were VEI ≥4.

Historically 40 volcanoes are recorded produced 357 eruptions. Of these, 8 were VEI ≥4, though pyroclastic flows are recorded in 16 eruptions. Lava flows have more commonly been recorded and 14% of eruptions have resulted in lahars. The largest historical eruption in Chile occurred at Cerro Azul in 1916. This VEI 5 eruption ejected 9.5 cubic kilometres of tephra and was one of the world's largest eruptions in the 20th century.

Only a small total population is situated within 10 km of one or more Holocene volcanoes in Chile, however this grows considerably at 30 km and to about 10.6 million at 100 km, accounting for about 63% of the population. Ten historic eruptions have resulted in loss of life, at Lonquimay, Llaima, Villarrica, Carran-Los Venados, Chaiten and Cerro Hudson.

The Red de Vigilancia Volcanic (Volcano monitoring network) and the Observatorio Volcanologico de Los Andes del Sur (OVDAS) are part of the Servicio Nacional de Geologia y Mineria (SERNAGEOMIN). This body is government funded, and was founded in 1996. The main objective of these groups is to establish monitoring systems and monitor the most dangerous volcanoes in Chile (based on the frequency of activity, proximity to population centres and vulnerability of public and private infrastructure) in order to provide information to the relevant authorities.

Monitoring is undertaken at many volcanoes using seismic networks, cameras, deformation and gas measurements. Success of the network has been proven in the eruption of Puyehue-Cordon Caulle and alerts at Hudson and Copahue. Resources and plans are available for responding to developing unrest and eruption at current un- or under-monitored volcanoes.

Scientific, technical and support staff are present at the monitoring institution, and about 20% of these have experience of responding to activity, however large amounts of data are gathered and further scientific experience and support is required for full analysis.

Regular technical meetings are held in the event of increased activity and an informal response protocol is followed, including alerting the regional VAAC. The Oficina Nacional de Emergencia del Ministerio del Interior y Seguridad Pública (ONEMI) coordinates emergency response. OVDAS communicates hazard assessments and alerts to ONEMI who use a civil protection alert system.

A relative threat ranking is produced by SERNAGEOMIN for the volcanoes of Chile. This is similar to the NVEWS method and VHI, using hazard indicators taken from the records and coupling these with exposure factors. The relative threat is the sum of the hazard x sum of exposure. This ranking system indicates that Villarrica and Llaima have the largest relative threat ranking, with these volcanoes being the most frequently active here with 126 historical eruptions between them coupled with large populations within 100 km.

A questionnaire was completed by SERNAGEOMIN as part of this study. This indicated that a number of volcano records in VOTW4.0 require updating, with some volcanoes considered Holocene age in VOTW4.0 but designated as Pleistocene age by SERNAGEOMIN. This highlights the value of close collaboration between the volcanological community to ensure up-to-date and sustainable data systems. Updates will be considered by the Smithsonian Institution.

See also:

SERNAGEOMIN: http://www.sernageomin.cl/volcan-observatorio.php

Volcano Facts

Number of Holocene volcanoes	105, inclusive of 19 on the border with Argentina, 7 on the border with Bolivia and 1 on the border with Peru
Number of Pleistocene volcanoes with M≥4 eruptions	20, inclusive of 3 on the border with Argentina
Number of volcanoes generating pyroclastic flows	19
Number of volcanoes generating lahars	13
Number of volcanoes generating lava flows	25
Number of fatalities caused by volcanic eruptions	?473
Tectonic setting	101 Subduction zone, 3 Intra-plate, 1 Rift zone
Largest recorded Pleistocene eruption	The Loma Seca Tuff, units S, V and L from Calabozos are all recorded at M7.4 at 150 ka, 300 ka and 800 ka respectively.
Largest recorded Holocene eruption	The M6.3 H1/T2 eruption from Cerro Hudson at 7710 BP.
Number of Holocene eruptions	476 confirmed eruptions. 74 uncertain and 9 discredited eruptions.
Recorded Holocene VEI range	0 – 6 and unknown.
Number of historically active volcanoes	40
Number of historic eruptions	357

Number of volcanoes	Primary volcano type	Dominant rock type
6	Caldera(s)	Andesitic (3), Dacitic (2), Rhyolitic (1)
78	Large cone(s)	Andesitic (51), Basaltic (12), Dacitic (12), Unknown (3)
2	Lava dome(s)	Andesitic (1), Dacitic (1)
3	Shield(s)	Basaltic (3)
15	Small cone(s)	Andesitic (5), Basaltic (7), Dacitic (1), Unknown (2)
1	Submarine	Unknown (1)

Table 280: The number of volcanoes in Chile, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	17,479,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	15,272
Gross National Income (GNI) per capita (2005 PPP $)	14,987
Human Development Index (HDI) (2012)	0.819 (Very High)

Population Exposure

Capital city	Santiago
Distance from capital city to nearest Holocene volcano	80.5 km
Total population (2011)	16,888,760
Number (percentage) of people living within 10 km of a Holocene volcano	21,030 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	208,768 (1.2%)
Number (percentage) of people living within 100 km of a Holocene volcano	10,623,259 (62.9%)

Ten largest cities, as measured by population, and populations:

Santiago	4,837,295
Antofagasta	309,832
Valparaiso	282,448
Temuco	238,129
Iquique	227,499
Concepcion	215,413

Talca	197,479
Puerto Montt	160,054
La Serena	154,521
Copiapo	129,280

Infrastructure Exposure

Number of airports within 100 km of a volcano	10
Number of ports within 100 km of a volcano	8
Total length of roads within 100 km of a volcano (km)	16,196
Total length of railroads within 100 km of a volcano (km)	2,139

The numerous volcanoes of Chile are located primarily along the country's eastern border with Argentina, Bolivia and Peru, and as such the 100 km radii of these volcanoes extend into these neighbouring countries. Similarly, volcanoes near the borders in these countries have radii extending into Chile, exposing the infrastructure here. Several volcanoes are situated in the Pacific off the coast of Chile. The capital, Santiago, lies within 100 km of the historically active Tupungatito and San José volcanoes, hence considerable critical infrastructure is exposed here. Being a relatively narrow stretch of land, much of southern Chile lies within 100 km of Holocene volcanoes, and many ports are exposed here. A very extensive road and rail network is exposed throughout the country, and many of the country's largest cities lie within 100 km.

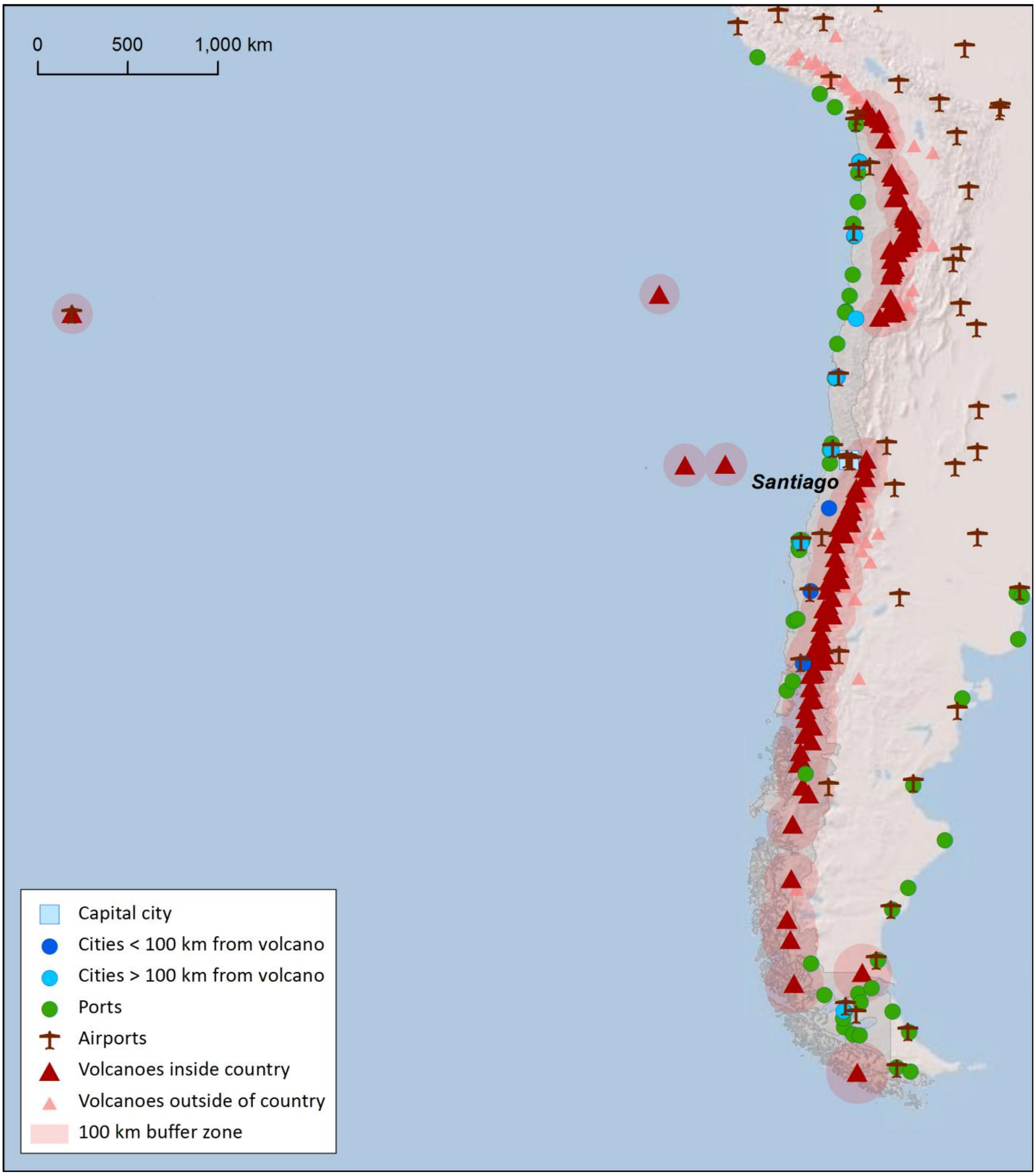

Figure 299: The location of Chile's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of Chile's volcanoes. About 20% of the volcanoes here (20 out of 105) have sufficient detail to define the hazard through the calculation of the VHI. These are classified across all three Hazard Levels, with most being classed at Hazard Levels I and II. Four volcanoes are classed at Hazard Level III, all with Holocene records of eruptions of VEI 4 and 5 and all with records of explosive volcanism accompanied by the production of pyroclastic flows.

Of the unclassified volcanoes, 49 have no records of confirmed Holocene age eruptions. 36 volcanoes have a Holocene eruption record, of which 20 have erupted historically (post 1500 AD) including eruptions since 1900 AD at 11 volcanoes. Unrest is described at nine unclassified volcanoes since 1900 AD. Seven unclassified volcanoes have Holocene records of large explosive VEI ≥4 eruptions.

The PEI ranges from 1 to 4, low to moderate, in Chile, with an overwhelming majority at PEI 2. The classified volcanoes are therefore Risk Levels of I and II. Although the risk levels cannot be defined for the unclassified volcanoes due to the absence of hazard details, these would all also be clased at Risk Level I and II.

CLASSIFIED	**Hazard III**		Cerro Azul; Puyehue-Cordón Caulle; Osorno	Calbuco				
	Hazard II		Láscar; Planchón-Peteroa; Chillán, Nevados de; Antuco; Copahue; Lonquimay; Llaima	Villarrica				
	Hazard I		Guallatiri; Isluga; San Pedro; Huequi; Lautaro	Maipo	Tupungatito; San José			
UNCLASSIFIED	**U – HHR**	Robinson Crusoe	**Irruputuncu**; **Olca-Paruma**; Putana; Llullaillaco; **Tinguiririca**; **Descabezado Grande**; **Callaqui**; Quetrupillan; **Mocho-Choshuenco**; Puntiagudo-Cordón Cenizos; Minchinmávida; Mentolat; **Cerro Hudson**; **Arenales**; **Reclus**; **Monte Burney**; Fueguino	**Carrán-Los Venados; Chaitén**				
	U- HR		Taapaca; Parinacota; Socompa; **Nevados Ojos del Salado**; Longaví, Nevado de; Lanín; Antillanca Group; Cayutué-La Viguería; **Yanteles**; Corcovado; **Melimoyu**; Macá; Aguilera; Pali-Aike Volcanic Field	Sollipulli; Caburgua-Huelemolle				
	U- NHHR	San Félix; Unnamed	Tacora; **Ollagüe**; Azufre, Cerro del; Sairecabur; Licancabur; Guayaques; Purico Complex; Colachi; Acamarachi; Overo, Cerro; **Chiliques**; Cordón de Puntas Negras; Miñiques; Tujle, Cerro; Caichinque; Tilocalar; Negrillar, El; Pular; Negrillar, La; Escorial; **Lastarria**; Cordón del Azufre; Bayo Gorbea, Cerro; Nevada, Sierra; Falso Azufre; Incahuasi, Nevado de; Solo, El; Copiapó; Palomo; Calabozos; Maule, Laguna del; San Pedro-Pellado; Blancas, Lomas; Resago; Mariñaqui, Laguna; **Tolguaca**; Pantojo, Cerro; Tronador; **Cuernos del Diablo**; Yate; Hornopirén; Apagado; Palena Volcanic Group; Puyuhuapi; Cay; Río Murta	Easter Island				
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 281: Identity of Chile's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Tupungatito	4	I
San José	4	I
Villarrica	3	II
Calbuco	3	II
Maipo	3	I
Azul, Cerro	2	II
Puyehue-Cordón Caulle	2	II
Osorno	2	II
Guallatiri	2	I
Isluga	2	I
San Pedro	2	I
Láscar	2	I
Planchón-Peteroa	2	I
Chillán, Nevados de	2	I
Antuco	2	I
Copahue	2	I
Lonquimay	2	I
Llaima	2	I
Huequi	2	I
Lautaro	2	I

Table 282: Classified volcanoes of Chile ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 15 volcanoes; Risk Level II – 5 volcanoes; Risk Level III – 0 volcanoes.

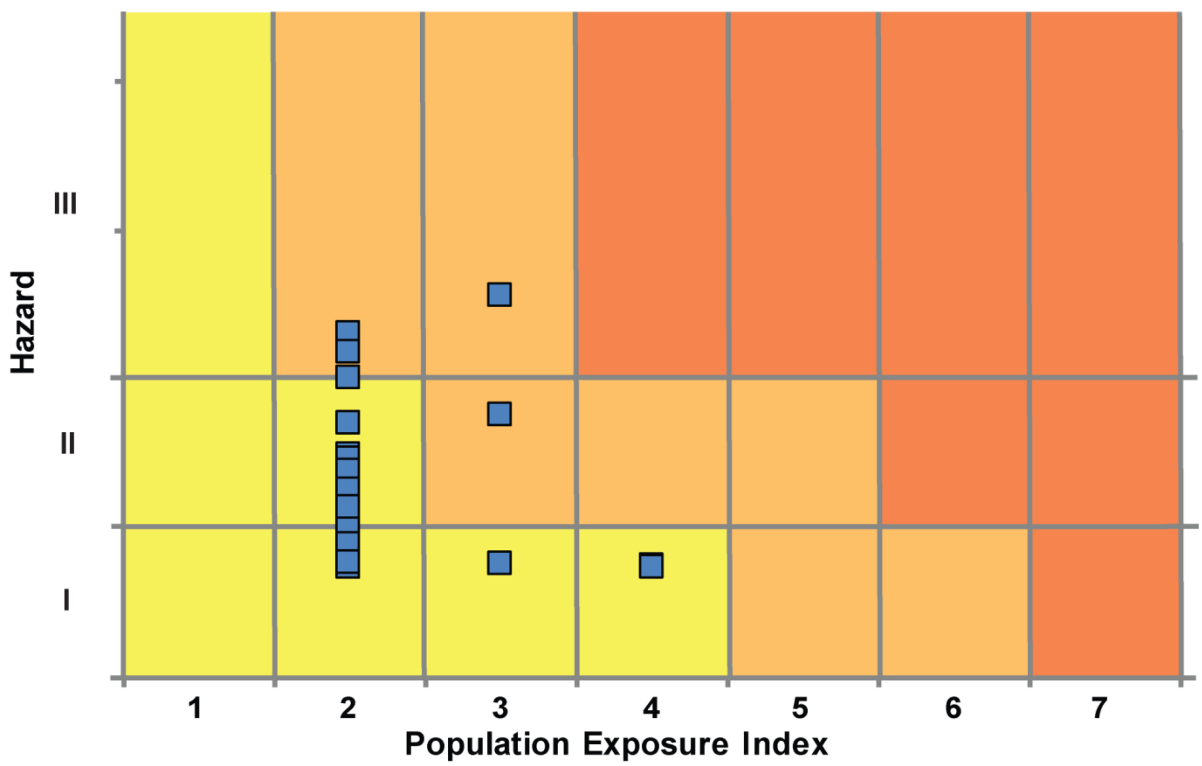

Figure 300: Distribution of Chile's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Forty volcanoes have records of historical activity in Chile. These volcanoes are primarily classed at Risk level I. All Risk Level II historical volcanoes are monitored by SERNAGEOMIN using seismic stations as a minimum. Many volcanoes also have deformation monitoring.

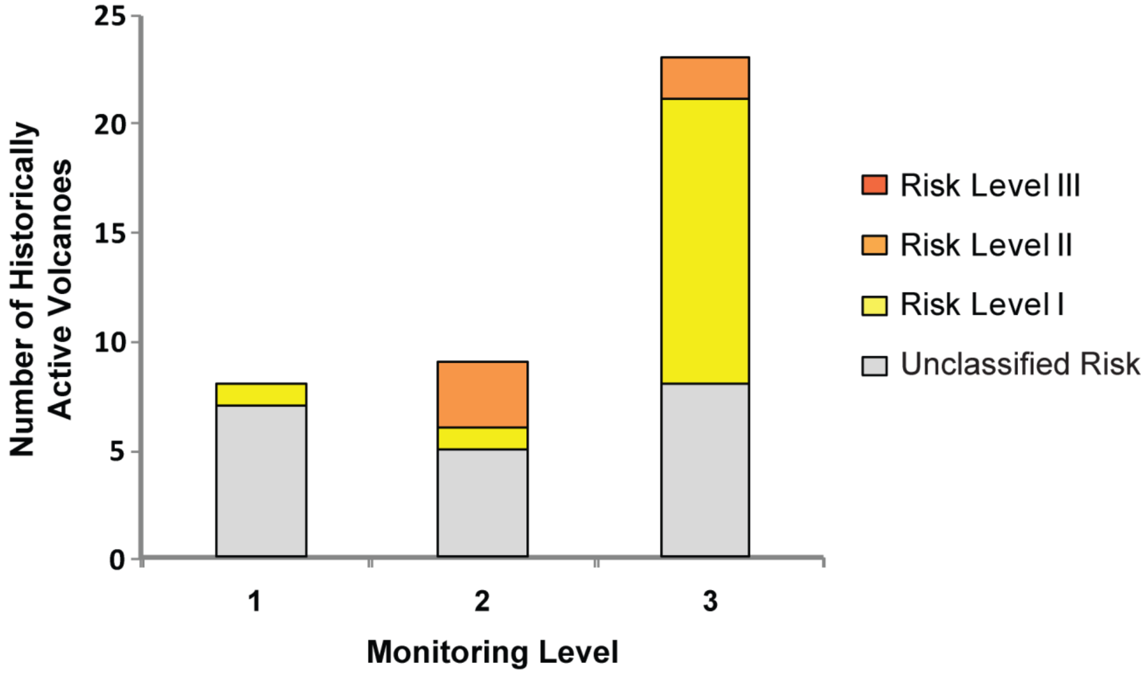

Figure 301: The monitoring and risk levels of the historically active volcanoes in Chile. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Colombia

Description

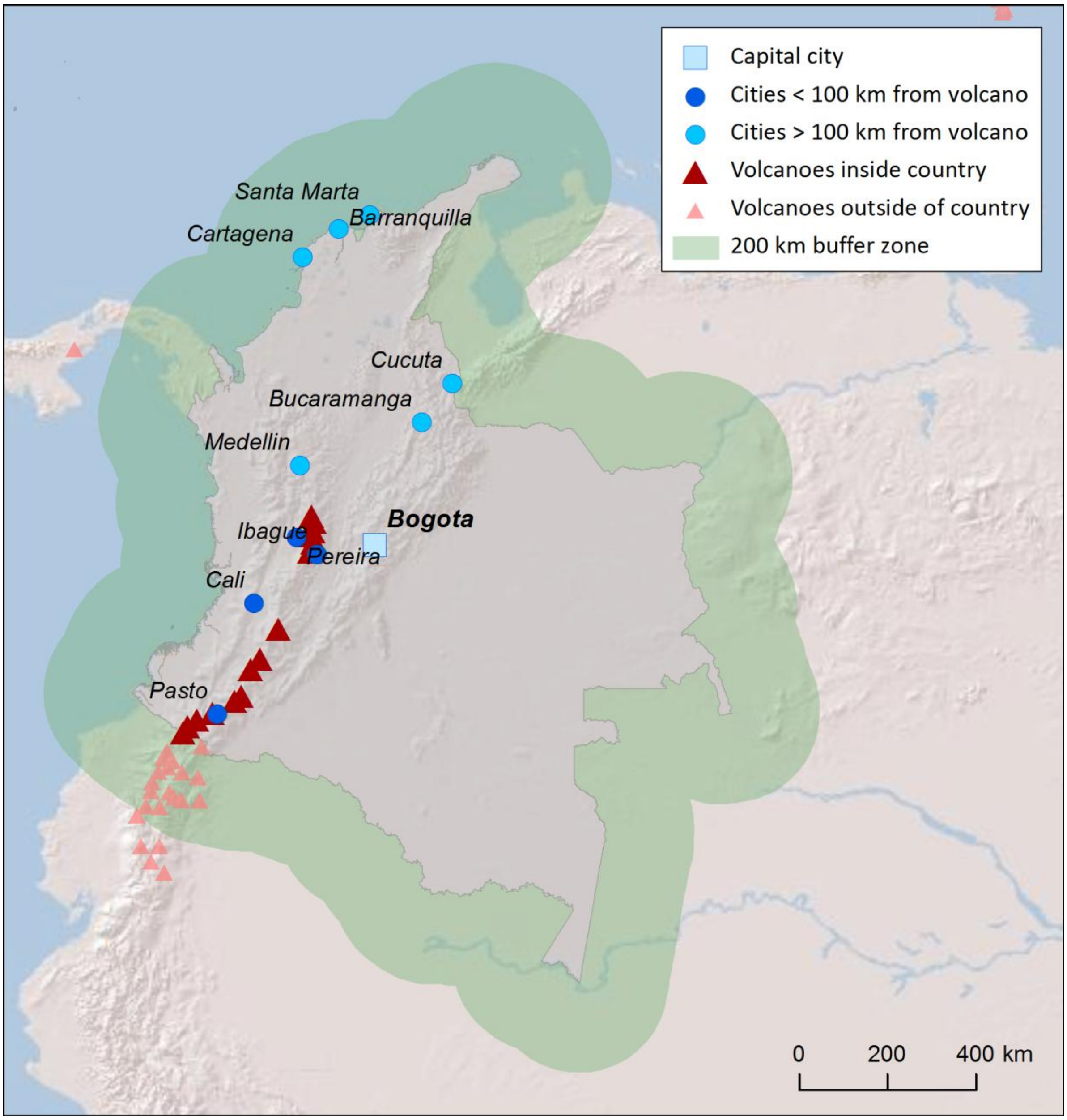

Figure 302: Location of Colombia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Colombia.

Fifteen Holocene volcanoes are distributed through the northern Andes in western Colombia to the Ecuador border, paralleling the Pacific coastline. These volcanoes are related to the subduction of the Nazca Plate beneath the South American Plate.

All Holocene volcanoes in Colombia form edifices typically associated with explosive-type activity, including stratovolcanoes and complex volcanoes, with the exception of the Petacas lava dome and Santa Isabel shield. The Colombian volcanoes are dominantly andesitic in composition. The explosive record continues into the Pleistocene, with three Colombian volcanoes hosting M/VEI ≥4 eruptions in this period.

125 confirmed eruptions are recorded in the Holocene, at VEI 1 to 5, indicating a range of activity from mild to strongly explosive. Eight volcanoes have a Holocene record of producing pyroclastic flows, and six are associated with lahars. Nine of the Colombian volcanoes have 79 eruptions recorded in historical times.

Many of Colombia's most populous cities are located on or towards the northern coast, away from volcanoes, however the cities of Cali, Ibague, Pasto and Pereira lie within 100 km of one or more Holocene volcanoes, with the latter three over-looked by Machin, Galeras and the Ruiz-Tolima chain. Numerous eruptions of Nevado del Ruiz, Nevado del Huila, Puracé and Galeras have resulted in evacuations and property damage. Fatalities are recorded in nine eruptions of these volcanoes and Doña Juana.

The assessment of hazard is complicated by sparse eruptive histories at over half of Colombia's volcanoes, resulting in Hazard Levels with large associated uncertainties hence just five volcanoes have a hazard level classified here. Nevado del Ruiz, Galeras and Cerro Bravo are classed with the highest hazard in Colombia based on detailed eruptive histories. Coupled with the high proximal population, these volcanoes are classed at Risk Level III.

Both Galeras and Nevado del Ruiz have caused loss of life. Machín has not caused any fatalities but has shown recent unrest, and its geological record indicates the potential for violent and destructive explosive eruptions. In 1993, a sudden intense but small magnitude explosive eruption of Galeras killed nine people, including six volcanologists who were in the inner crater or on its rim. A far larger disaster, the largest in South America's history, was the 1985 eruption of Nevado del Ruiz. Though only VEI 3, the eruption generated pyroclastic flows that melted the volcano's glacier cap and caused lahars. The mudflows descended the western flanks, flowing along the Río Lagunillas valley. The town of Armero, located on the banks of Río Lagunillas 48 km from the volcano, was completely buried. Though the death toll is uncertain, it is estimated that 21,000 of the 29,000 residents of Armero were killed, along with others elsewhere bringing the total loss of life to between 23,000 and 26,000.

Further eruptions with human impacts have occurred very recently at Galeras volcano. An eruption starting on 25th August 2010 spread ash as far as 30 km to the northwest; 7,000 people were advised to evacuate though few left their homes. Activity did not increase after this until January 2011.

Eruptions at a number of the northernmost volcanoes in Ecuador may directly affect Colombia as they lie within 100 km of the border. Similarly, Galeras, Cumbal and Azufral lie within 100 km of Ecuador.

Following the 1985 Nevado del Ruiz tragedy, the Colombian Government took steps to strengthen the monitoring and response mechanisms for Colombian volcanoes. These measures included making INGEOMINAS responsible for the monitoring of volcanoes and provision of scientific advice.

The Servicio Geologico Colombiano (INGEOMINAS) operate three volcano observatories in Colombia: Observatorio Pasto (responsible for Galeras, Cumbal, Chiles, Cerro Negro, Las Animas, Doňa Juana and Azufral); Observatorio Manizales (responsible for Nevado del Ruiz, Cerro Machin, Cerro Bravo, Nevado Santa Isabel, and Nevado Tolima); and Observatorio Popayan (responsible for Nevado del Huila, Sotará and Puracé). INGEOMINAS operate a monitoring network at Colombia's active volcanoes and the status of the volcanoes is communicated publically and is available online.

See also:

INGEOMINAS - http://www.sgc.gov.co/

Volcano Facts

Number of Holocene volcanoes	15, inclusive of one on the border with Ecuador
Number of Pleistocene volcanoes with M≥4 eruptions	3
Number of volcanoes generating pyroclastic flows	8
Number of volcanoes generating lahars	6
Number of volcanoes generating lava flows	3
Number of fatalities caused by volcanic eruptions	?25,567
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The El Boqueron Ancestral caldera collapse eruption of 580 ka at Nevado del Tolima and the 560 ka Coba Negra caldera forming eruption of Galeras are both recorded at M6.2.
Largest recorded Holocene eruption	The M5.5 R8 eruption of Nevado del Ruiz at 2.8 ka.
Number of Holocene eruptions	125 confirmed eruptions. 10 uncertain eruptions.
Recorded Holocene VEI range	1 – 5 and unknown.
Number of historically active volcanoes	9
Number of historic eruptions	79

Number of volcanoes	Primary volcano type	Dominant rock type
13	Large cone(s)	Andesitic (9), Dacitic (4)
1	Lava dome(s)	Unknown (1)
1	Shield(s)	Andesitic (1)

Table 283: The number of volcanoes in Colombia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	47,783,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	8,861
Gross National Income (GNI) per capita (2005 PPP $)	8,711
Human Development Index (HDI) (2012)	0.719 (High)

Population Exposure

Capital city	Bogatá
Distance from capital city to nearest Holocene volcano	138.6 km
Total population (2011)	44,725,543
Number (percentage) of people living within 10 km of a Holocene volcano	451,010 (1%)
Number (percentage) of people living within 30 km of a Holocene volcano	3,236,251(7.2%)
Number (percentage) of people living within 100 km of a Holocene volcano	13,408,843 (30%)

Ten largest cities, as measured by population, and populations:

Bogota	7,102,602
Cali	2,392,877
Medellin	1,999,979
Barranquilla	1,380,425
Cartagena	952,024
Cucuta	721,398
Bucaramanga	571,820
Pereira	440,118
Santa Marta	431,781
Ibague	421,685

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	3,159
Total length of railroads within 100 km of a volcano (km)	420

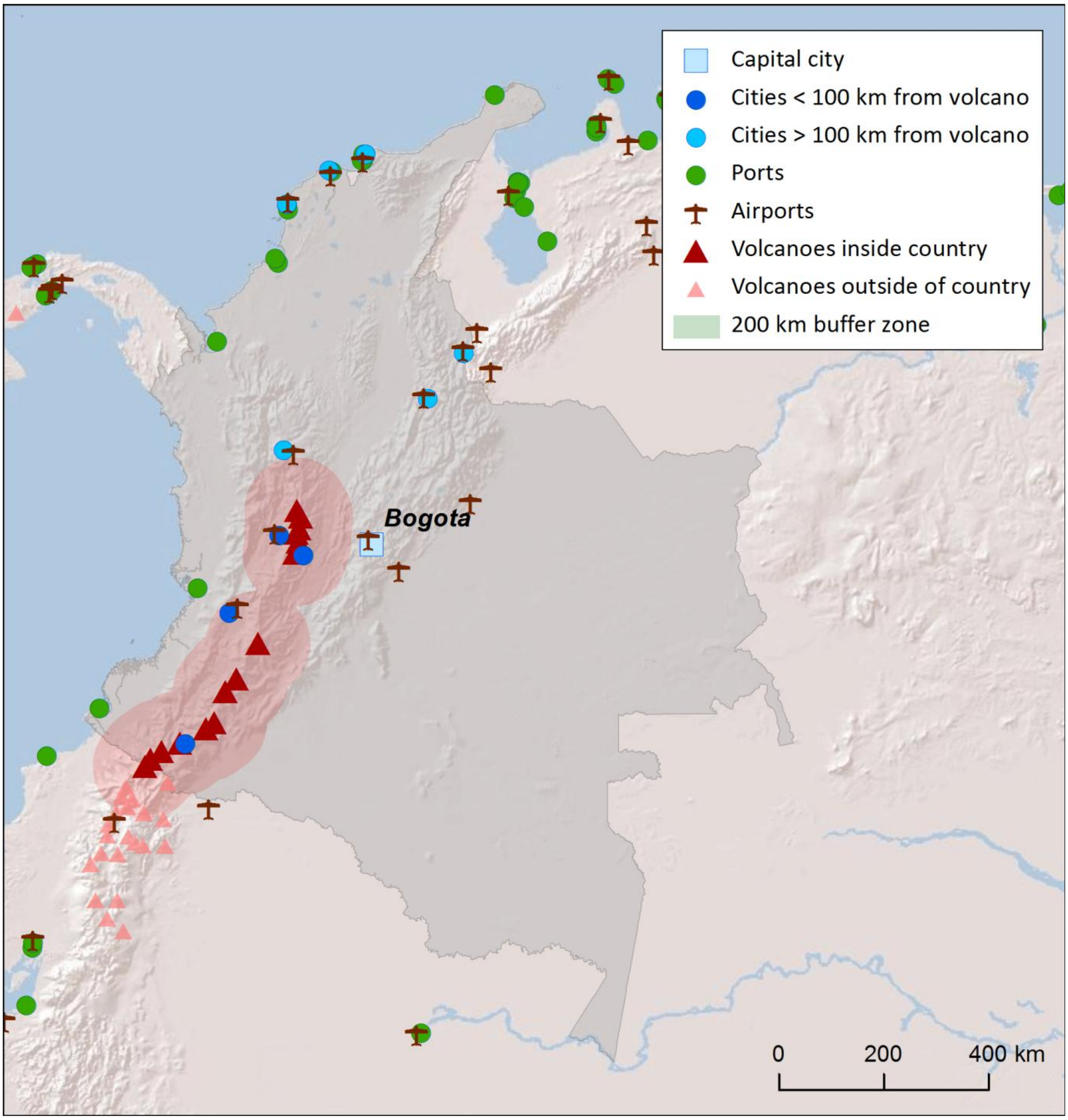

Figure 303: The location of Colombia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The volcanoes in Colombia are located in the west of the country from the border with Ecuador to just north of the capital, Bogata. The southernmost volcanoes, Galeras, Cumbal and Azufral lie close to the Ecuador border, and their 100 km radii extend into Ecuador, exposing infrastructure here.

Similarly, six of the northernmost of Ecuador's volcanoes have 100 km radii which extend into Colombia. Four of the largest cities in Colombia are situated within 100 km of Holocene volcanoes, including Pasto, Cali, Ibague and Pereira, exposing much of the critical infrastructure here. The capital, Bogata, lies within 140 km of several Holocene volcanoes, including the historically active Nevado del Ruiz and Nevado del Tolima.

Hazard, Uncertainty and Exposure Assessments

The volcanoes in Colombia are classed at Hazard Levels I to III. Ten of the 15 Colombian volcanoes have insufficient data available in their eruption records to adequately calculate a hazard score without very large uncertainties. The highest hazard levels are found at Nevado del Ruiz, Galeras and Cerro Bravo.

Of the unclassified volcanoes, three, Azufral, Machín and Sotará have had recorded periods of unrest above background levels since 1900. Both Azufral and Machín have Holocene eruption records but no historical eruptions. Four Colombian volcanoes: Nevado del Huila, Doña Juana, Cumbal and Cerro Negro de Mayasquer are unclassified, but have historical records of activity including post-1900 eruptions.

CLASSIFIED	**Hazard III**				Cerro Bravo	Nevado del Ruiz	Galeras	
	Hazard II				Nevado del Tolima			
	Hazard I				Puracé			
UNCLASSIFIED	**U – HHR**				Nevado del Huila, Doña Juana, Cumbal, Cerro Negro de Mayasquer			
	U- HR				Romeral	Santa Isabel, **Machín**, **Azufral**		
	U- NHHR			Petacas	**Sotará**			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 284: Identity of Colombia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Galeras	6	III
Ruiz, Nevado del	5	III
Bravo, Cerro	4	III
Tolima, Nevado del	4	II
Puracé	4	I

Table 285: Classified volcanoes of Colombia ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 1 volcano; Risk Level III – 3 volcanoes.

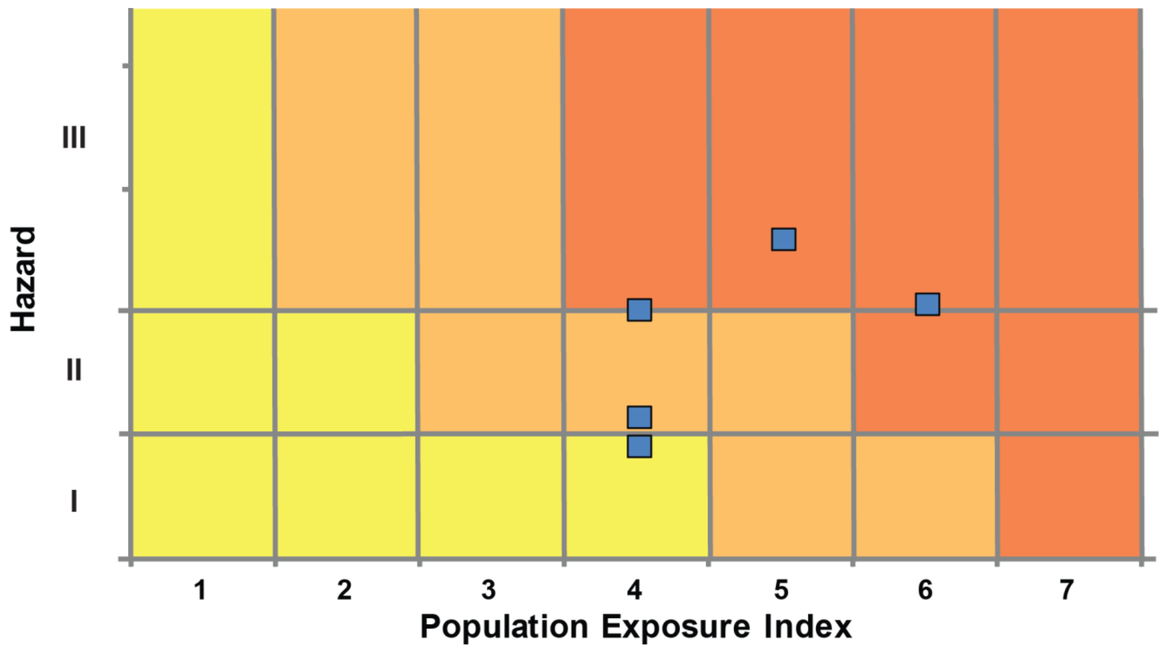

Figure 304: Distribution of Colombia's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

All Colombian volcanoes have moderate to high PEI levels at PEI 3 to 6. The highest PEI is found at Galeras, which has over 120,000 living just within 10 km. Combined with a Hazard Level of III, Galeras is classed as a Risk Level III volcano. Of the classified volcanoes, just one volcano, Puracé is deemed Risk Level I, whilst one, Nevado del Tolima, is classed at Risk Level II.

National Capacity for Coping with Volcanic Risk

Nine volcanoes in Colombia have recorded historical activity. Of these, all have dedicated ground-based monitoring systems operated by INGEOMINAS. Seven volcanoes are classed here at monitoring level 3, with seismic networks in operation and additional deformation and or gas monitoring. The three volcanoes with the highest risk classification here are continuously monitored at this level.

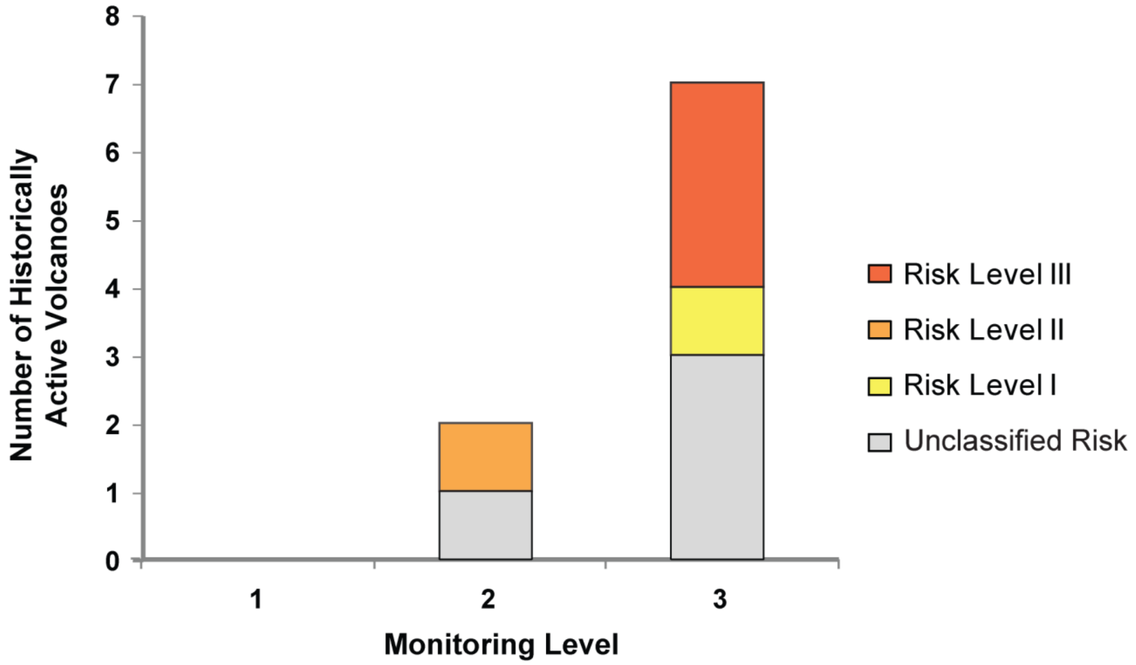

Figure 305: The monitoring and risk levels of the historically active volcanoes in Colombia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Ecuador and the Galapagos

Description

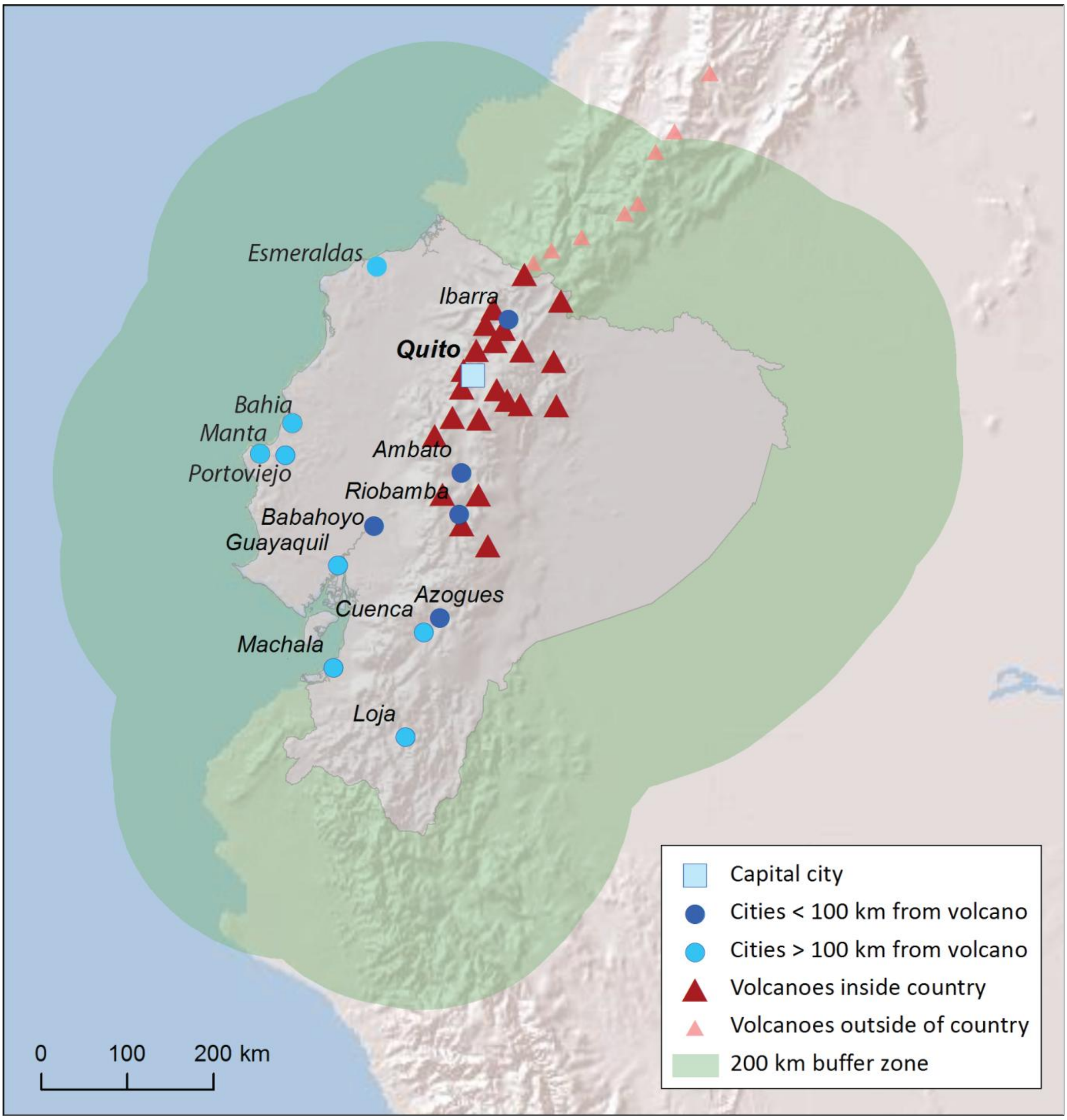

Figure 306: Location of Ecuador's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Ecuador.

Thirty-five volcanoes of Holocene age are identified in Ecuador. This includes volcanoes on mainland Ecuador and in the Galapagos Islands, nearly 1000 km to the west. Volcanism in mainland Ecuador is related to the subduction of the Nazca Plate beneath the South American Plate, whilst Galapagos volcanism is due to intra-plate hotspot volcanism and the Galapagos spreading centre. Volcanoes of the Galapagos are predominantly basaltic shields, while in mainland Ecuador the composition is more felsic and andesitic stratovolcanoes are most common.

Twenty-eight of the volcanoes have 311 confirmed Holocene eruptions, the remaining volcanoes have suspected Holocene activity. With records of activity ranging in size from VEI 0 to 6, a range of activity styles is indicated, from mild effusions of lavas to large explosive events. The largest Holocene eruption on record is the ~1280 AD eruption of Quilotoa at VEI 6 / M6.4. This event generated extensive pyroclastic flows, ash fall and lahars. A larger eruption (M6.9) is recorded in the Pleistocene at 211 ka, with the Ash Flow of the Chalupas Caldera. Numerous Pleistocene eruptions of VEI/M ≥4 are recorded in Ecuador, and 43 large explosive eruptions of this size are recorded in the Holocene.

197 historical eruptions are recorded at nineteen volcanoes. 11 of these eruptions were VEI 4 indicating that large explosive eruptions are relatively frequent in Ecuador. The dominantly andesitic composition and stratovolcano morphology indicates typical explosive activity. The altitude of the volcanoes in Ecuador means that many of the volcanoes are capped with snow or glaciers. This increases the propensity to cause hazardous lahars as even small eruptions can result in the melting of ice caps. Indeed eight volcanoes in Ecuador have a Holocene record of lahar triggering.

The most frequently active volcanoes here are Cotopaxi, Reventador and Tungurahua, while Sangay is continuously active since 1628, but poses little threat since it is isolated from population centres.

The Galapagos Island volcanoes are exclusively shield volcanoes. With a small population of just over 20,000, the main hazard they pose is largely environmental, but also to wildlife, such as slow moving giant tortoises, as a result of lava flows and ash fall. One exception to this is Fernandina, which has erupted explosively on numerous occasions producing pyroclastic flows and debris avalanches. No fatalities are recorded as a result of eruptions of Fernandina.

Much of central and northern mainland Ecuador lies within 100 km of one or more Holocene volcanoes, and six of the most populous cities in the country fall in this zone. The capital, Quito, lies within 100 km of many volcanoes, and within about 12 km of the historically active Guagua Pichincha. This volcano had a VEI 4 eruption in 1660 resulting in extensive ash fall and ash accumulation in the capital. Pyroclastic flows and surges were channelled mainly to the west as the caldera is breached in this direction. This breach will still likely act to channel flows to the west, however surges in particular are not always constrained by topography and can reach small communities such as Lloa, but have never jumped the topographic barrier into the Quito basin.

The presence of many cities within 100 km of the Holocene volcanoes exposes a large proportion of the population to direct volcanic hazards, with 50% of Ecuador’s population residing within 100 km of one or more Holocene volcano.

The assessment of hazard at many of Ecuador’s volcanoes is complicated by incomplete or sparse eruption records and publication of this information in “grey literature” that is difficult to access, hence the assignment of Hazard Levels is associated with large degrees of uncertainty.

Fatalities have resulted from eruptions of Reventador, Guagua Pichincha, Cotopaxi, Tungurahua, Sangay and Cerro Azul. Greatest loss of life as a result of volcanism in Ecuadorian territories occurred in 1640, following an eruption of Tungurahua. Though some uncertainty surrounds the eruption record, it is believed an approximately VEI 3 eruption caused pyroclastic flows and a small sector collapse that destroyed a village and its 5,000 inhabitants. Eruptions of Cotopaxi in 1742, 1768, and

1877 have also significantly added to the death toll from volcanoes in Ecuador, with roughly 1,200 deaths as a result of lahars attributable to these three eruption periods.

The Instituto Geofisico of the Escuela Politécnica Nacional (IGEPN) is responsible for the study, monitoring and hazard assessment of Ecuador's volcanoes. Sixteen volcanoes are monitored with at least one broadband seismic instrument and one or more continuously operating GPS staton. Tungurahua, Cotopaxi, Guagua Pichincha, Reventador, Cuicocha and Antisana volcanoes are monitored with a broad suite of geophysical instruments and because of the completeness of their real-time networks are considered to b in an "A" category. Ten other volcanoes: Atacazo, Pululagua, Imbabura, Chachimburo, Cerro Negro, Cayambe, Soche, Sangay, Chimborazo and Quilotoa all have at least one or more broadband seismic and deformation-detecting stations. The IGEPN provides advice and information regarding volcanic activity and presents this information online, accessible to the public. Reports are regularly issued summarising volcanic activity and early warnings before a notable increase in eruptive activity is given on this web, via calls, over local radio stations and through social media. Close collaborations exist with the Secretariat for Risk Management. Before and during volcanic crises IGEPN scientists communicate and provide hazard assessments to local, regional and national authorities. At Tungurahua volcano, which has been erupting since 1999, a volunteer volcano observers group (Vigias) has been very successful in providing in situ observations of eruptive activity, via a radio system to the local observatory IGEPN scientists.

From here we provide the information for mainland Ecuador and the Galapagos Islands separately.

See also:

Servicio Nacional de Sismologia y Vulcanologia: http://www.igepn.edu.ec/

Mainland Ecuador

Volcano Facts

Number of Holocene volcanoes	22, inclusive of one on the border with Colombia
Number of Pleistocene volcanoes with M≥4 eruptions	7
Number of volcanoes generating pyroclastic flows	14
Number of volcanoes generating lahars	8
Number of volcanoes generating lava flows	7
Number of fatalities caused by volcanic eruptions	?5,690
Tectonic setting	22 Subduction zone
Largest recorded Pleistocene eruption	The M6.9 Chalupas Ash Flow eruption of Chalupas at 211 ka.
Largest recorded Holocene eruption	The M6.4 eruption of Quilotoa

	about 700 years ago.
Number of Holocene eruptions	229 confirmed eruptions
Recorded Holocene VEI range	0 – 6 and unknown.
Number of historically active volcanoes	10 according to VOTW4.22 (Cotopaxi, Reventador, Tungurahua, Guagua Pichincha, Cayambe, Sangay, Chacana, Antisana, Sumaco and Cerro Negro de Mayasquer). Activity at the latter three volcanoes is ambiguous.
Number of historic eruptions	131

Number of volcanoes	Primary volcano type	Dominant rock type
4	Caldera(s)	Dacitic (3), Rhyolitic (1)
17	Large cone(s)	Andesitic (13), Basaltic (1), Dacitic (3)
1	Small cone(s)	Andesitic (1)

Table 286: The number of volcanoes in Ecuador, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	15,520,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	7,443
Gross National Income (GNI) per capita (2005 PPP $)	7,471
Human Development Index (HDI) (2012)	0.724 (High)

Population Exposure

Capital city	Quito
Distance from capital city to nearest Holocene volcano	12.2 km
Total population (2011)	15,007,343
Number (percentage) of people living within 10 km of a Holocene volcano	750,552 (5%)
Number (percentage) of people living within 30 km of a Holocene	4,352,168 (29%)

volcano

Number (percentage) of people living within 100 km of a Holocene volcano	7,393,692 (49.3%)

Ten largest cities, as measured by population, and populations (2010, from UN data, data.un.org):

Guayaquil	2,278,691
Quito	1,607,734
Cuenca	329,928
Machala	231,260
Manta	217,553
Portoviejo	206,682
Loja	170,280
Ambato	165,185
Esmeraldas	154,035
Riobamba	146,324

Infrastructure Exposure

Number of airports within 100 km of a volcano	6 (Tulcan, Quito, Lago Agrio, Latacunga, Macas, Tena)
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	3,727
Total length of railroads within 100 km of a volcano (km)	0

In mainland Ecuador the 100 km radii of the volcanoes covers much of central and northern parts of the country, and the radii of six of the northernmost volcanoes extend into Colombia. Similarly, the three southernmost volcanoes of Colombia have radii which extend into Ecuador. Six of the largest cities in Ecuador are situated within 100 km of Holocene volcanoes, including the capital, Quito, hence much of the critical infrastructure of the country is exposed, including three airports and an extensive road network. Critical infrastructure such as two trans-Andean oil pipelines, four major hydroelectric installations, Quito's water supply from Antisana and Chacana volcanoes, as well as critical bridges are also exposed.

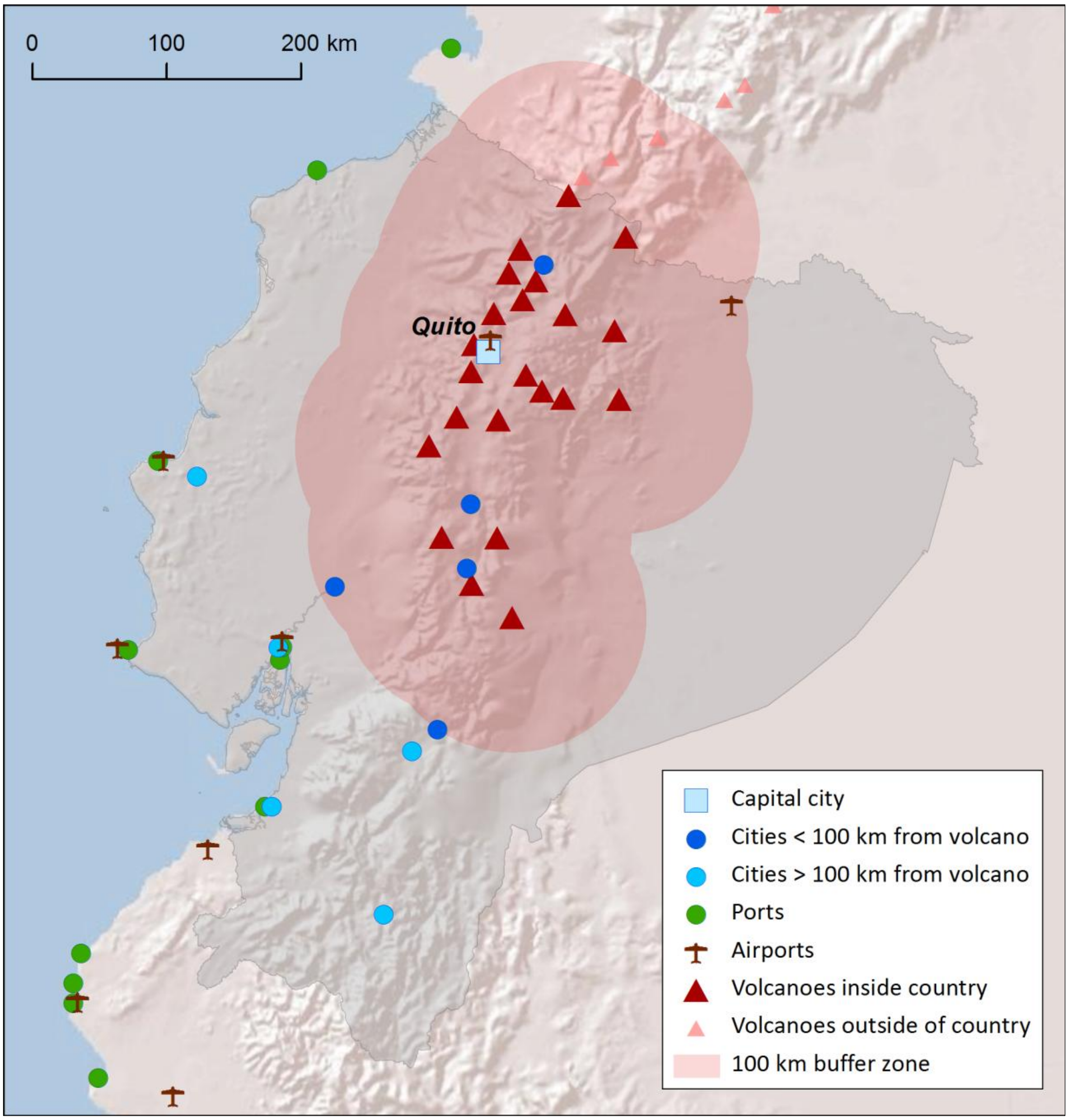

Figure 307: The location of Ecuador's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of mainland Ecuador's volcanoes. Seven volcanoes out of 23 have sufficient detail to define the hazard through the calculation of the VHI. All of these are classified at Hazard Level III, with Holocene records of VEI ≥3 eruptions and records of explosive eruptions with the production of pyroclastic flows.

Of the unclassified volcanoes, three have no confirmed Holocene eruptions on record. The remaining 12 volcanoes have a Holocene eruptive record, with historical events at four volcanoes including post-1900 AD eruptions at Cerro Negro de Mayasquer. Four unclassified volcanoes have a Holocene record of large VEI ≥4 eruptions.

The size of the proximal populations at Ecuador's volcanoes ranges from small to large, generating PEIs of 1 to 7. Moderate and high PEIs dominate. This range results in a range of Risk Levels when combined with the Hazard Levels, from II to III at the classified volcanoes. Although here we consider threat to life measured by population exposure, infrastructure exposure such as the water supply to Quito is also vital. This, for example, is supplied from the PEI4 Antisana volcano, which if it were to erupt would have grave consequences for Quito's water supply.

CLASSIFIED	**Hazard III**			Reventador; Sangay	Cayambe; Cotopaxi; Tungurahua	Guagua Pichincha	Atacazo	
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		Sumaco		**Cerro Negro de Mayasquer;** Antisana	Chacana		
	U- HR	Aliso		Soche	Chachimbiro; Chimborazo	Quilotoa	Cuicocha; **Imbabura**	Pululagua
	U- NHHR				Illiniza	Mojanda	Licto	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 287: Identity of Mainland Ecuador's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Atacazo	6	III
Guagua Pichincha	5	III
Tungurahua	4	III
Cotopaxi	4	III
Cayambe	4	III
Reventador	3	II
Sangay	3	II

Table 288: Classified volcanoes of Mainland Ecuador ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 2 volcanoes; Risk Level III – 5 volcanoes.

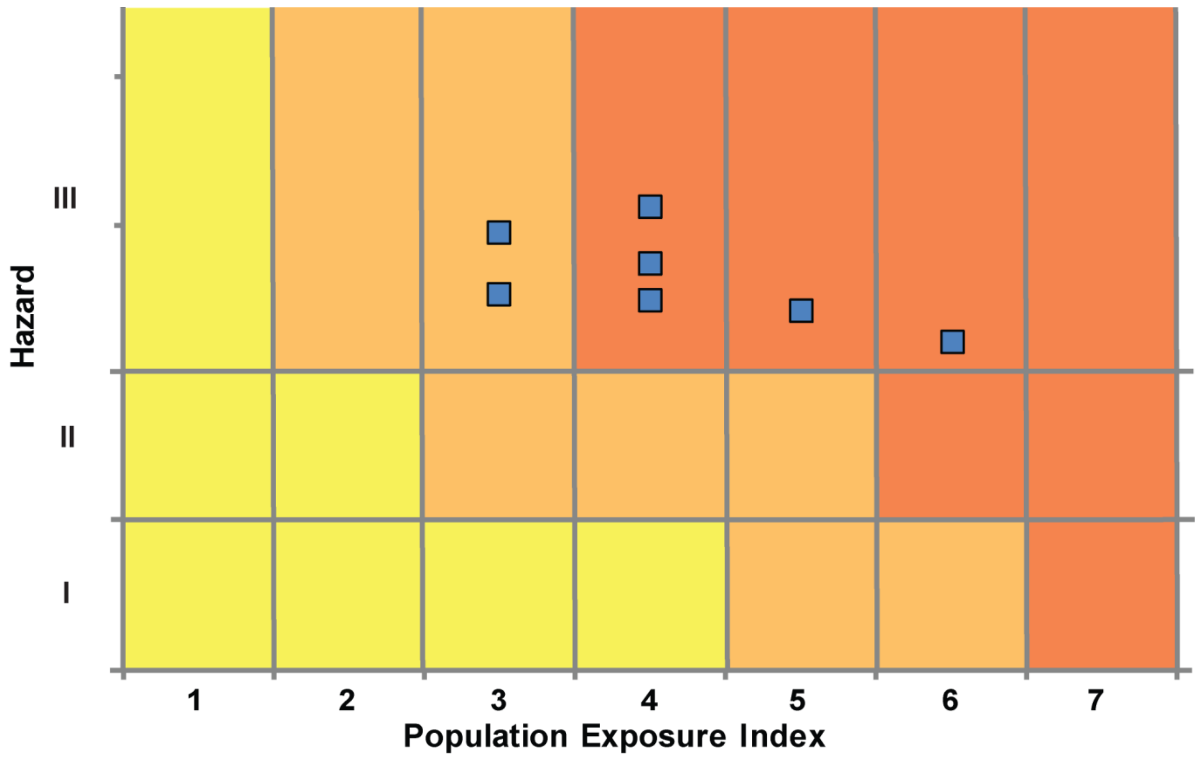

Figure 308: Distribution of mainland Ecuador's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Ten volcanoes in mainland Ecuador have recorded historical activity. These volcanoes are distributed across all three monitoring levels with half of the volcanoes being classed at Monitoring Level 3. All Risk Level III volcanoes are monitored at Level 3, with the exception of Cayambe which also has both seismic and deformation monitoring. The Risk Level III volcanoes, Tungurahua, Guagua Pichincha and Cotopaxi all have multiple monitoring systems in place inclduing continuous seismic and deformation monitoring.

Monitoring is undertaken by the Instituto Geofisico EPN. Note that this institute also uses Monitoring Levels 1 - 3 to describe levels of monitoring at Ecuador's volcanoes, but these are different levels to those used here.

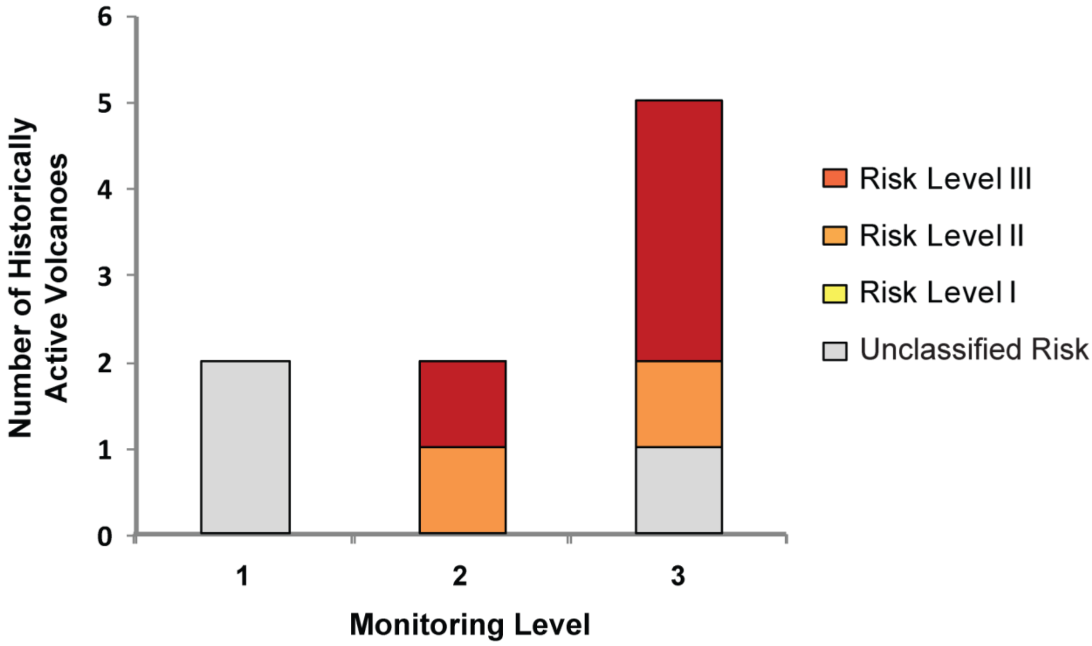

Figure 309: The monitoring and risk levels of the historically active volcanoes in mainland Ecuador. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Galapagos Islands

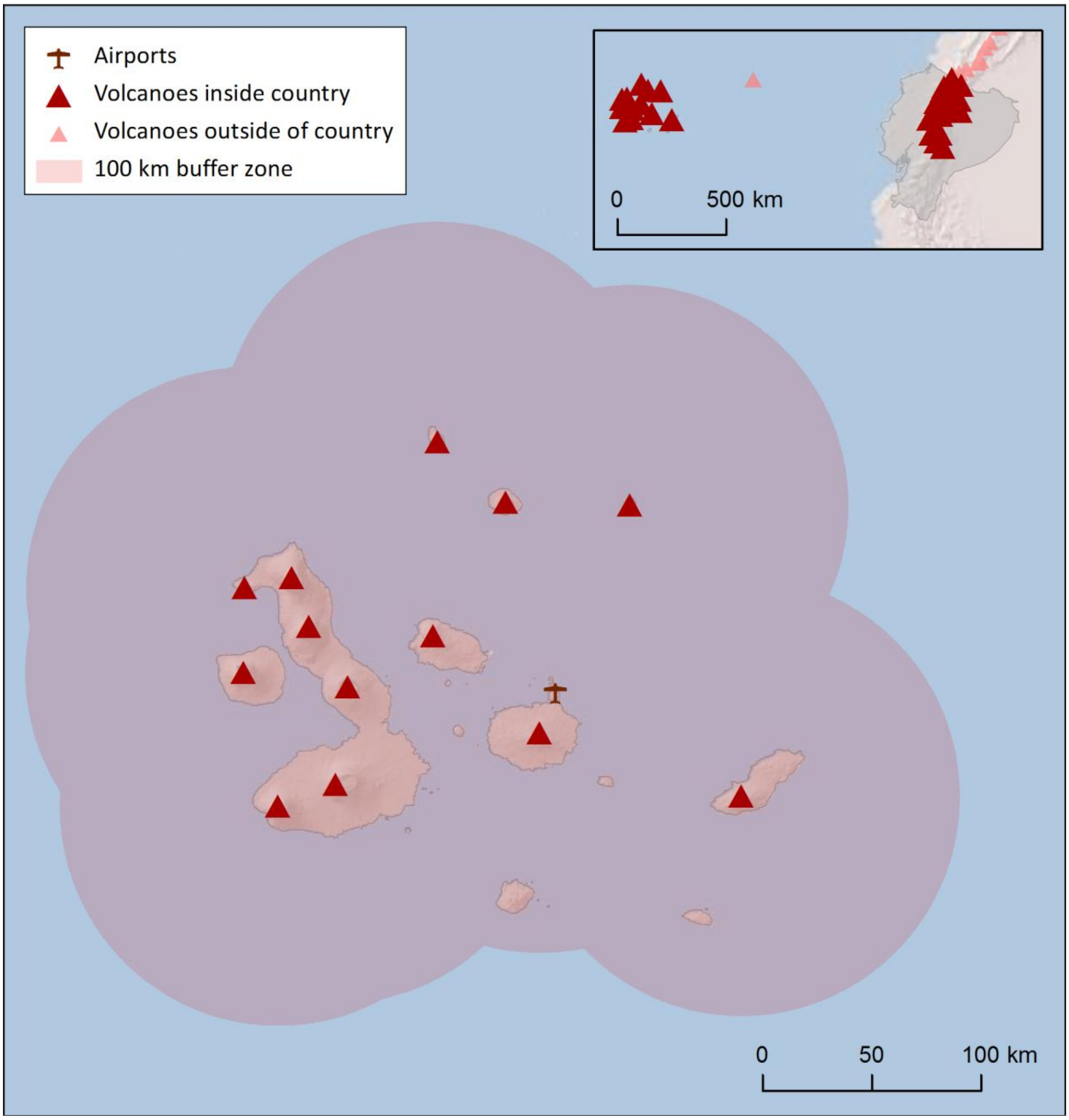

Figure 310: The volcanoes of the Galapagos Islands. Inset shows the location relative to mainland Ecuador.

Volcano Facts

Number of Holocene volcanoes	13
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	9

Number of fatalities caused by volcanic eruptions	?1
Tectonic setting	13 Rift zone
Largest recorded Pleistocene eruption	The M5.2/VEI 5 Alcedo-A,B Tephra eruption of about 90,000 years ago.
Largest recorded Holocene eruption	The VEI 4 eruption of Fernandina in 1968.
Number of Holocene eruptions	82 confirmed eruptions
Recorded Holocene VEI range	0 – 4 and unknown.
Number of historically active volcanoes	9
Number of historic eruptions	66

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
13	Shield(s)	Basaltic (13)

Table 289: The number of volcanoes in Ecuador, their volcano type classification and dominant rock type according to VOTW4.0.

Population Exposure

Capital city	Puerto Baquerizo Moreno
Distance from capital city to nearest Holocene volcano	12.3 km
Total population (2010, http://www.inec.gob.ec/estadisticas/)	25,124
Percentage of people living within 100 km of a Holocene volcano	100%

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	-
Total length of roads within 100 km of a volcano (km)	-
Total length of railroads within 100 km of a volcano (km)	0

In the Galapagos Islands, the 100 km radii extend to fully encompass the island group, exposing all infrastructure here.

Hazard, Uncertainty and Exposure Assessments

Of the thirteen volcanoes in the Galapagos Islands, just four have a sufficiently detailed eruption record to determine hazard levels through the calculation of the VHI. These are classified at Hazard Levels I and II.

Of the unclassified volcanoes, three have no confirmed Holocene eruptions on record. Six have a record of Holocene eruptions, including historical age events and post-1900 AD eruptions.

The size of the proximal populations at the volcanoes of the Galapagos is typically small, generating PEIs of 2 to 3. All classified volcanoes here are classed at Risk Level I.

CLASSIFIED	**Hazard III**							
	Hazard II		Fernandina					
	Hazard I		Wolf; Negra, Sierra; Azul, Cerro					
UNCLASSIFIED	**U – HHR**		Darwin; **Alcedo**; **Pinta; Marchena; Santiago**					
	U- HR		Ecuador					
	U- NHHR		Genovesa	Santa Cruz; San Cristóbal				
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 290: Identity of the Galapagos Islands' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Azul, Cerro	2	I
Fernandina	2	I
Negra, Sierra	2	I
Wolf	2	I

Table 291: Classified volcanoes of the Galapagos Islands ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 4 volcanoes; Risk Level II –0 volcanoes; Risk Level III – 0 volcanoes.

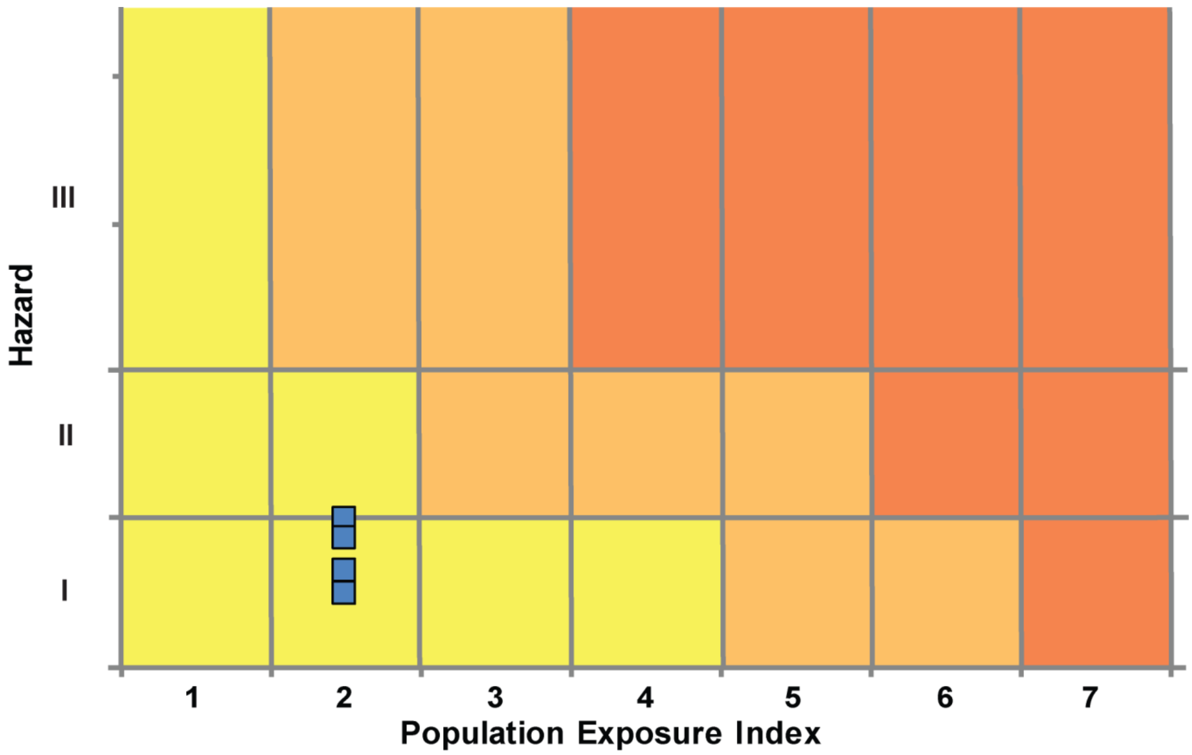

Figure 311: Distribution of the Galapagos Islands' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Nine volcanoes in the Galapagos Islands have recorded historical activity. Monitoring is undertaken by the Instituto Geofisico EPN. Note that this institute also uses Monitoring Levels 1 - 3 to describe levels of monitoring at Ecuador's volcanoes, but these are different levels to those used here. A seismic monitoring network in the Galapagos Islands has been installed.

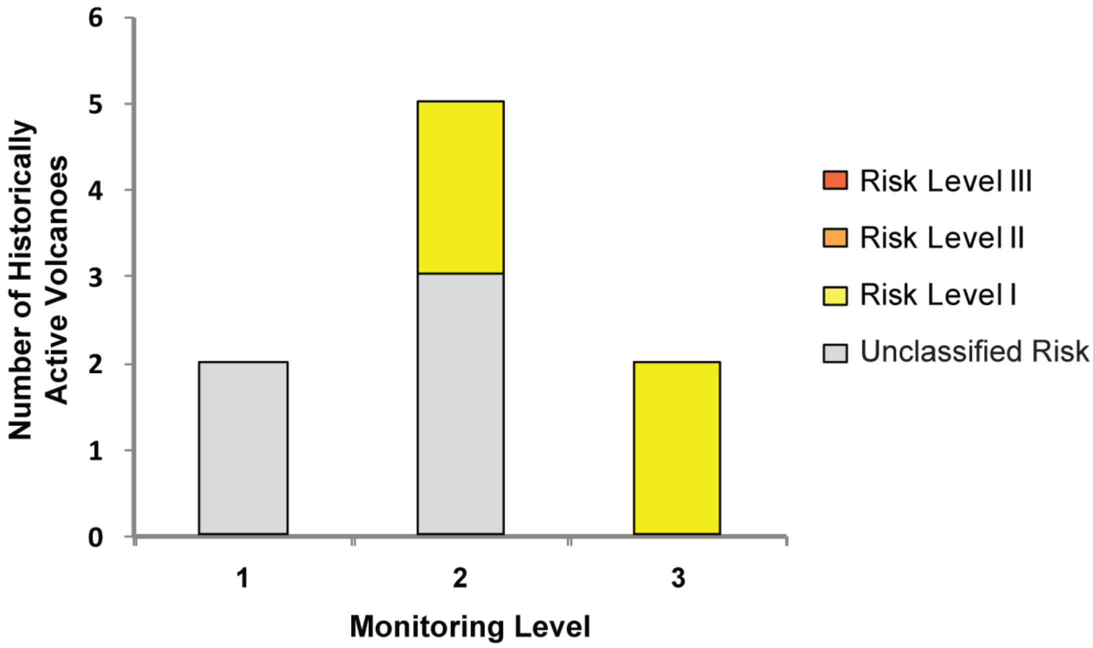

Figure 312: The monitoring and risk levels of the historically active volcanoes in the Galapagos Islands of Ecuador. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Peru

Description

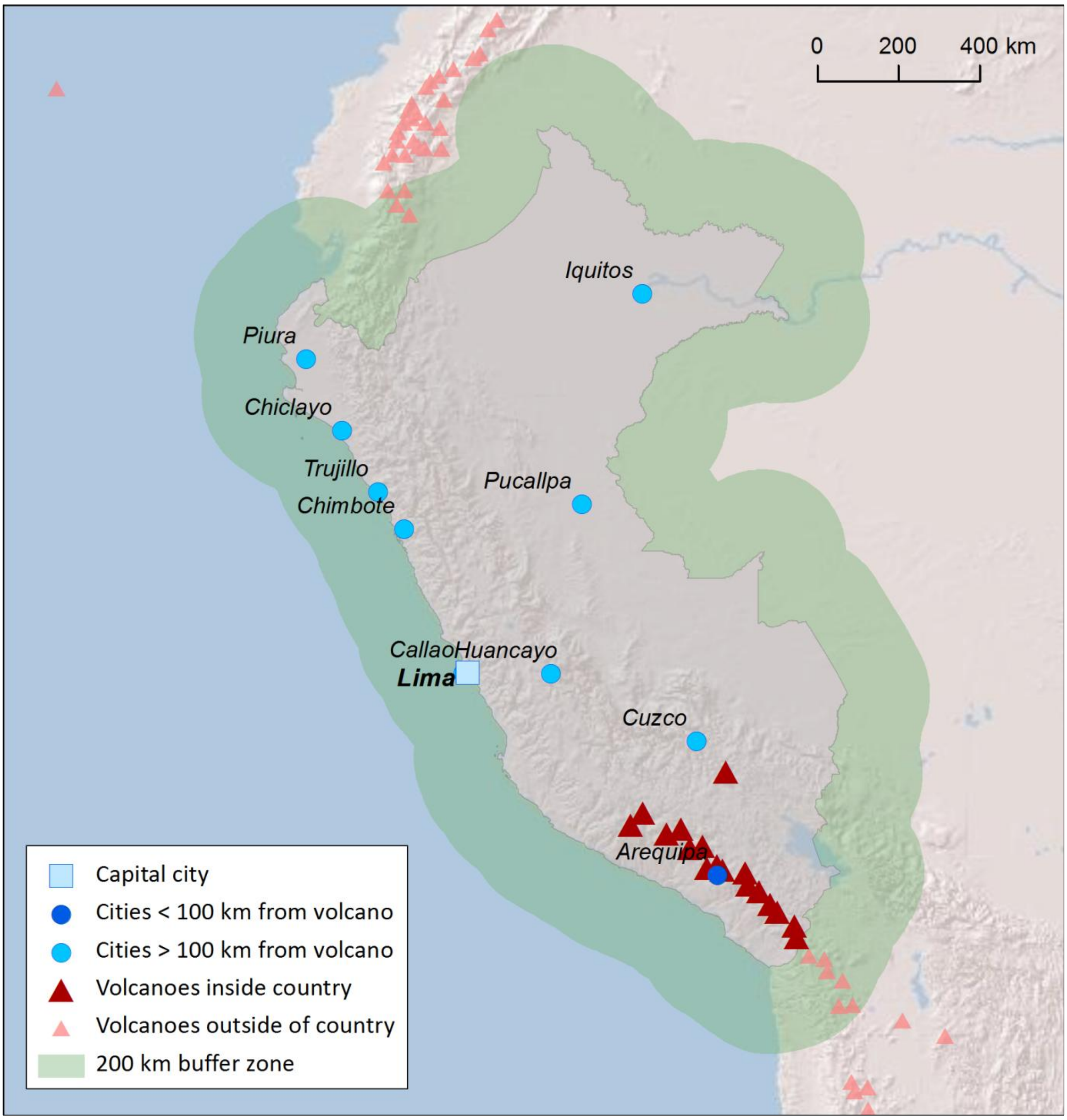

Figure 313: Location of Peru's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Peru.

Seventeen Holocene volcanoes are recorded in Peru. These volcanoes are located in the Andes in a chain through southern Peru to the border with Chile. Volcanism occurs here due to the subduction of the Nazca Plate beneath the South American Plate. Although subduction is also ongoing in northern Peru, the angle of the subducting slab has not led to recent volcanism. Although Peru's volcanoes are a variety of types, including cinder cones and lava domes, most are stratovolcanoes of dominantly andesitic composition.

Large explosive Pleistocene activity is recorded in Peru, and sixty eruptions of Holocene age are recorded here. Of these, thirty-six are of historical age. These historical eruptions occurred at six volcanoes, and covered a range of sizes, from small events of VEI 1 to very large explosive VEI 6 eruptions. Three volcanoes have Holocene records of producing pyroclastic flows and four with lahars. The largest historical eruption was the 1600 AD eruption of Huaynaputina. This eruption produced voluminous tephra falls, pyroclastic flows and surges which travelled 13 km and lahars that reached the Pacific Ocean, 120 km away. The cities of Arequipa and Moquengua suffered significant damage, and about 1500 lives were lost.

Arequipa, one of the most populous cities in Peru, lies at about 75 km from Huaynaputina, and within 100 km of five other Holocene volcanoes, including the historically active Sabancaya, El Misti and Ubinas, the most frequently active volcano in Peru in historic times.

The Instituto Geofisico del Peru (IGP) and the Instituto Geológico Minero y Metalúrgico (INGEMMET) are responsible for scientific research and the monitoring of the volcanoes in Peru, and indeed actively monitor five historically active volcanoes and three further Holocene volcanoes through a variety of dedicated ground-based instrumentation, including seismic stations, geochemical and gas monitoring and various deformation monitoring. Monitoring is undertaken regularly, with an alarm system and automated seismic system. A regional seismic network is operational in Peru, which can register seismicity throughout the volcanic chain. Some resources and plans are available for monitoring to be extended to currently un-monitored volcanoes in developing situations. About a quarter of the observatory staff have experience of responding to an eruption.

In addition to ground-based monitoring, VDAP – the Volcano Disaster Assistance Program of the U.S. Geological Survey provides satellite information during eruptions, and InSAR and MODIS images are provided by Cornell University and Torino University.

The IGP provide scientific and technical advice to the Instituo Nacional de Defensa Civil (INDECI) in the event of unrest and eruption. The director of the Observatorio Vulcanologico de Arequipa (OVA), Orlando Macedo, represents the IGP on the regional committee for crises (the Comite de Operaciones de Emergencia Regional, COER). The regional aviation authority, Corporacion Peruana de Aviacion Comercial (CORPAC) reports to the regional VAAC.

The IGP extend a program of hazard education to the public, and the IGP and INGEMMET websites are publically accessible, distributing information about Peru's volcanic activity. The IGP do not provide risk assessments but advise on management and mitigation of volcanic risk. An alert level system is in place, and the IGP, INGEMMET and IGUNSA recommend declaration of alerts to the COER authority.

Large and growing cities are located near active volcanoes in Peru, and with the expansion of the cities, the risk increases as larger populations live ever-closer to the volcanoes. Educational programs about volcanic risk and restriction of building in proximal areas would greatly improve the volcanic risk situation in Peru.

See also:

Instituto Geofisico del Peru: http://www.igp.gob.pe/portal/#

Instituto Geológico Minero y Metalúrgico (INGEMMET):
http://www.ingemmet.gob.pe/form/Inicio.aspx#

Volcano Facts

Number of Holocene volcanoes	17, inclusive of one on the border with Chile
Number of Pleistocene volcanoes with M≥4 eruptions	4
Number of volcanoes generating pyroclastic flows	3
Number of volcanoes generating lahars	4
Number of volcanoes generating lava flows	3
Number of fatalities caused by volcanic eruptions	1,500?
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M6.7 Sillar of Arequipa Ignimbrite eruption of Nevado Chachani at 2.42 Ma.
Largest recorded Holocene eruption	The 1600 AD eruption of Huaynaputina at M6.1.
Number of Holocene eruptions	60 confirmed eruptions. 14 uncertain eruptions.
Recorded Holocene VEI range	0 – 6 and unknown.
Number of historically active volcanoes	6
Number of historic eruptions	36

Number of volcanoes	Primary volcano type	Dominant rock type
11	Large cone(s)	Andesitic (9), Dacitic (1), Trachytic / Andesitic (1)
2	Lava dome(s)	Dacitic (1), Rhyolitic (1)
4	Small cone(s)	Andesitic (3), Unknown (1)

Table 292: The number of volcanoes in Peru, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	30,041,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	9,049
Gross National Income (GNI) per capita (2005 PPP $)	9,306
Human Development Index (HDI) (2012)	0.741 (High)

Population Exposure

Capital city	Lima
Distance from capital city to nearest Holocene volcano	533.1 km
Total population (2011)	29,248,943
Number (percentage) of people living within 10 km of a Holocene volcano	25,307 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	1,143,689 (3.9%)
Number (percentage) of people living within 100 km of a Holocene volcano	2,836,138 (9.7%)

Ten largest cities, as measured by population, and populations:

Lima	7,737,002
Arequipa	841,130
Callao	813,264
Trujillo	747,450
Chiclayo	577,375
Iquitos	437,620
Huancayo	376,657
Piura	325,466
Chimbote	316,966
Cuzco	312,140

Infrastructure Exposure

Number of airports within 100 km of a volcano	3
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	1,410
Total length of railroads within 100 km of a volcano (km)	0

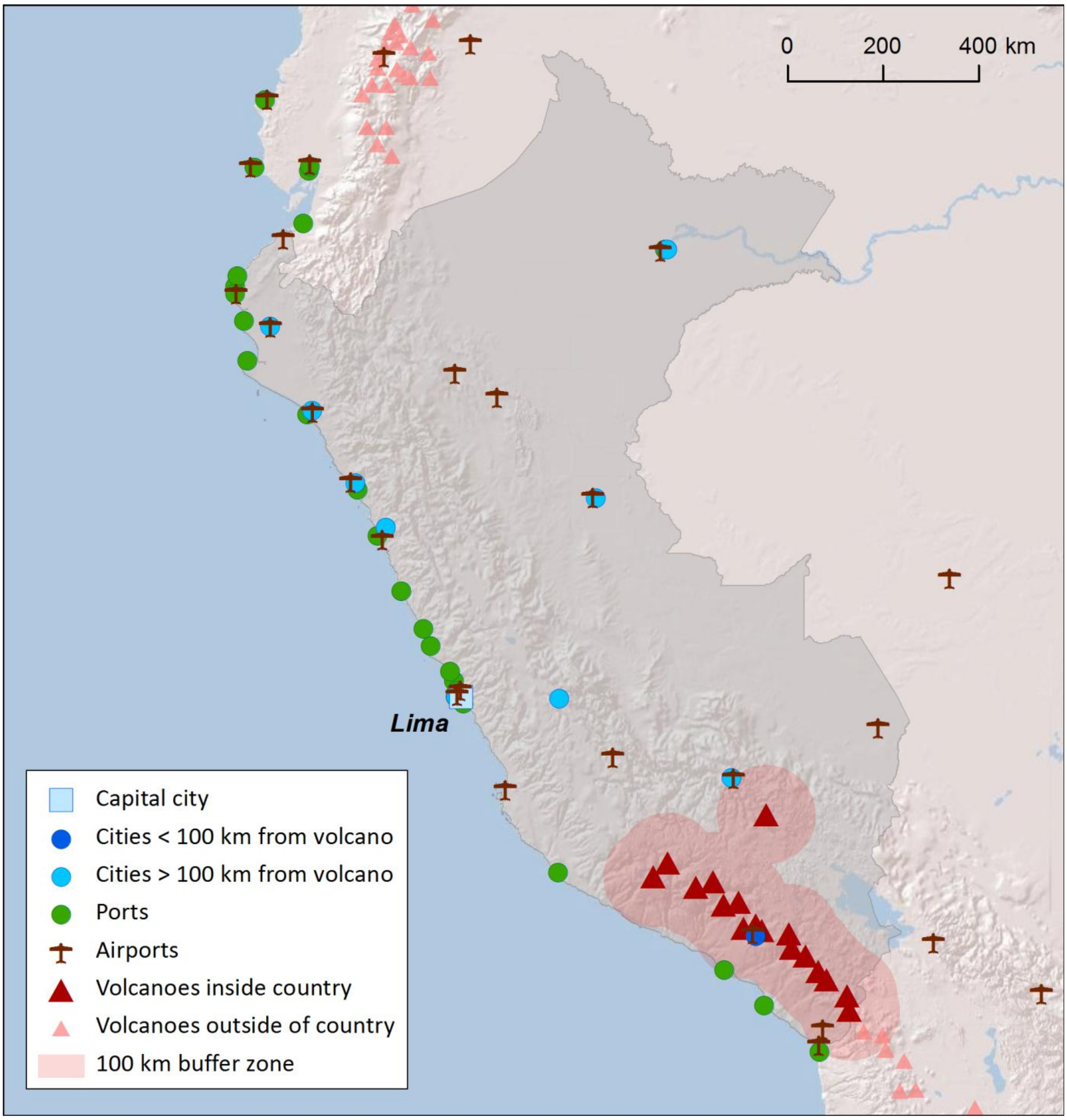

Figure 314: The location of Peru's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The Peruvian volcanoes are located in the south of the country bordering Chile, through the Andean chain. The southernmost two volcanoes in Peru have 100 km radii which extend into Chile, exposing the infrastructure here, and similarly, several of the northernmost volcanoes in Chile have radii which extend into southern Peru. The capital, Lima, is distal to the volcanoes, being located over 500 km north. However, one of the largest cities in Peru, Arequipa, is located with 100 km of six Holocene volcanoes, including the historically active Sabancaya, El Misti, Ubinas and Huaynaputina volcanoes, and hence considerable infrastructure is exposed here, including an extensive road network.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of Peru's volcanoes. The record is sufficient at just four volcanoes to define the hazard through the calculation of the VHI. These are classified across Hazard Levels I and II.

Of the unclassified volcanoes, eight have no confirmed Holocene age eruptions on record. Five have a Holocene record, including historical (post-1500 AD) age activity at Ticsani and Huaynaputina. Just the latter has a record of large explosive VEI ≥4 Holocene eruptions.

The PEI ranges from low to high in Peru, at PEI 2 to 4. Of the classified volcanoes, two are classed as Risk Level II and two at Risk Level I.

CLASSIFIED	**Hazard III**							
	Hazard II		Yucamane	Sabancaya; Ubinas				
	Hazard I				Misti, El			
UNCLASSIFIED	**U – HHR**		Ticsani	Huaynaputina				
	U- HR			Huambo	Quimsachata; Andahua-Orcopampa			
	U- NHHR		Auquihuato, Cerro; Sara Sara; Coropuna; Tutupaca; Casiri, Nevados; Tacora		Chachani, Nevado; Nicholson, Cerro			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 293: Identity of Peru's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Misti, El	4	I
Sabancaya	3	II
Ubinas	3	II
Yucamane	2	I

Table 294: Classified volcanoes of Peru ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 2 volcanoes; Risk Level II – 2 volcanoes; Risk Level III – 0 volcanoes.

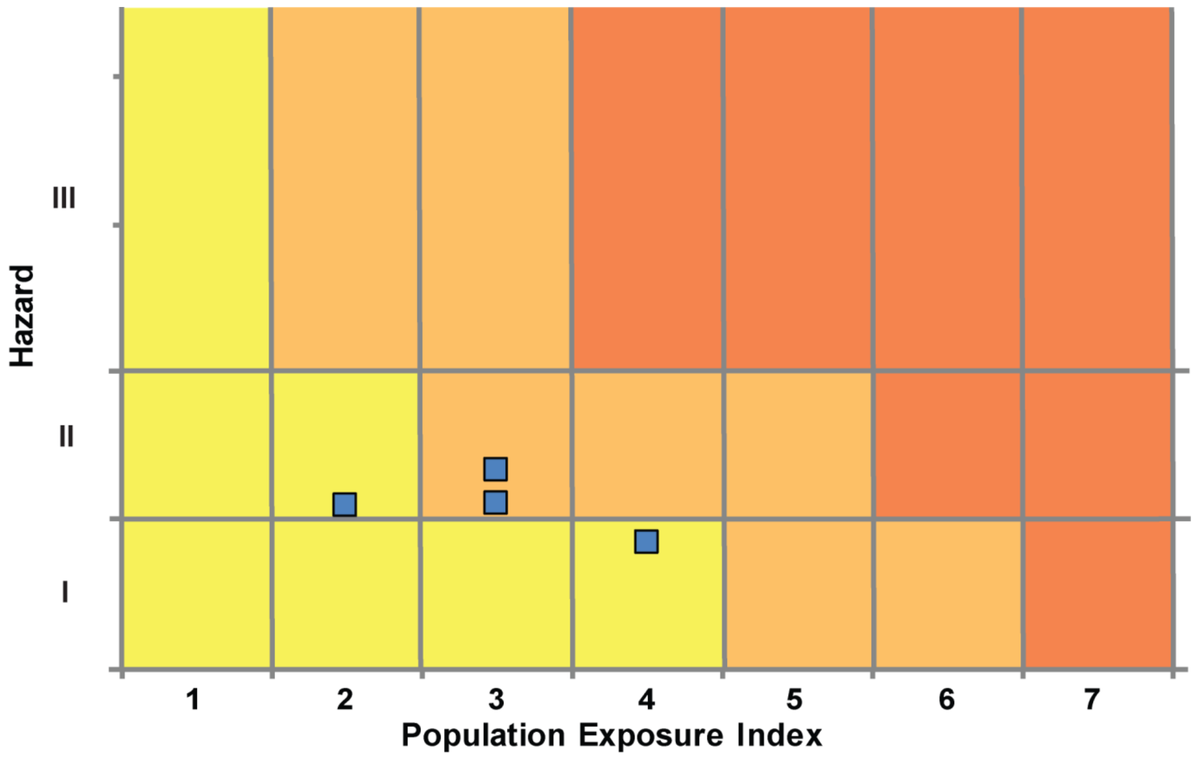

Figure 315: Distribution of Peru's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Six volcanoes have records of historical activity in Peru. Of these, five have regular monitoring. Just Yucamane, a Risk Level I volcano, currently has no dedicated regular ground-based monitoring. The five others, including El Misti (Risk Level I), Sabancaya and Ubinas (Risk Level II) and Huaynaputina and Ticsani (Unclassified), are monitored by the Instituto Geofisico del Peru and the Instituto Geológico Minero y Metalúrgico (INGEMMET). These institutes also monitor Tutupaca, Coropuna and Nevado Chachani. Seismic networks are used at Sabancaya and Huaynaputina. Seismic networks and additional deformation and gas monitoring is undertaken at Ticsani, El Misit and Ubinas.

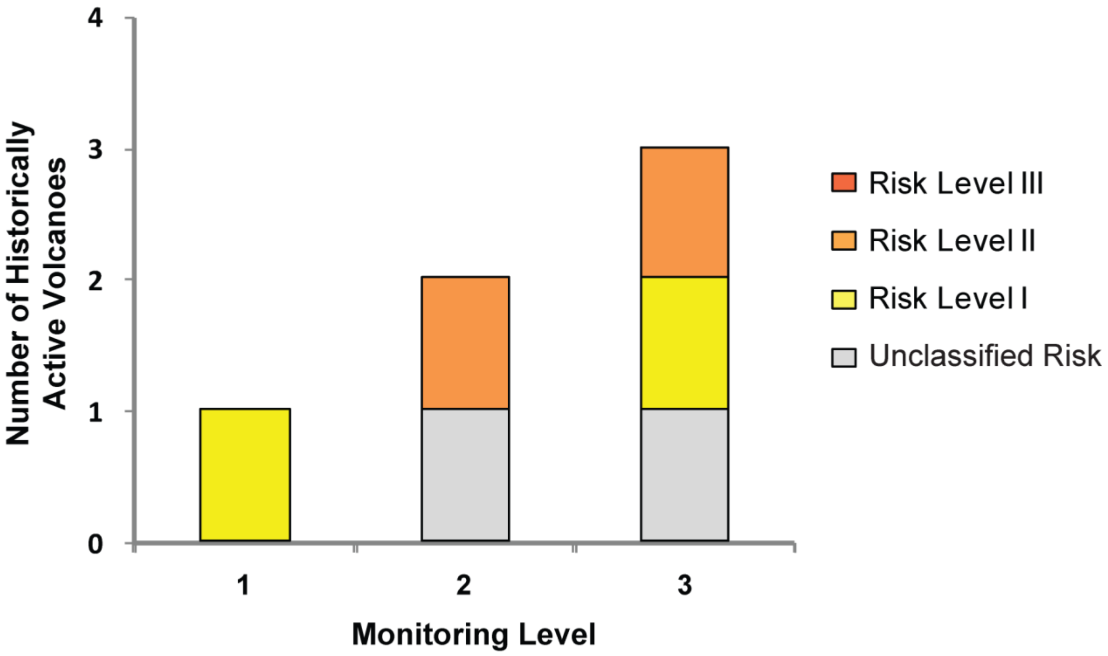

Figure 316: The monitoring and risk levels of the historically active volcanoes in Peru. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 16: West Indies

The West Indies region comprises the islands of the Lesser Antilles. Some of these islands are independent countries, whilst other retain ties to Europe.

Country	Number of volcanoes
Dominica	5
France	2
Grenada	2
Netherlands –Dutch Antilles	2
St. Kitts and Nevis	2
St. Lucia	1
St. Vincent and the Grenadines	1
UK - Montserrat	1

Table 295: The countries represented in this region and the number of Holocene volcanoes.

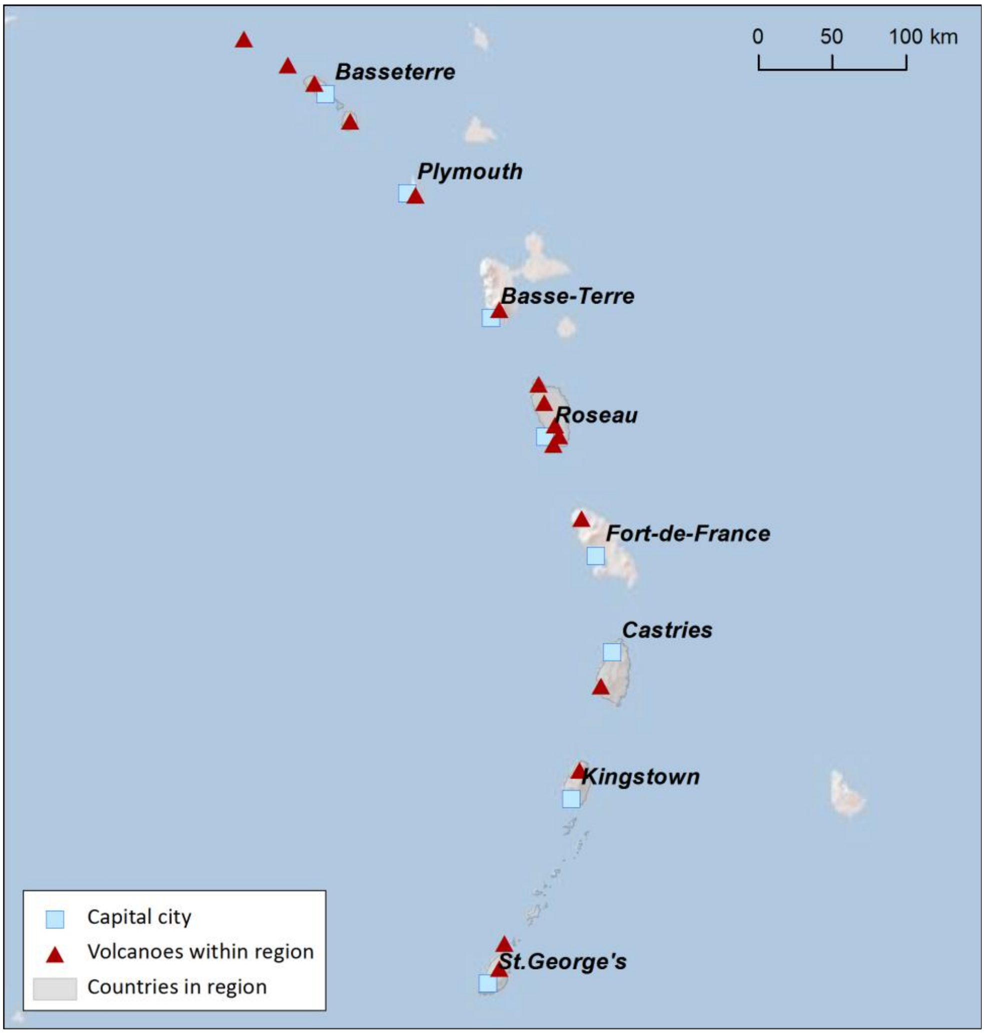

Figure 317: The distribution of Holocene volcanoes through the West Indies region. The capital cities of the constituent countries are shown.

The Lesser Antilles arc forms along the eastern edge of the Caribbean Plate, with volcanism generated by the subduction of the Atlantic Ocean crust beneath this Caribbean Plate.

Sixteen Holocene volcanoes are located in the Lesser Antilles, from the southernmost island of Grenada to the northern island of Saba, of the Dutch Antilles. Of these, nearly 90% are andesitic stratovolcanoes.

Activity here is dominantly explosive with most eruptions recorded with explosive elements. Whereas the most common eruption size in most regions is VEI 2, here nearly half of all eruptions with a given size have been VEI 4. Nearly 70% of the volcanoes have Holocene records of producing pyroclastic flows, and about three quarters of all recorded eruptions here produced pyroclastic flows. Pyroclastic flows are recorded in about half of all historical eruptions, whilst only 2% of historical events have recorded lava flows. About a third of historical eruptions have resulted in lahars. Four historical eruptions have generated tsunamis.

Comprising multiple small islands, the population of much of the West Indies is located in close proximity to the volcanoes. Whilst population sizes of individual islands may be low, commonly 100% of the population live within 30 or 100 km of one or more Holocene volcano. Critically, the proximity of the islands to each other also means that eruptions on one island may impact on neighbouring islands. This is particularly relevant for tsunamis.

The assessment of hazard by the Volcanic Hazard Index is complicated by large uncertainties at many of the volcanoes of the West Indies. Further efforts in understanding the size of those eruptions with unknown magnitudes and confirming the occurrence of some uncertain events would help understanding here, however, individual focussed hazard assessments based on likely eruption scenarios have been undertaken at the volcanoes here with detailed integrated hazard maps and descriptions of probable activity (see Lindsay et al., 2005).

The volcanoes of the West Indies are very well monitored, with both observatories in Guadeloupe and Martinique run by the Institut de Physique du Globe Paris and the Seismic Research Centre (SRC) of the University of West Indies operating comprehensive monitoring systems throughout the island chain. Most monitoring is undertaken through seismic stations, with deformation and additional monitoring (gases, geochemical etc) at some volcanoes. Informal arrangements are in place for access to Earth Observation data as needed. Plans and resources are available for responding to developing situations at un- or under-monitored volcanoes, and in the event of significant unrest temporary observatories would be established staffed by members of the SRC and local equivalent groups where possible.

Monitoring equipment is not manned continuously, instead a monitoring alert system is in place. The SRC is funded by annual contributions from island governments and additional grant funding. About 60% of the staff members of the SRC have experience of responding to eruptions.

In the event of unrest or eruption, the SRC will provide regular updates to the National Emergency Operations Committee and will contact the regional VAAC. Response is guided by an Alert Level Table. This outlines actions to be taken by Scientific Staff and Civil Authorities. Generally response to unrest involves increased/intensification of monitoring with additional measurements and instruments deployed, increased site visits and provision of advice to civil authorities via regular

Scientific Advisories. Response will depend on the signals derived from monitoring sites. Communications with local authorities is normally via the National Disaster Coordinator but there is allocation for contacting the highest office on the island if thought necessary by the SRC monitoring team.

The SRC are not responsible for providing risk assessments, but are involved in risk management and mitigation through the provision of educational materials, hazard maps and public outreach.

See also:

University of the West Indies Seismic Research Centre http://www.uwiseismic.com/

Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano facts

Number of Holocene volcanoes	16
Number of Pleistocene volcanoes with M≥4 eruptions	6
Number of volcanoes generating pyroclastic flows	11+ (101 eruptions)
Number of volcanoes generating lahars	6 (26 eruptions)
Number of volcanoes generating lava flows	3-4 (6 eruptions)
Number of eruptions with fatalities	4
Number of fatalities attributed to eruptions	31,283
Largest recorded Pleistocene eruption	The M6.4 eruption of the Roseau Tuff from Morne Trois Pitons in Dominica, about 36,000 years ago.
Largest recorded Holocene eruption	The 1812 AD M4.7 eruption of Soufrière St. Vincent is the largest recorded Holocene eruption in this region in LaMEVE.
Number of Holocene eruptions	132 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 4 and unknown.
Number of historically active volcanoes	8
Number of historical eruptions	42

Number of	Primary volcano type	Dominant rock type

volcanoes		
1	Caldera(s)	Andesitic (10)
14	Large cone(s)	Andesitic (13), Dacitic (1)
1	Submarine	Basaltic (1)

Table 296: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	10
Large (> VEI 3)	110

Table 297: Average recurrence interval (years between eruptions) for small and large eruptions in the West Indies.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about 10 years, whilst the ARI for large eruptions is longer, at about 110 years.

Eruption Size

Eruptions are recorded through the West Indies of VEI 0 to 4, representing a range of eruption styles from effusive events to large explosive eruptions. VEI 4 events dominate the record, with nearly 45% of all Holocene eruptions classed as such.

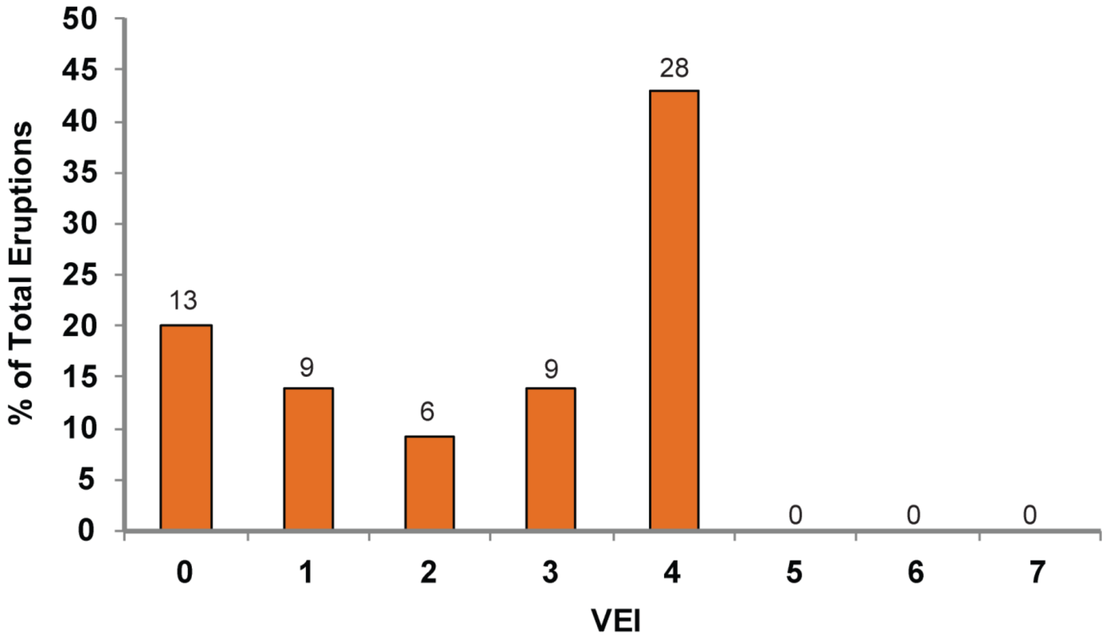

Figure 318: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 67 eruptions were recorded with unknown VEI.

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	309,233 (22.30 %)
Number (percentage) of people living within 30 km of a Holocene volcano	1,093,521 (78.87 %)
Number (percentage) of people living within 100 km of a Holocene volcano	1,388,737 (>100 %)

Infrastructure Exposure

Number of airports within 100 km of a volcano	5
Number of ports within 100 km of a volcano	14
Total length of roads within 100 km of a volcano (km)	753
Total length of railroads within 100 km of a volcano (km)	0

Hazard, Uncertainty and Exposure Assessments

<table>
<tr><td rowspan="3">CLASSIFIED</td><td>Hazard III</td><td></td><td></td><td></td><td>Soufrière Hills; Pelée; Soufrière St. Vincent</td><td>Soufrière Guadeloupe</td><td></td><td></td></tr>
<tr><td>Hazard II</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Hazard I</td><td></td><td></td><td>Kick 'em Jenny</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="9"></td></tr>
<tr><td rowspan="3">UNCLASSIFIED</td><td>U – HHR</td><td></td><td>Saba</td><td></td><td></td><td>Watt, Morne; Qualibou</td><td></td><td></td></tr>
<tr><td>U- HR</td><td></td><td>Quill, The</td><td>Liamuiga</td><td></td><td>Trois Pitons, Morne; Plat Pays, Morne</td><td></td><td></td></tr>
<tr><td>U- NHHR</td><td></td><td></td><td></td><td>Nevis Peak; Diables, Morne aux; Diablotins, Morne</td><td>St. Catherine</td><td></td><td></td></tr>
<tr><td></td><td></td><td>PEI 1</td><td>PEI 2</td><td>PEI 3</td><td>PEI 4</td><td>PEI 5</td><td>PEI 6</td><td>PEI 7</td></tr>
</table>

*Table 298: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
6	5
6	4
2	3
2	2
0	1

Table 299: The number of volcanoes in the West Indies classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
4	III
0	II
1	I
11	Unclassified

Table 300: The number of volcanoes in the West Indies region classified at each Risk Level.

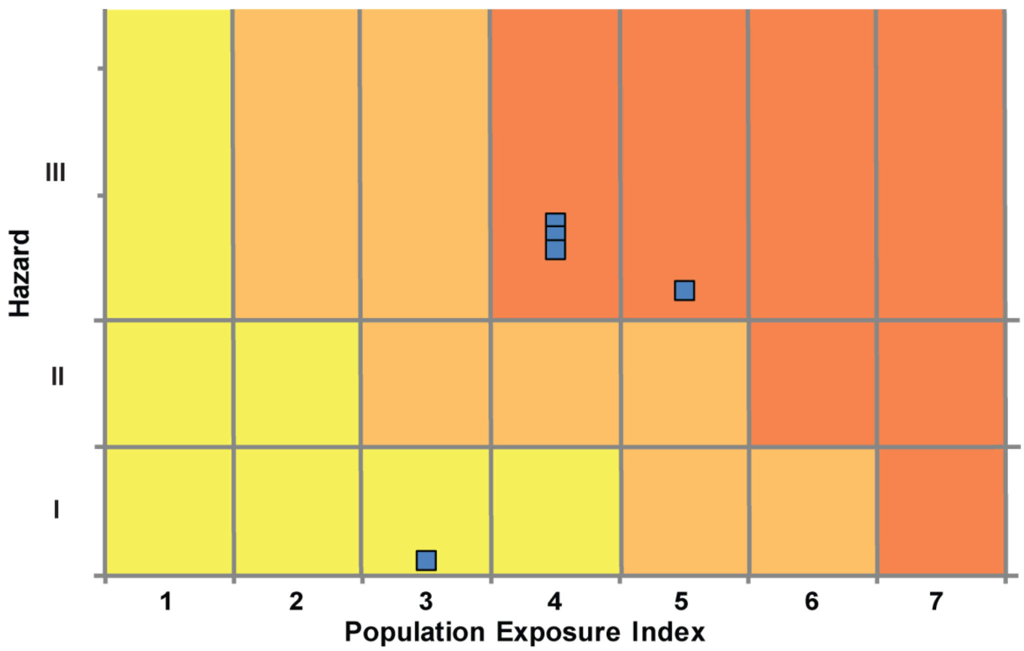

Figure 319: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

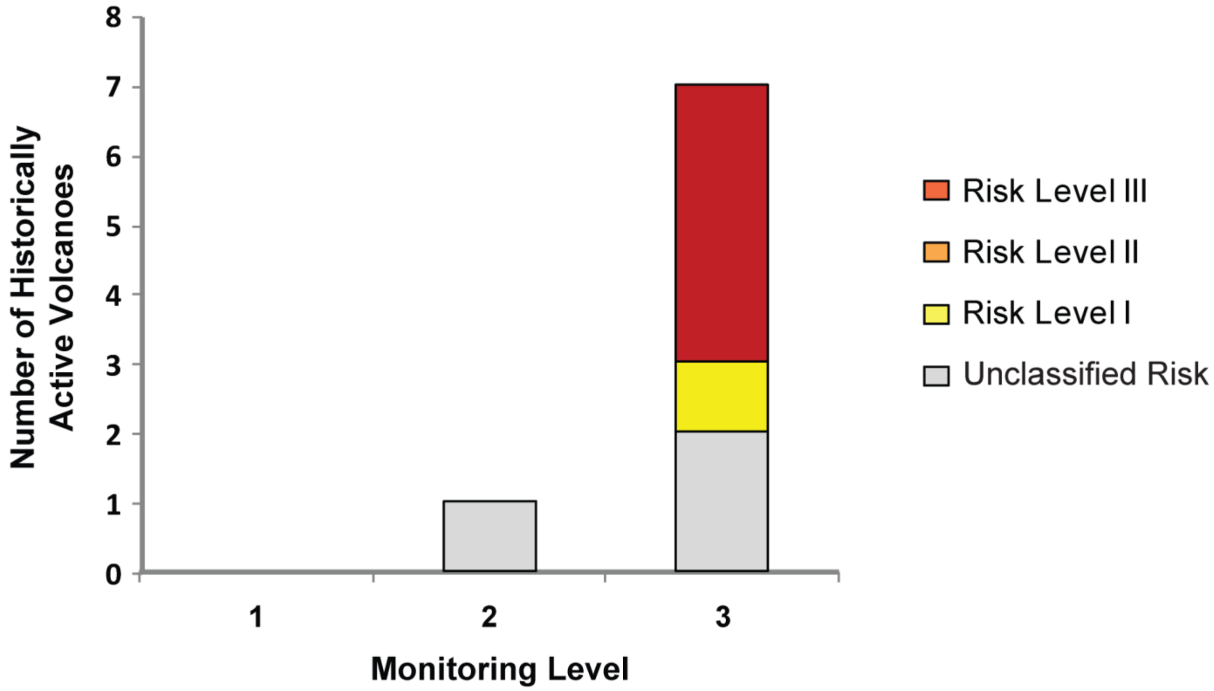

Figure 320: The monitoring and risk levels of the historically active volcanoes in the West Indies. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Dominica

Description

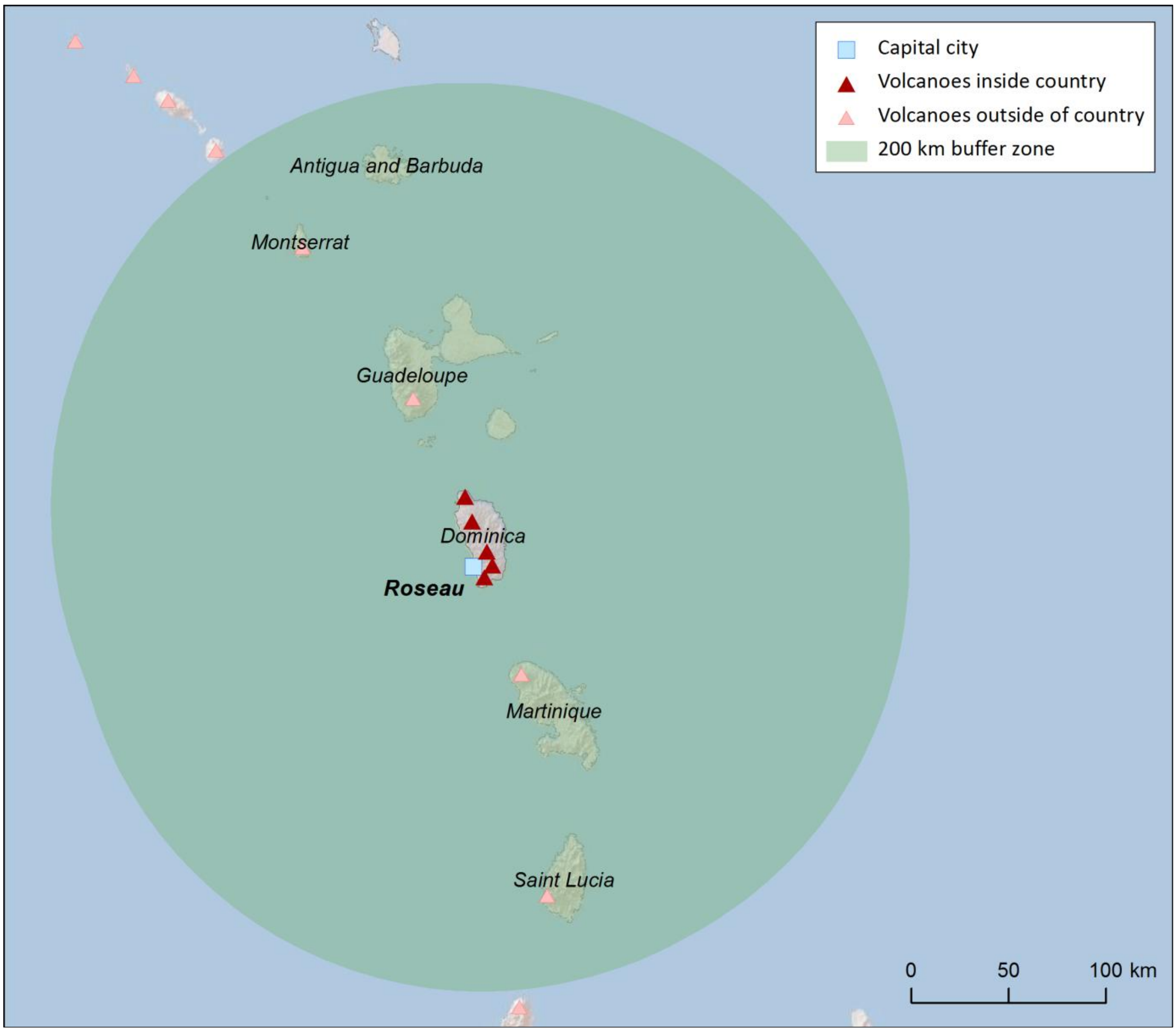

Figure 321: Location of Dominica's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Dominica.

Five Holocene volcanoes are listed in Dominica, aligned roughly in a chain north-south through the centre of the island. Five volcanoes are listed in VOTW4.0, however separate features of these volcanoes including domes and stratovolcanoes are described as separate volcanoes by the University of the West Indies Seismic Research Centre, making a total of nine Holocene volcanoes on Dominica. Here we consider the record of five volcanoes. Volcanism here is due to the subduction of the Atlantic Ocean crust beneath the Caribbean Plate. All volcanoes are stratovolcanoes and complex volcanoes, of dominantly andesitic composition.

Large explosive eruptions are recorded in Dominica from three volcanoes during the Pleistocene, including the M6.4 eruption of the Roseau Tuff from Morne Trois Pitons at about 36,000 years ago. Only Morne Trois Pitons, Morne Watt and Morne Plat Pays have a record of confirmed eruptions during the Holocene, with 11 eruptions of VEI 1 to 2. The other two volcanoes, Morne aux Diables and Morne Diablotins in the north of the island have suspected but unconfirmed Holocene activity. The largest recorded Holocene eruption was that of Morne Watt in 1880, however the size of nine of eleven eruptions is unknown. Morne Watt is the only historically active volcano here, with, in addition to the VEI 2 eruption of 1880, a VEI 1 eruption in 1997.

Despite the absence of data regarding the size of eruptions here, seven out of eleven eruptions produced pyroclastic flows, indicating explosive activity has been commonplace.

Being a relatively small volcanic island, the whole population resides within 30 km of one or more Holocene volcanoes. Indeed, about 84% of the population live within 10 km. The highest proximal population is at Morne Plat Pays, where several towns lie in the valleys radiating from the volcano and the capital, Roseau, lies within 10 km.

Lindsay et al. (2005) present hazard maps for a number of hazard scenarios on the island and present an integrated hazard map of the most likely eruption scenarios. This divides the island into four colour-coded zones, from Green Zone 4 Low hazard to Red Zone 1 Very High Hazard. The southern tip of the island is designated as Very High Hazard, as it includes the immediate area around Morne Watt. Much of the south of the Island is Zone 2, High Hazard, including the capital, Roseau. See Lindsay et al. (2005) for full details.

The University of the West Indies Seismic Research Centre (SRC) is responsible for the monitoring of Dominica's volcanoes. Indeed, they monitor the historically active Morne Watt with multiple dedicated ground-based systems, and also monitor those volcanoes with known or suspected Holocene activity. A monitoring alert system is in place. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre http://www.uwiseismic.com/

Lindsay, J.M., Smith, A.L., Roobol, M.J., and Stasiuk, M.V. (2005) Dominica, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition http://www.uwiseismic.com/Downloads/Dominica_VHA.pdf

Volcano Facts

Number of Holocene volcanoes	5
Number of Pleistocene volcanoes with M≥4 eruptions	3
Number of volcanoes generating pyroclastic flows	3
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-

Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M6.4 eruption of the Roseau Tuff from Morne Trois Pitons at 36,385 BP.
Largest recorded Holocene eruption	The VEI 2 eruption of Morne Watt in 1880 AD.
Number of Holocene eruptions	11 confirmed eruptions.
Recorded Holocene VEI range	1 – 2 and unknown.
Number of historically active volcanoes	1
Number of historic eruptions	2

Number of volcanoes	Primary volcano type	Dominant rock type
5	Large cone(s)	Andesitic (4), Dacitic (1)

Table 301: The number of volcanoes in Dominica, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	72,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	11,120
Gross National Income (GNI) per capita (2005 PPP $)	10,977
Human Development Index (HDI) (2012)	0.745 (High)

Population Exposure

Capital city	Roseau
Distance from capital city to nearest Holocene volcano	7.3 km
Total population (2011)	72,969
Number (percentage) of people living within 10 km of a Holocene volcano	61,224 (83.9%)
Number (percentage) of people living within 30 km of a Holocene volcano	71,052 (97.4%)
Number (percentage) of people living within 100 km of a Holocene volcano	71,052 (97.4%)

Largest cities, as measured by population, and populations:

Roseau	16,571

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	2
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes in Dominca form a chain across the island. Being only a small island, measuring no more than 50 km across the country in its entirety lies within a short distance from Holocene volcanoes. Indeed the 100 km radii of the Dominican volcanoes extends beyond Dominica to encompass Guadeloupe and much of Martinique, exposing much of the critical infrastructure on these islands. The volcanoes of Martinique and Guadeloupe likewise have 100 km radii extending to expose Dominica and the infrastructure here. The capital of Dominica, Roseau, lies less than 10 km from three Holocene volcanoes – Morne Plat Pays, Morne Trois Pitons and the historically active Morne Watt. All infrastructure in Dominica and the whole population lie within 50 km of a Holocene volcano.

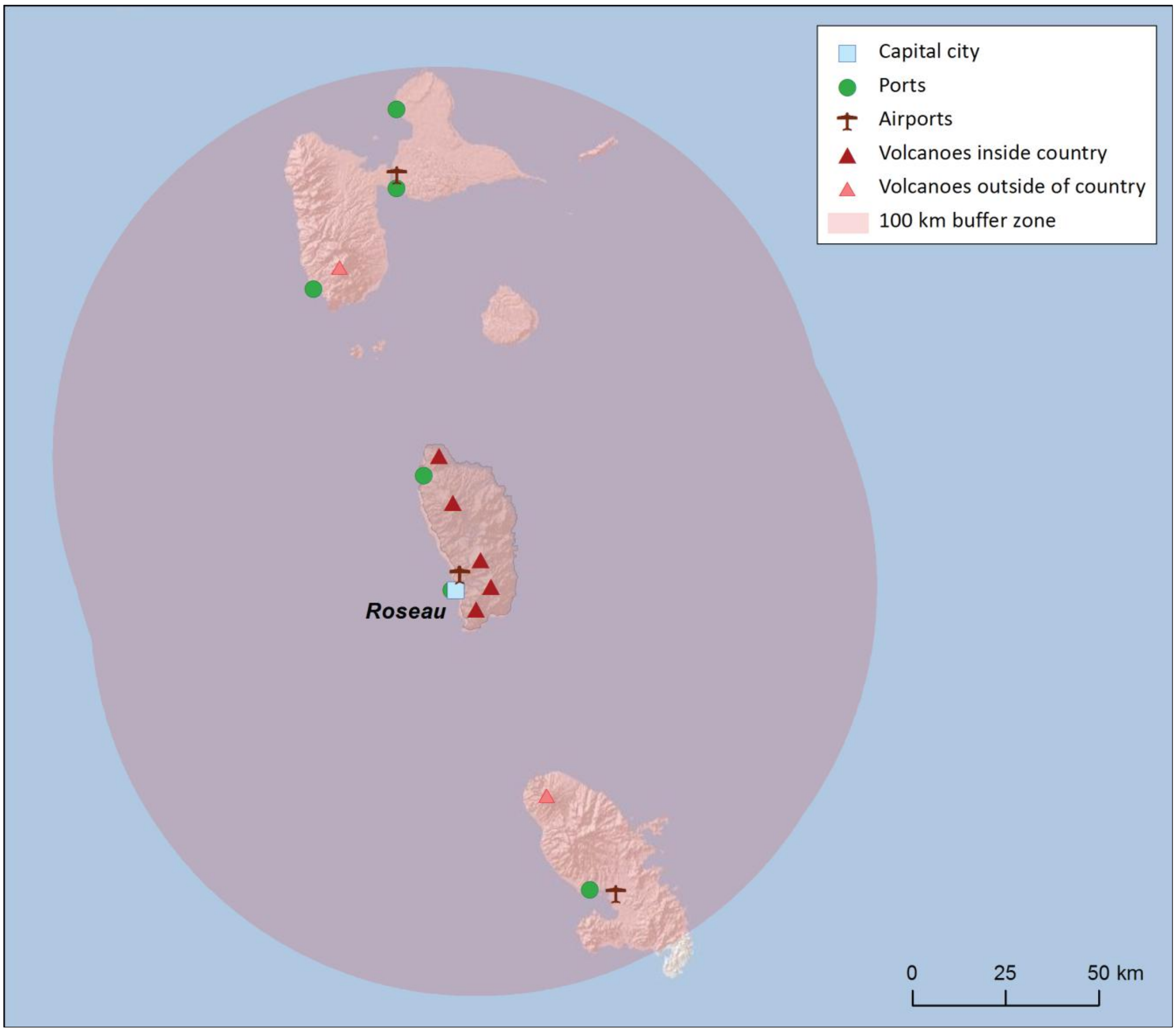

Figure 322: The location of Dominica's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

No volcanoes in Dominica have a sufficiently detailed eruption record to be able to define the hazard level through the calculation of the VHI. These volcanoes are therefore unclassified. Two volcanoes have no confirmed Holocene activity on record. Morne Trois Pitons, Morne Plat Pays and Morne Watt have a Holocene eruption record, including historical activity at the latter. Unrest has been described at Morne aux Diables and Morne Trois Pitons since 1900 AD.

The PEI ranges from 4 to 5 in Dominica, with moderate to high proximal populations. The risk levels cannot be determined here due to the absence of a hazard classification.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**					**Morne Watt**		
	U- HR					**Morne Trois Pitons;** Morne Plat Pays		
	U- NHHR				**Morne aux Diables;** Morne Diablotins			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 302: Identity of Dominica's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

One volcano, Morne Watt, has a record of historical eruptions. This volcano and all Holocene volcanoes here are actively monitored by the Seismic Research Centre (University of the West Indies). At Morne Watt a seismic and deformation network is continuously in operation. Additional monitoring of gases and geochemistry of waters and fumaroles is also regularly undertaken.

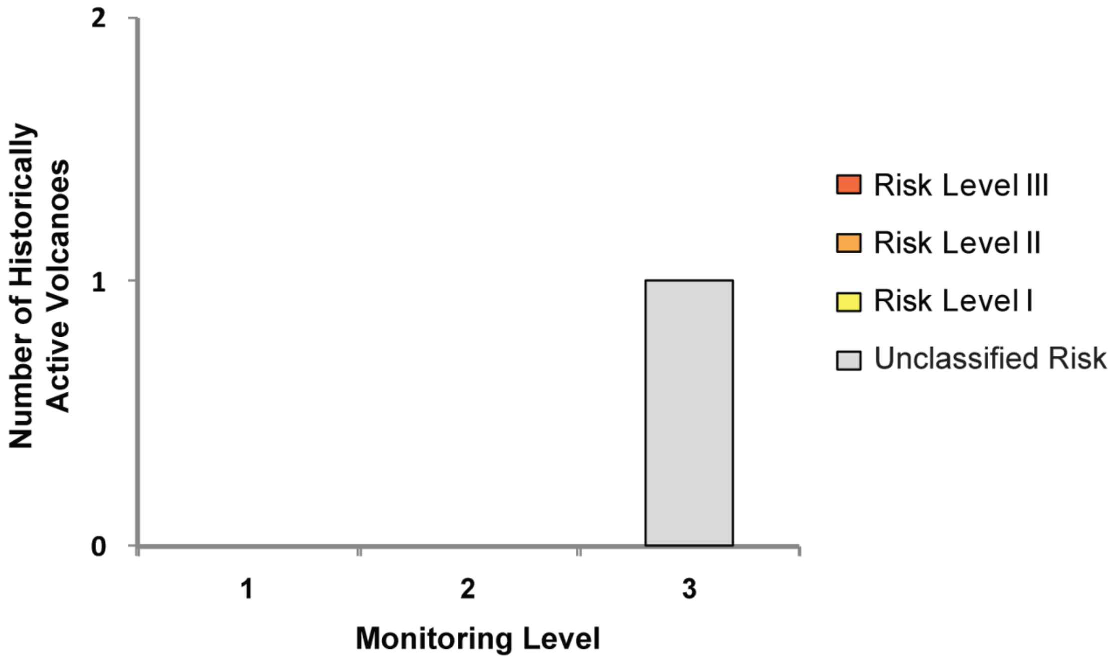

Figure 323: The monitoring and risk levels of the historically active volcanoes in Dominica. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

France – Martinique, Guadeloupe

See Region 1 for mainland France, Region 3 for French territories in the Indian Ocean, Region 13 for French territories in the Pacific Ocean.

Description

Figure 324: Location of Guadeloupe and Martinique's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Guadeloupe and Martinique.

Two islands in the Lesser Antilles are overseas territories of France: Martinique and Guadeloupe. Both of these islands have a Holocene volcano. On Guadeloupe, the La Soufrière Guadeloupe volcano sits in the southern tip of the island. On Martinique, Montagne Pelée is situated in the northern tip of the island. Both these volcanoes are andesitic stratovolcanoes, related to the subduction of the North American Plate beneath the Caribbean Plate.

Both La Soufrière Guadeloupe and Montagne Pelée have a record of Holocene and Pleistocene eruptions. The largest Pleistocene eruption was at La Soufrière of Guadeloupe at about 46,000 years ago, with the M5.3 Pintade eruption.

During the Holocene a total of 74 eruptions are confirmed between the two volcanoes, with most, 54, being recorded at Pelée. These eruptions were of VEI 1 – 4, with large explosive eruptions of VEI 4 recorded at both volcanoes. Twenty-three events were of this size, demonstrating the prevalence of explosive activity on these French islands. Indeed, 86% of recorded eruptions have associated pyroclastic flows.

Eight historical eruptions are recorded at La Soufrière of Guadeloupe, and five at Montagne Pelée. These eruptions have ranged in size from VEI 1 to 4. The largest historical eruption was that of Montagne Pelée in 1902. This catastrophic VEI 4 eruption produced pyroclastic flows and destroyed the city of St. Pierre, resulting in nearly 30,000 fatalities.

Being small islands, relatively high proportions of the population live within 10 km of the volcanoes here, with about 5% of the population of Martinique and 17% of the population of Guadeloupe living within this distance. The whole population lives within 100 km of these volcanic centres.

Boudon et al. (2005) present possible future eruption scenarios for Martinique and suggest that the most probable activity is phreatic events, dome-forming eruptions or open-vent pumiceous eruptions. They also suggest that collapse of the south-western flank of the volcano is of low probability, but consider it due to the devastating effects it could have, including potential for directed blasts and tsunami generation. They present a hazard map for Martinique based on a quantitative assessment of volcanic hazard, showing hazard concentrated around Montagne Pelée and St. Pierre, with much of the southern half of the island being of low hazard.

Komorowski et al., (2005) suggest future eruption scenarios for Guadeloupe in order of decreasing probability of occurrence of: intense prolonged fumarolic activity, phreatic eruptions, edifice collapse eruptions, effusive and explosive dome-forming eruptions and large explosive eruptions. They present an integrated hazard map for these scenarios with the area of highest hazard being located around the summit of La Soufrière of Guadeloupe and to the south-west, with additional high hazard in the valleys radiating from the volcano.

Both La Soufrière of Guadeloupe and Montagne Pelée have dedicated volcano observatories. The Observatoire Volcanologique et Sismologique de la Guadeloupe and the Observatoire Volcanologique et Sismologique de la Martinique run by the Institut de Physique du Globe de Paris manage extensive seismic, deformation and geochemical monitoring networks that are complemented by other geophysical techniques and geological surveys. The monitoring equipment is also used for regional seismic monitoring and tsunami alerts. These monitoring institutions also conduct scientific research to better understand activity here. About 10% of the staff have experience of responding to an eruption. These monitoring institutions do not present risk assessments but are involved in management and mitigation of risks, through interactions with national responsible agencies as well as through a program of hazard education for the public. Since 1999, the level of activity and main results of the monitoring of La Soufrière of Guadeloupe and Montagne Pelée as well as the regional seismic activity are communicated on a monthly basis widely to the authorities, population and stakeholders through a bulletin available on the internet and via email.

In the event of unrest and eruptions the institutions release alerts using an alert level system. Alert levels are also communicated regularly.

See also:

Observatoire Volcanologique et Sismologique de la Guadeloupe - http://www.ipgp.fr/pages/03030402.php

Observatoire Volcanologique et Sismologique de la Martinique - http://www.ipgp.fr/pages/03030302.php

Boudon, G., Le Friant, A., Villemant, B., and Viode, J-P. (2005) Martinique, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Komorowski, J-C., Boudon, G., Semet, M., Beauducel, F., Anenor-Habazac, C., Bazin, S., and Hammouya, G. (2005) Guadeloupe, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	Martinique: 1; Guadeloupe: 1
Number of Pleistocene volcanoes with M≥4 eruptions	Martinique: 1; Guadeloupe: 1
Number of volcanoes generating pyroclastic flows	Martinique: 1; Guadeloupe: 1
Number of volcanoes generating lahars	Martinique: 1; Guadeloupe: 1
Number of volcanoes generating lava flows	Martinique: - Guadeloupe: 1
Number of fatalities caused by volcanic eruptions	Martinique:29,523
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption:	The M5.3 Pintade eruption of Soufrière Guadeloupe at 46,465 BP.
Largest recorded Holocene eruption	The P1, P2 and P3 eruptions of Pelée on Martinique are all recorded as M4.6 and occurred at 610, 1,600 and 1,940 BP.
Number of Holocene eruptions	Guadeloupe: 20 confirmed.

	Martinique: 54 confirmed eruptions.
Recorded Holocene VEI range	1 – 4 and Unknown
Number of historically active volcanoes	Guadeloupe:1
	Martinique: 1
Number of historic eruptions	Guadeloupe: 8
	Martinique: 5

Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Andesitic (2)

Table 303: The number of volcanoes in the French West Indies, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	Martinique: 403,000;
	Guadeloupe: 464,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	-
Gross National Income (GNI) per capita (2005 PPP $)	-
Human Development Index (HDI) (2012)	-

Population Exposure

Capital city	Martinique: Fort-de-France;
	Guadeloupe: Basse-Terre
Distance from capital city to nearest Holocene volcano	Martinique: 26.3 km Guadeloupe: 7.7 km
Total population (2011)	Martinique: 412,465
	Guadeloupe: 456,703
Number (percentage) of people living within 10 km of a Holocene volcano	Martinique: 20,924 (5.1%)
	Guadeloupe: 78,100 (17.1%)
Number (percentage) of people living within 30 km of a Holocene	Martinique: 281,424 (68.2%)

volcano	Guadeloupe: 296,828 (65%)
Number (percentage) of people living within 100 km of a Holocene volcano	Martinique: 402,028 (97.5%) Guadeloupe: 460,883 (100%)

Largest cities, as measured by population, and populations (2011 census data from Institut National de la Statisique et des Études Économiques (INSEE, www.insee.fr):

Fort-De-France	88,182
Les Abymes	60,079
Pointe-à-Pitre	16,191
Basse-Terre	11,962

Infrastructure Exposure

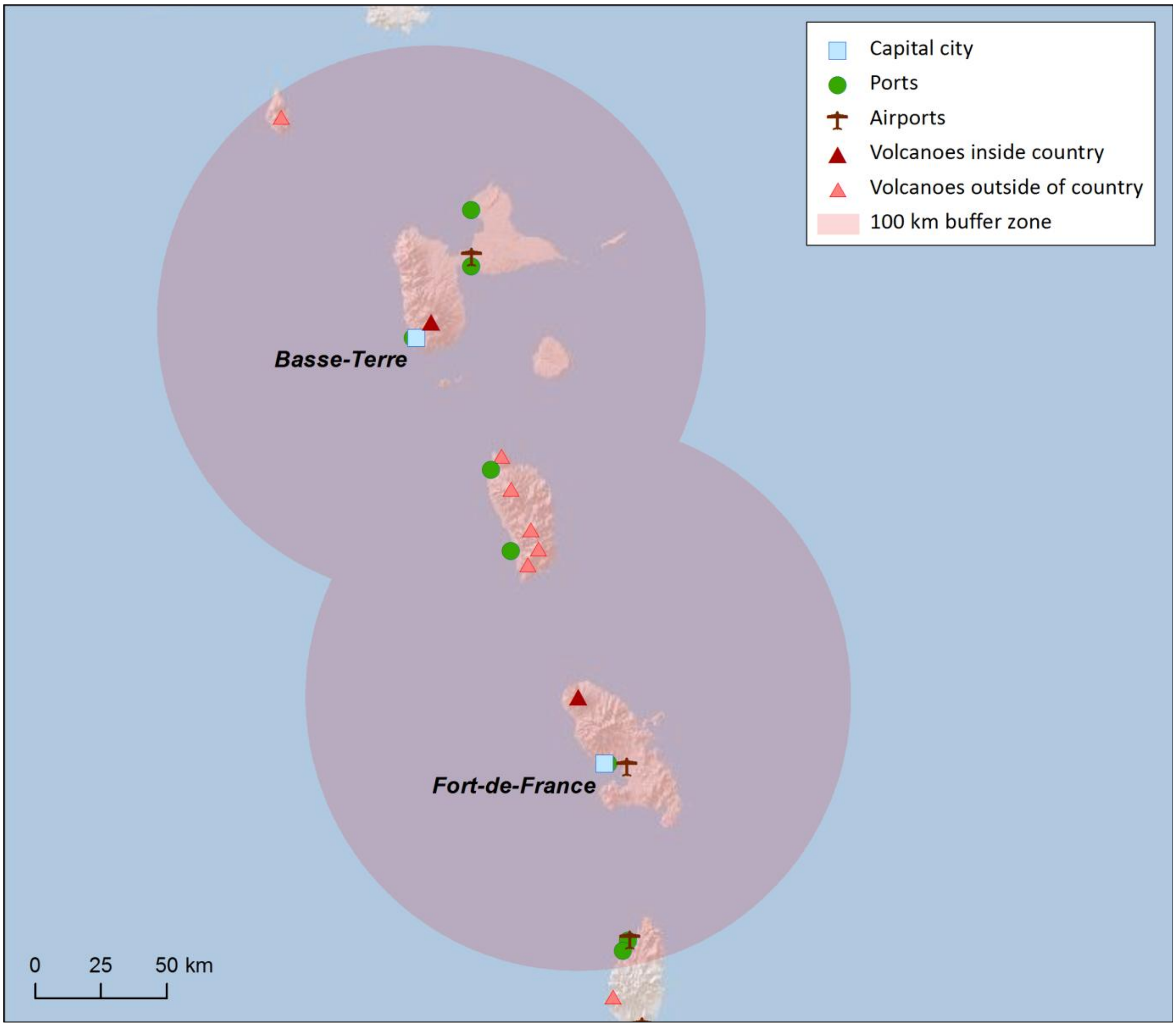

Figure 325: The location of Guadeloupe's and Martinique's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	4
Total length of roads within 100 km of a volcano (km)	753
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes in the French West Indies are located on the southern tip of the island of Guadeloupe and the northern tip of the island of Martinique. Being small islands, measuring no more than 70 km across, these are in their entirety within the 100 km radii of these volcanoes, exposing all infrastructure and population on Guadeloupe and Martinique. The 100 km radii also extend to fully encompass Dominica, exposing all infrastructure here. The 100 km radius of Pelée on Martinique extends to encompass the northern tp of St. Lucia, whilst much of the island of Montserrat is exposed in the 100 km radius of La Soufrière of Guadeloupe. Likewise, the radii of Soufrière Hills Volcano extends to Guadeloupe.

Hazard, Uncertainty and Exposure Assessments

Both La Soufrière of Guadeloupe and Montagne Pelée have sufficient information in their eruption records to define a hazard level through calculation of the VHI. Both are classed as Hazard Level III, with VEI 4 Holocene eruptions and a history of explosive eruptions producing pyroclastic flows.

The PEI at La Soufrière of Guadeloupe and Montagne Pelée is 5 and 4 respectively, with moderate to large proximal populations, including over 70,000 living within 10 km at Soufrière Guadeloupe. With a Hazard Level of III, both volcanoes are classed at Risk Level III.

Volcano	Population Exposure Index	Risk Level
Soufrière Guadeloupe	5	III
Pelée	4	III

Table 304: Classified volcanoes of Guadeloupe and Martinique ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 2 volcanoes.

CLASSIFIED	**Hazard III**				Pelée	Soufrière Guadeloupe		
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR							
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 305: Identity of Martinique's and Guadeloupe's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

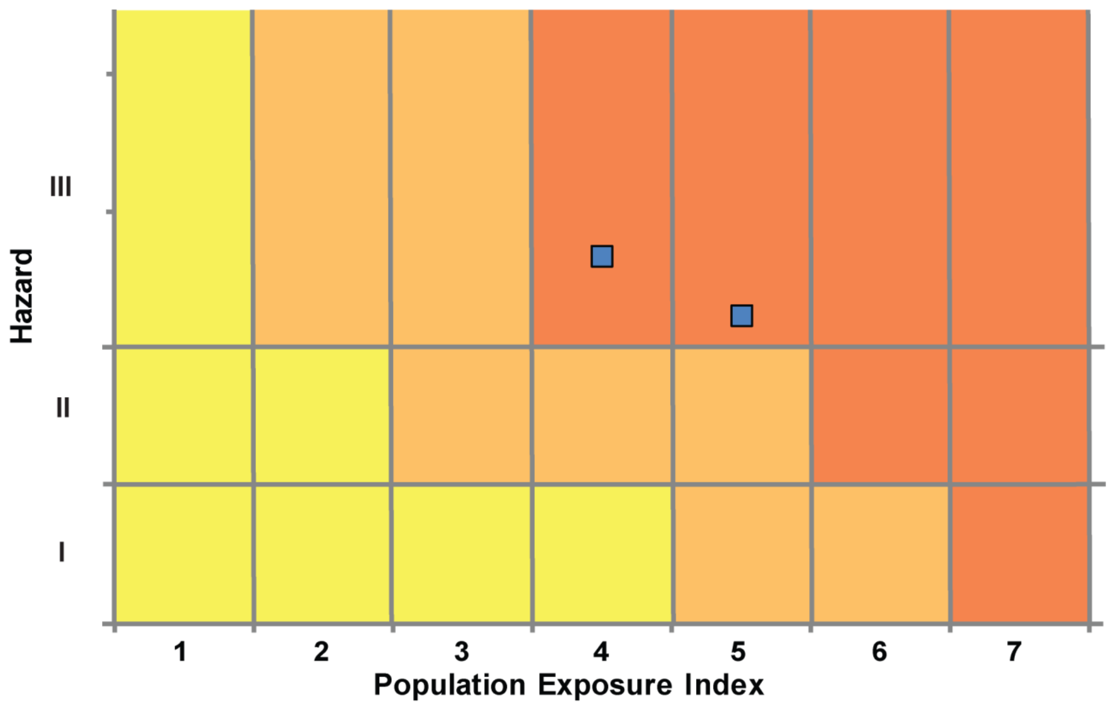

Figure 326: Distribution of Martinique and Guadeloupe's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Both Soufrière Guadeloupe and Pelée are monitored by the Observatoire Volcanologique et Sismologique de Guadeloupe (OVSG/IPGP) and Observatoire Volcanologique et Sismologique de Martinique (OVSM/IPGP) respectively. Extensive seismic, deformation and geochemical networks are in place at both volcanoes.

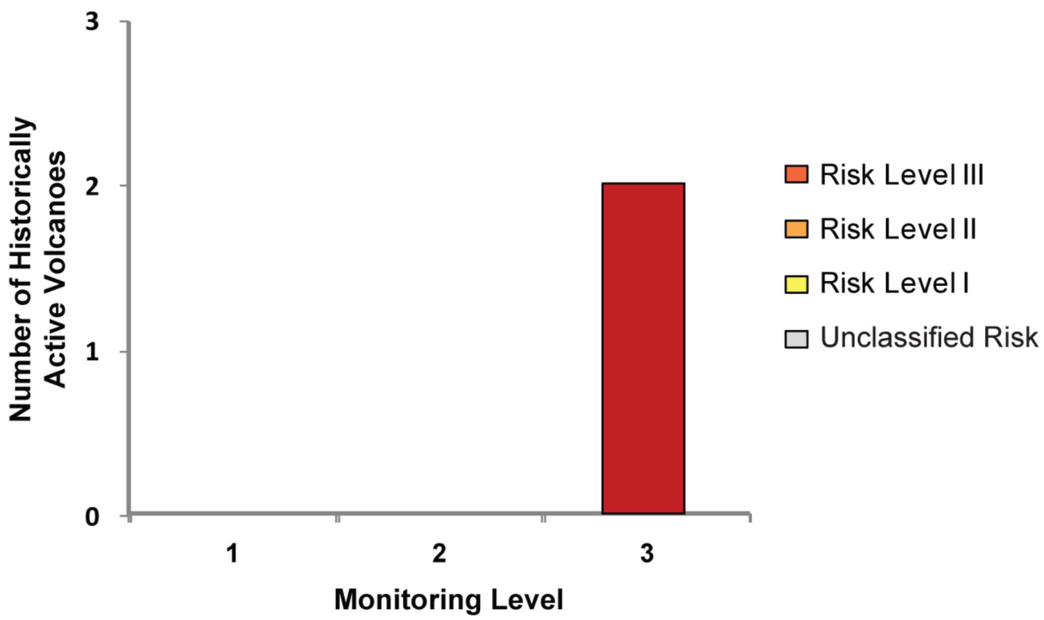

Figure 327: The monitoring and risk levels of the historically active volcanoes in Martinique and Guadeloupe. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Grenada

Description

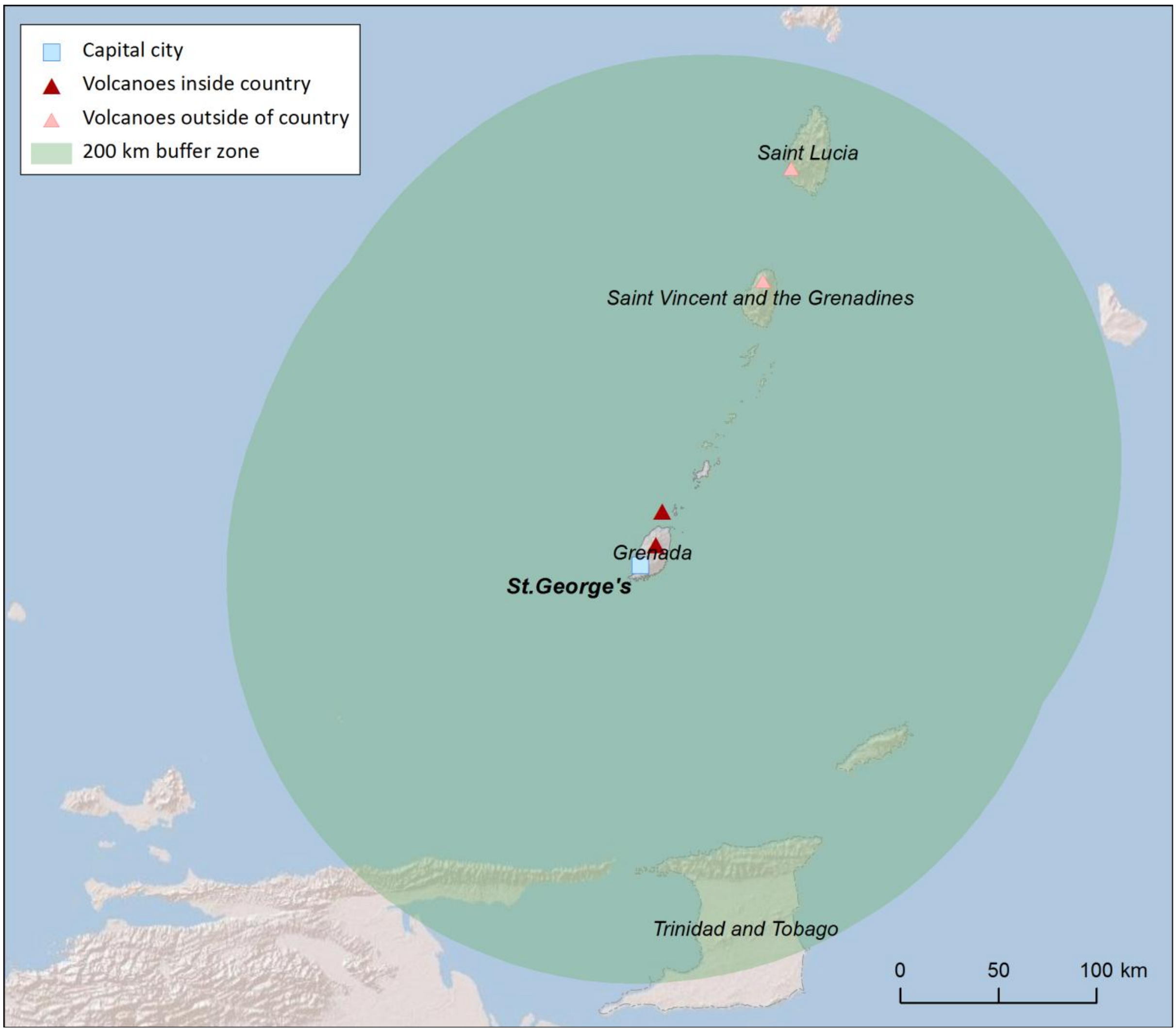

Figure 328: Location of Grenada volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Grenada.

Two Holocene volcanoes are present in Grenada: one, the andesitic stratovolcano St.Catherine is situated in the north of the island, and the second, the basaltic submarine Kick 'em Jenny located off the northern shore. Volcanism here is due to the subduction of the Atlantic Ocean beneath the Caribbean Plate.

Only Kick 'em Jenny has a Holocene record of confirmed eruptions, with 13 VEI 0 – 1 eruptions. St. Catherine is also suspected of having Holocene age activity. Activity at Kick 'em Jenny has involved both explosions and lava effusion. The largest eruption on record occurred in 1939 when an eruption cloud rose to nearly 300 m above the surface of the sea.

Being a small island group, the entire population lives close to the volcanoes. Being the only subaerial volcano here, the largest proximal population is located at St. Catherine.

Submarine volcanoes can pose various hazards. Ballistics may breach the surface though these are unlikely to reach the main island of Grenada. Gas release from the volcanoes can lower the water density. Ships may lose buoyancy and sink due to this, and indeed it is suggested that Kick 'em Jenny may have caused the sinking of the Island Queen with over 60 people on board in 1944.

Robertson (2005) presents eruption scenarios for the island, comprising dome growth and explosive eruption. Integrated hazard maps are presented in which the highest hazard is concentrated in the north of the island around St. Catherine volcano. Also of note is the presence of explosion craters running approximately NNE-SSW through the island, which may suggest that further craters may develop.

The University of the West Indies Seismic Research Centre (SRC) is responsible for the monitoring of Grenada's volcanoes. Indeed, they monitor the historically active Kick 'em Jenny with multiple seismic and deformation stations placed on islands close to this submarine volcano. They also monitor the Holocene volcano St. Catherine. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre: http://www.uwiseismic.com/

Robertson, R. (2005) Grenada, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The VEI 1 eruption of Kick 'em Jenny of 1939 AD.
Number of Holocene eruptions	13 confirmed eruptions.
Recorded Holocene VEI range	0 – 1 and unknown.
Number of historically active volcanoes	1

Number of historic eruptions	12

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Andesitic (1)
1	Submarine	Basaltic (1)

Table 306: The number of volcanoes in Grenada, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	106,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	9,806
Gross National Income (GNI) per capita (2005 PPP $)	9,257
Human Development Index (HDI) (2012)	0.770 (High)

Population Exposure

Capital city	St. George's
Distance from capital city to nearest Holocene volcano	12.6 km
Total population (2011)	108,419
Number (percentage) of people living within 10 km of a Holocene volcano	50,457 (46.5%)
Number (percentage) of people living within 30 km of a Holocene volcano	103,820 (95.8%)
Number (percentage) of people living within 100 km of a Holocene volcano	105,009 (96.9%)

Largest cities, as measured by population, and populations:

Saint George's	7,500

Infrastructure Exposure

Number of airports within 100 km of a volcano	1

Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes of Grenada are located on the main island and about 8 km off the coast of the main island. Being a group of small islands, with Grenada itself measuring no more than 40 km across, the country in its entirety lies within 100 km of the Holocene volcanoes, exposing all infrastructure here. Indeed, the 100 km radii of the volcanoes here extends beyond Grenada to encompass much of the Grenadines.

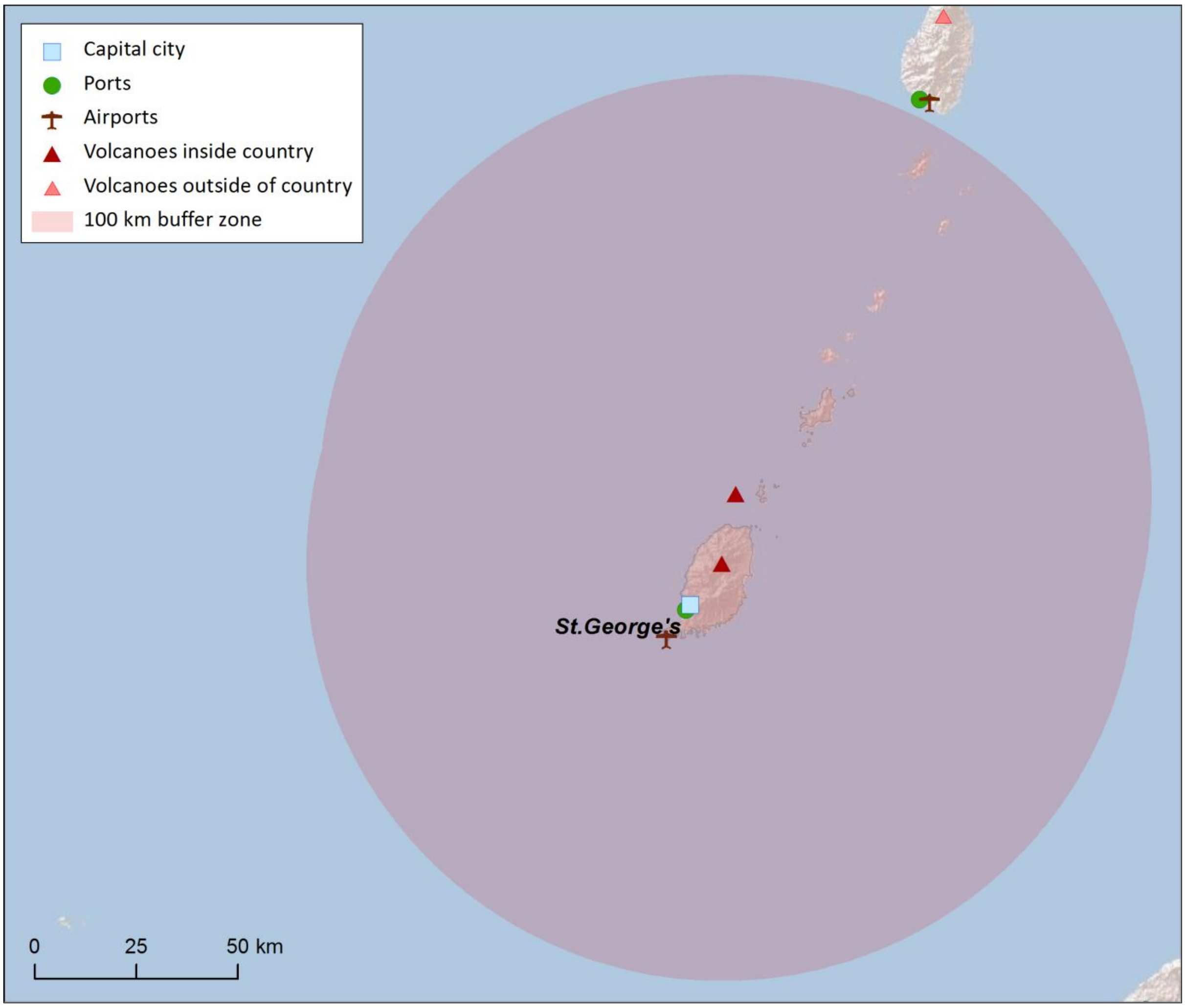

Figure 329: The location of Grenada's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The two volcanoes of Grenada have very different eruption records. St. Catherine has no confirmed Holocene eruptions, and this volcano cannot therefore have a hazard level determined without large associated uncertainties. Kick ‘em Jenny is sufficiently well known to classify this volcano as Hazard Level I. Kick’em Jenny has a moderate PEI and is classed at Risk Level I.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I			Kick ‘em Jenny				
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR					St. Catherine		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 307: Identity of Grenada’s volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed “classified” (top). Those without sufficient data are “Unclassified” (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Kick 'em Jenny	3	I

Table 308: Volcanoes of Grenada ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

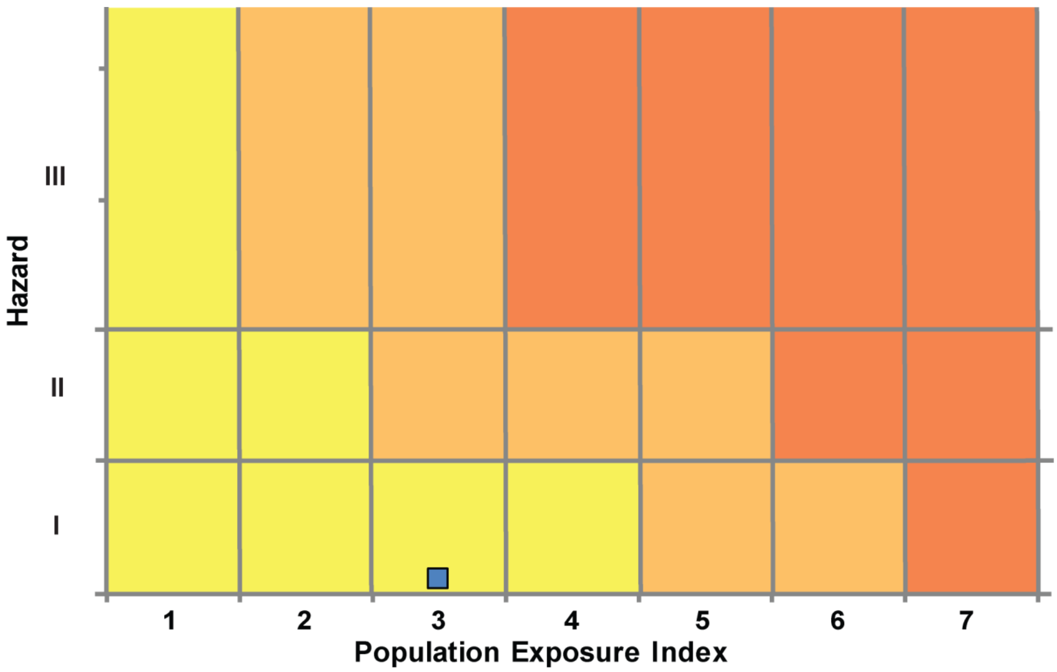

Figure 330: Distribution of Grenada's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Kick'em Jenny, the only historically active volcano in Grenada is monitored by the University of West Indies Seismic Research Centre. Being a submarine volcano, monitoring is undertaken using seismic and deformation stations on nearby islands. The SRC also monitor the Holocene volcano St. Catherine.

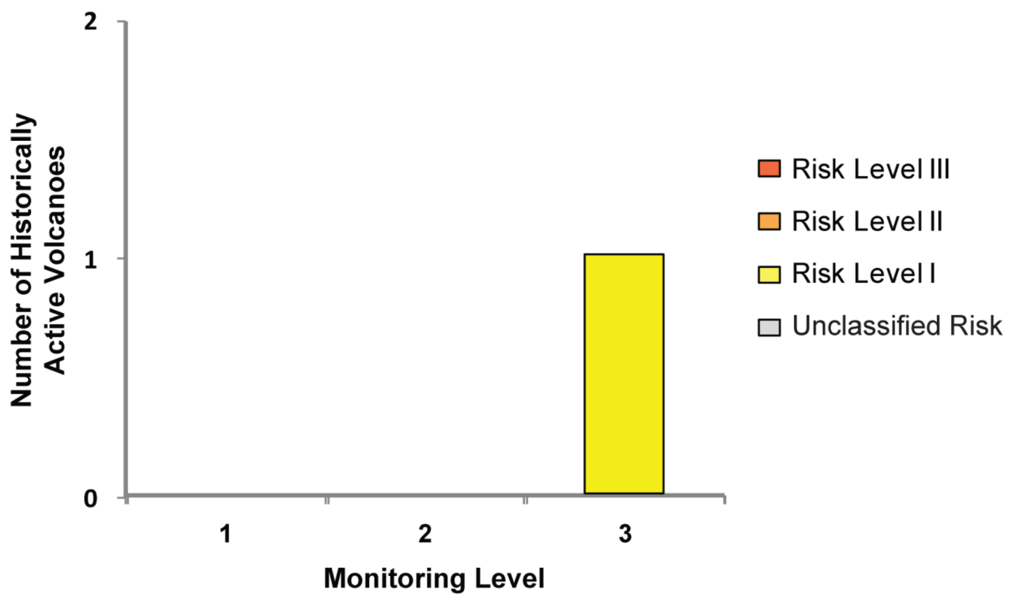

Figure 331: The monitoring and risk levels of the historically active volcanoes in Grenada. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Netherlands (Dutch Antilles)

Description

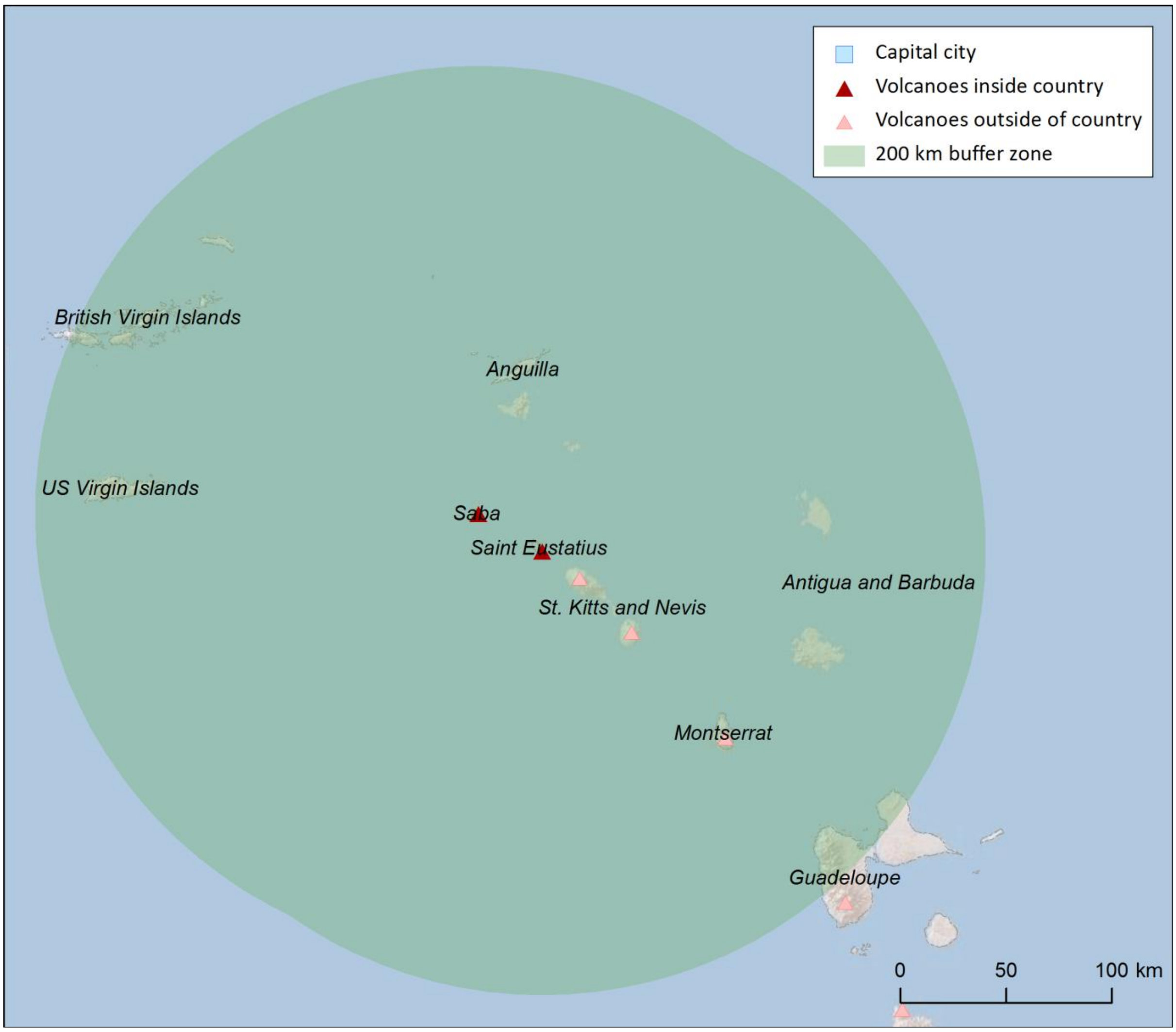

Figure 332: Location of the Dutch Antilles' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Dutch Antilles.

Two Holocene volcanoes are located in the Dutch Antilles, on the islands of Saba and Sint Eustatius in the northern Lesser Antilles. These andesitic stratovolcanoes result from the subduction of the Atlantic Ocean Crust beneath the Caribbean Plate.

Both Saba and The Quill volcanoes have confirmed Holocene eruptions on record, with just one historic eruption at Saba in 1640, and three Holocene eruptions at The Quill from 6140 BC to 250 AD. Only the 6140 BC eruption of The Quill has a known size, at VEI 4; the other eruptions are of unknown magnitude. Despite the absence of data regarding the size of eruptions, all four events produced pyroclastic flows, indicating explosive activity has been commonplace. Hot springs are located on these islands and recent unrest in the form of seismicity is recorded.

Being small islands, the population of Saba and Sint Eustatius are situated in close proximity to the volcanoes. This accounts for about 25% of the population of the Dutch Antilles, with much of the population located in another island group off the Venezuela coast.

Smith and Roobol (2005) present eruption scenarios and suggest that the most likely style of future magmatic activity at Saba will involve the growth of a lava dome and associated block and ash flows and surges. They present volcanic hazard maps for Saba indicating that the entire island is considered Very High Hazard in the event of a dome-forming eruption. Smith and Roobol (2005) suggest that the most likely eruption scenario for future activity at The Quill is an explosive eruption producing pyroclastic flows, surges and ash fall. They indicate that only the north-west section of the island of Sint Eustatius lies outside of the High hazard zone for pyroclastic flows and surges (but still considered moderate), with much of the island being considered Very High Hazard and the whole island being High to Very High Hazard. See Smith and Roobol (2005) for full details.

The Koninklijk Nederlands Meteorologisch Instituut is responsible for the monitoring of the volcanoes of the Dutch Antilles. Indeed, they monitor the historically active Saba volcano with seismic and deformation stations, and also monitor the Quill. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

Smith, A.L., and Roobol, M.J. (2005) Saba, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Smith, A.L., and Roobol, M.J. (2005) St. Eustatius, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	2
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The M4 6140 BC eruption of The Quill.
Number of Holocene eruptions	4 confirmed eruptions.

Recorded Holocene VEI range	4 and unknown.
Number of historically active volcanoes	1
Number of historic eruptions	1

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
2	Large cone(s)	Andesitic (2)

Table 309: The number of volcanoes in the Dutch Antilles, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	44,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	
Gross National Income (GNI) per capita (2005 PPP $)	
Human Development Index (HDI) (2012)	

Population Exposure

Capital city	Willemstad
Distance from capital city to nearest Holocene volcano	789.3 km
Total population (2011)	15,021
Number (percentage) of people living within 10 km of a Holocene volcano	3,797 (25.3%)
Number (percentage) of people living within 30 km of a Holocene volcano	3,797 (25.3%)
Number (percentage) of people living within 100 km of a Holocene volcano	3,797 (25.3%)

Largest cities, as measured by population, and populations:

Willemstad	125,000

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The islands of the Dutch Antilles form two groups in the Caribbean, one group off the coast of Venezuela and another in the northern Lesser Antilles. It is this northern group where the volcanoes are situated on the islands of Saba and Sint Eustatius. Being small islands, these are encompassed in their entirety within the 100 km radii of the volcanoes, as are the islands of St. Kitts and Nevis and north beyond Anguilla. Indeed, the 100 km radii of the volcanoes of St. Kitts and Nevis extend to encompass these northern islands of the Dutch Antilles exposing the infrastructure here. All infrastructure in this group of islands is exposed.

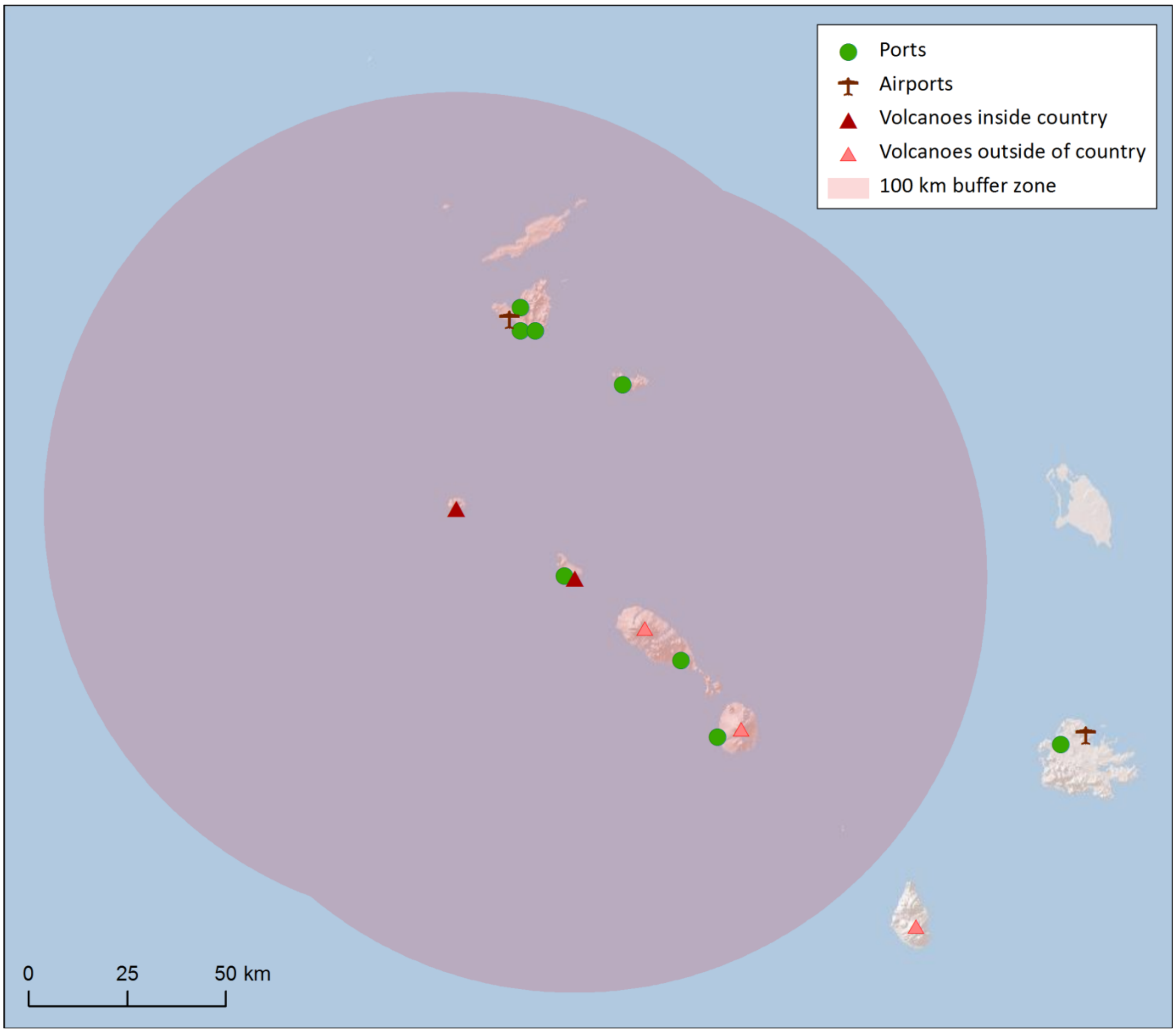

Figure 333: The location of the Dutch Antilles volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Neither Saba nor The Quill have sufficiently detailed eruptive records to enable hazard classification through calculation of the VHI. Saba has a historical record of activity, along with unrest documented since 1900 AD. The Quill has three known Holocene eruptions, with one a VEI 4.

The PEI at Saba and The Quill is low at PEI 2.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		**Saba**					
	U- HR		The Quill					
	U- NHHR							
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 310: Identity of the Dutch Antilles' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Seismometers are in place for monitoring of the Saba volcano, operated by the Koninklijk Nederlands Meteorologisch Instituut.

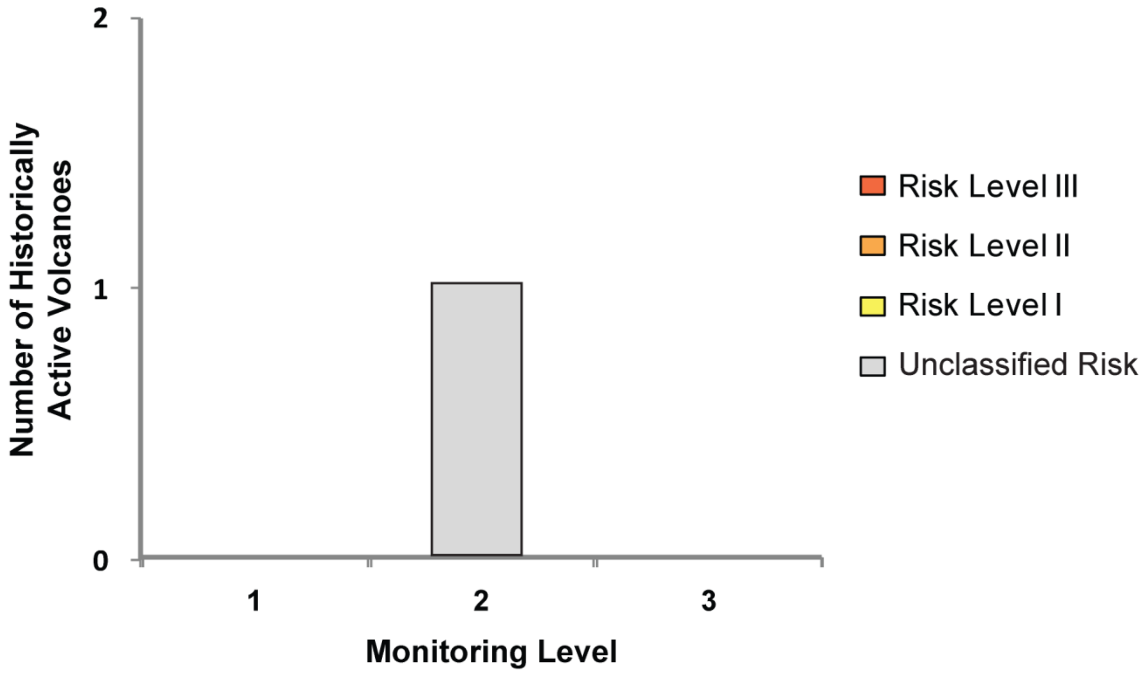

Figure 334: The monitoring and risk levels of the historically active volcanoes in the Dutch Antilles. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

St. Kitts and Nevis

Description

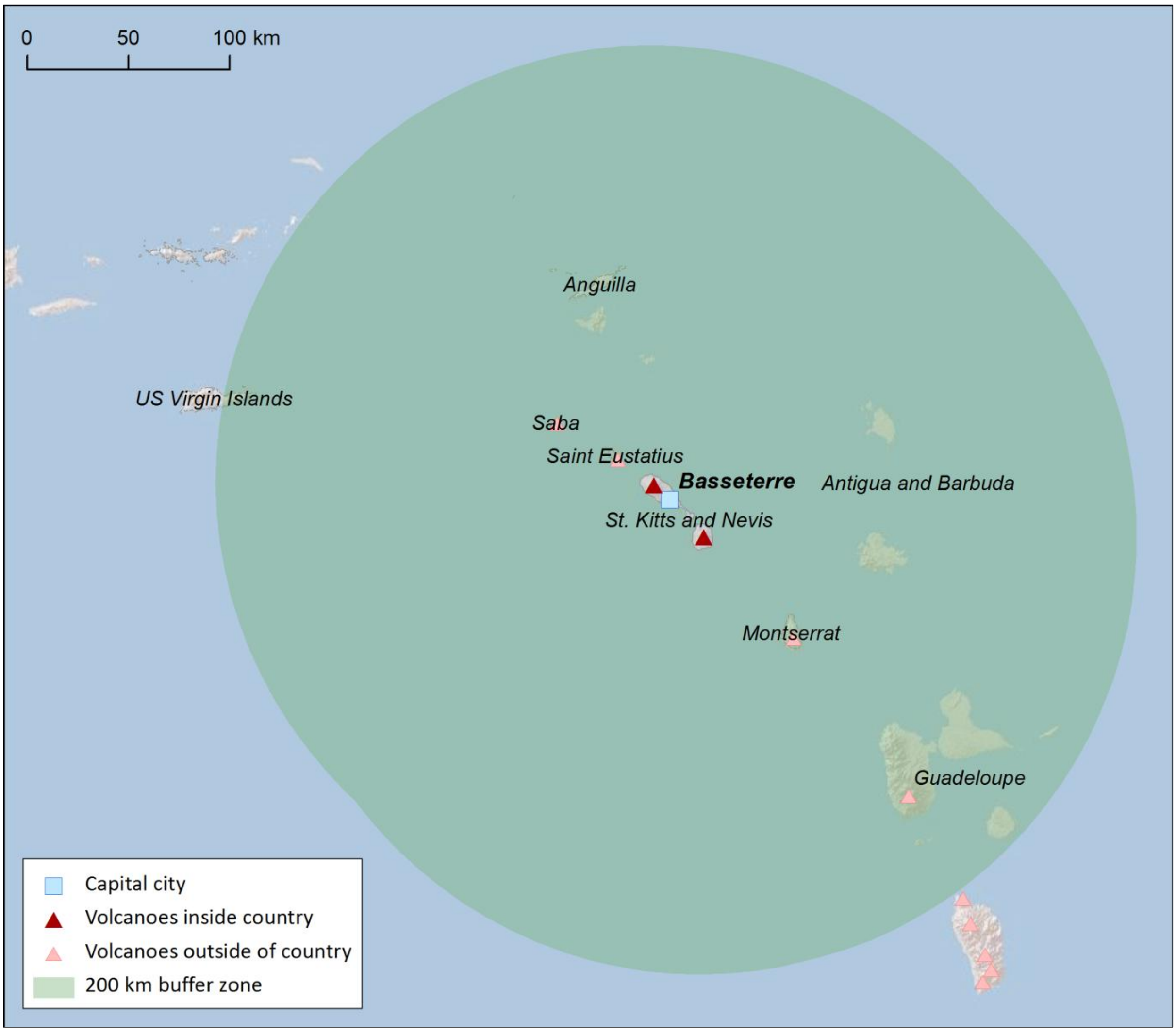

Figure 3355: Location of St Kitts and Nevis' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect St Kitts and Nevis.

Two Holocene volcanoes are located in St. Kitts and Nevis: Liamuiga on the island of St. Kitts and Nevis Peak central on Nevis. These two andesitic stratovolcanoes have formed due to the subduction of the Atlantic Ocean crust beneath the Caribbean Plate.

Only Liamuiga has a confirmed Holocene record of eruptions, with two eruptions of VEI 4 and one of unknown magnitude recorded in 2010 BC, 160 AD and 60 AD respectively. All three eruptions of Liamuiga reportedly produced pyroclastic flows, indicating that explosive activity is prevalent here. One of these events also resulted in a lahar and the deposits of this now underlie populated coastal regions on the island. The most recent dated eruption of Nevis Peak was about 100,000 years ago and the Holocene age of other activity here is questionable, however, active fumaroles and hot springs on Nevis Island and seismic swarms during the 20th century indicate unrest.

With a sparse eruptive record, assessment of hazard at Nevis Peak is difficult and associated with large uncertainties. The record is better constrained at Liamuiga, however recent historical eruptions are uncertain. Robertson (2005) present hazard maps for a number of eruption scenarios at Liamuiga and present integrated hazard maps, where the north of the island of St. Kitts is considered the area of highest hazard. Simpson (2005) present hazard maps for effusive dome building eruptions from Nevis Peak and shows that the whole of Nevis Island is considered Very High Hazard or high hazard with a large proportion of the island susceptible to inundation by pyroclastic flows.

Being relatively small islands, the whole country is situated close to these Holocene volcanoes, and about three quarters of the population live within 10 km of a Holocene volcano.

The University of the West Indies Seismic Research Centre (SRC) monitors the volcanoes of St. Kitts and Nevis using seismic and deformation networks and additional monitoring of springs and fumaroles when activity permits. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre http://www.uwiseismic.com/

Robertson, R. (2005) St. Kitts, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Simpson, K. (2005) Nevis, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Both the D and F eruptions of Liamuiga, at 4470 and 1777 BP respectively are recorded at M4.
Number of Holocene eruptions	3 confirmed eruptions. 2 uncertain eruptions.

Recorded Holocene VEI range	4 and unknown.
Number of historically active volcanoes	-
Number of historic eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Andesitic (2)

Table 311: The number of volcanoes in St Kitts and Nevis, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	54,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	13,291
Gross National Income (GNI) per capita (2005 PPP $)	12,460
Human Development Index (HDI) (2012)	0.745 (High)

Population Exposure

Capital city	Basseterre
Distance from capital city to nearest Holocene volcano	10 km
Total population (2011)	50,314
Number (percentage) of people living within 10 km of a Holocene volcano	37,080 (73.7%)
Number (percentage) of people living within 30 km of a Holocene volcano	52,989 (>100%)
Number (percentage) of people living within 100 km of a Holocene volcano	52,989 (>100%)

Largest cities, as measured by population, and populations:

Basseterre	12,920

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	2
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes of St. Kitts and Nevis are located on both islands. Being small islands measuring no more than about 50 km across, this country in its entirety lies close to Holocene volcanoes. The 100 km radii of these volcanoes extend beyond the country's borders to encompass the northern islands of the Dutch Antilles, Montserrat, Antigua and Barbuda and much of Anguilla, exposing much of the infrastructure in the northern Lesser Antilles. Indeed the 100 km radii of the volcanoes of these other islands, including Soufriere Hills on Montserrat and Saba and The Quill of the Dutch Antilles encompasses and exposes St.Kitts and Nevis to the volcanic hazard.

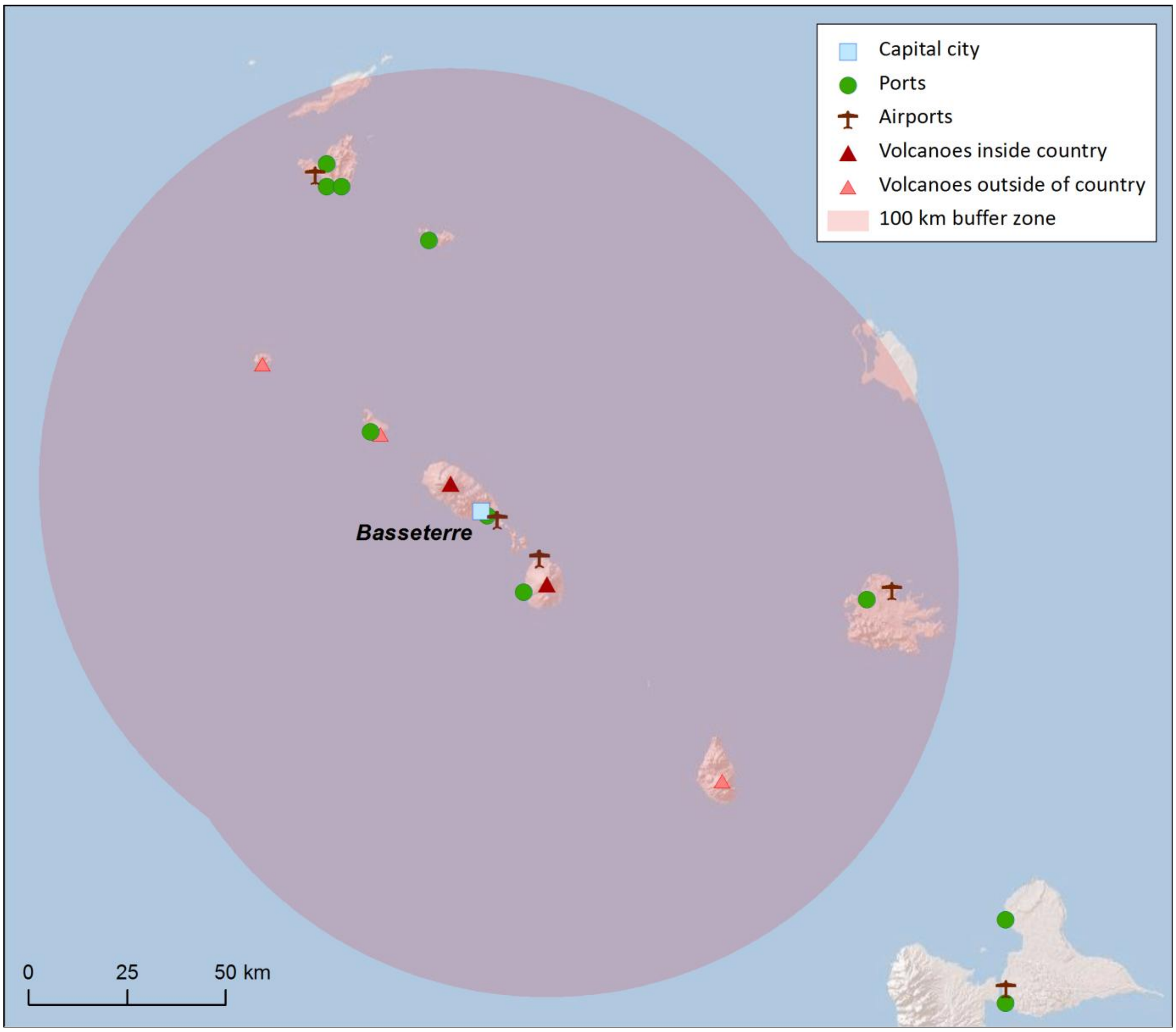

Figure 336: The location of St Kitts and Nevis' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Neither Liamuiga nor Nevis Peak have sufficient eruption records to determine the hazard level through calculation of the VHI. Indeed, there are no confirmed Holocene age eruptions at Nevis Peak. Three Holocene eruptions are recorded at Liamuiga, with two VEI 4 events. Both volcanoes have experienced unrest since 1900 AD suggesting active systems.

With moderate proximal populations in St Kitts and Nevis, these volcanoes are classed at PEI 3 and 4. Risk levels cannot be determined due to lack of hazard data.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR			**Liamuiga**				
	U- NHHR				**Nevis Peak**			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 312: Identity of St Kitts and Nevis' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in St Kitts and Nevis have recorded historical eruptions, however seismic and deformation monitoring is undertaken here by the Seismic Research Centre.

St. Lucia

Description

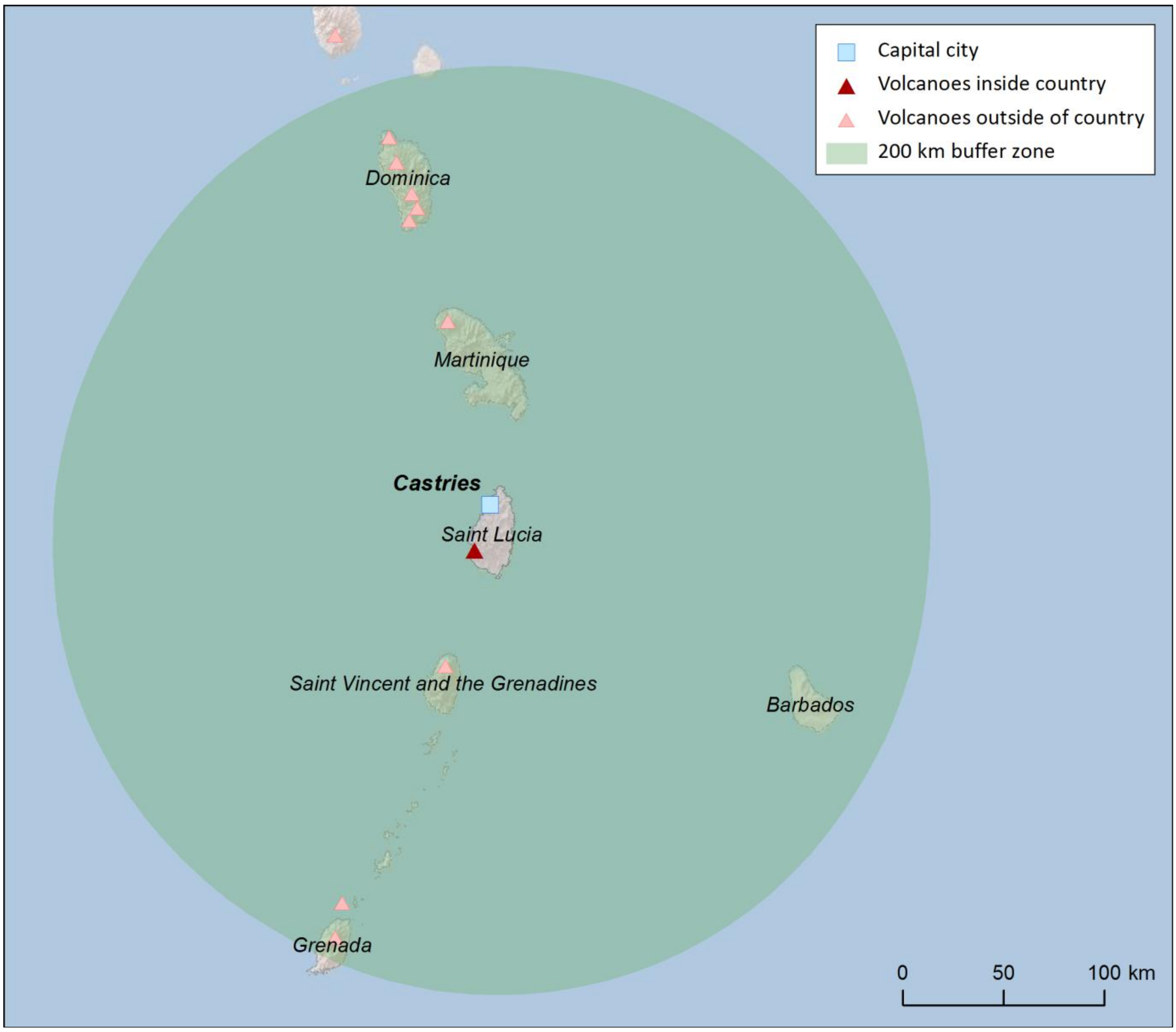

Figure 337: Location of St Lucia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect St Lucia.

One Holocene volcano, Qualibou, is located in the south-east of the island of St. Lucia. This andesitic caldera is due to the subduction of the Atlantic Ocean crust beneath the Caribbean Plate.

Qualibou has a Pleistocene record of large explosive eruptions, with the M6.1 eruption of the Choiseul Tuff about 42,000 years ago forming the present caldera. Numerous post-caldera lava dome fill the crater floor. Only one Holocene eruption is confirmed, with a small VEI 1 phreatic eruption in 1766 that produced a thin layer of ash over an extensive area. The history of large explosive eruptions and andesitic composition suggests that future large explosive eruptions cannot be ruled out. However, Lindsay (2005) suggests that phreatic or hydrothermal eruptions or small explosive eruptions forming explosion craters are most likely. Unrest occurred in 1990 with a volcanic earthquake swarm.

Lindsay (2005) presents eruption scenarios and hazard maps for dome forming eruptions and explosive Plinian eruptions at Qualibou. These show the hazard concentrated in the south-east of the island, around the volcanic centre, with High and Very High Hazard across much of the south and centre of St. Lucia in the event of an explosive Plinian eruption. See Lindsay (2005) for further detail.

Being a relatively small island, the whole population resides close to the volcano, with about 20% of the population living within 10 km.

The University of the West Indies Seismic Research Centre (SRC) is responsible for the monitoring of St. Lucia's volcanoes. Indeed, they monitor Qualibou with multiple dedicated ground-based systems. A monitoring alert system is in place. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre http://www.uwiseismic.com/

Lindsay, J.M. (2005) St. Lucia, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M6.1 eruption of the Choiseul Tuff from Qualibou at 42,264 BP.
Largest recorded Holocene eruption	The VEI 1 eruption of Qualibou in 1766 AD.
Number of Holocene eruptions	1 confirmed eruption.
Recorded Holocene VEI range	1
Number of historically active volcanoes	1
Number of historic eruptions	1

Number of volcanoes	Primary volcano type	Dominant rock type
1	Caldera(s)	Andesitic (1)

Table 313: The number of volcanoes in St Lucia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	181,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	8,231
Gross National Income (GNI) per capita (2005 PPP $)	7,971
Human Development Index (HDI) (2012)	0.725 (High)

Population Exposure

Capital city	Castries
Distance from capital city to nearest Holocene volcano	23.5 km
Total population (2011)	161,557
Number (percentage) of people living within 10 km of a Holocene volcano	28,310 (17.5%)
Number (percentage) of people living within 30 km of a Holocene volcano	178,196 (>100%)
Number (percentage) of people living within 100 km of a Holocene volcano	179,005 (>100%)

Largest cities, as measured by population, and populations:

Cul De Sac	8,467
Castries	<50,000

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

Qualibou volcano is located in the south-east of the island of St. Lucia. Being only a small island, measuring no more than about 50 km across, this country in its entirety lies within the 100 km radius of this volcano and thus all infrastructure and population is exposed here. Indeed the 100 km radius extends beyond St. Lucia to fully encompass St. Vincent and extend into the Grenadines, and largely encompass Martinique, exposing the infrastruture and population on these islands. The 100 km radii of Pelée on Martinique and Soufrière St.Vincent on the island of St. Vincent also extend to encompass St. Lucia and thus expose the infrastructure here.

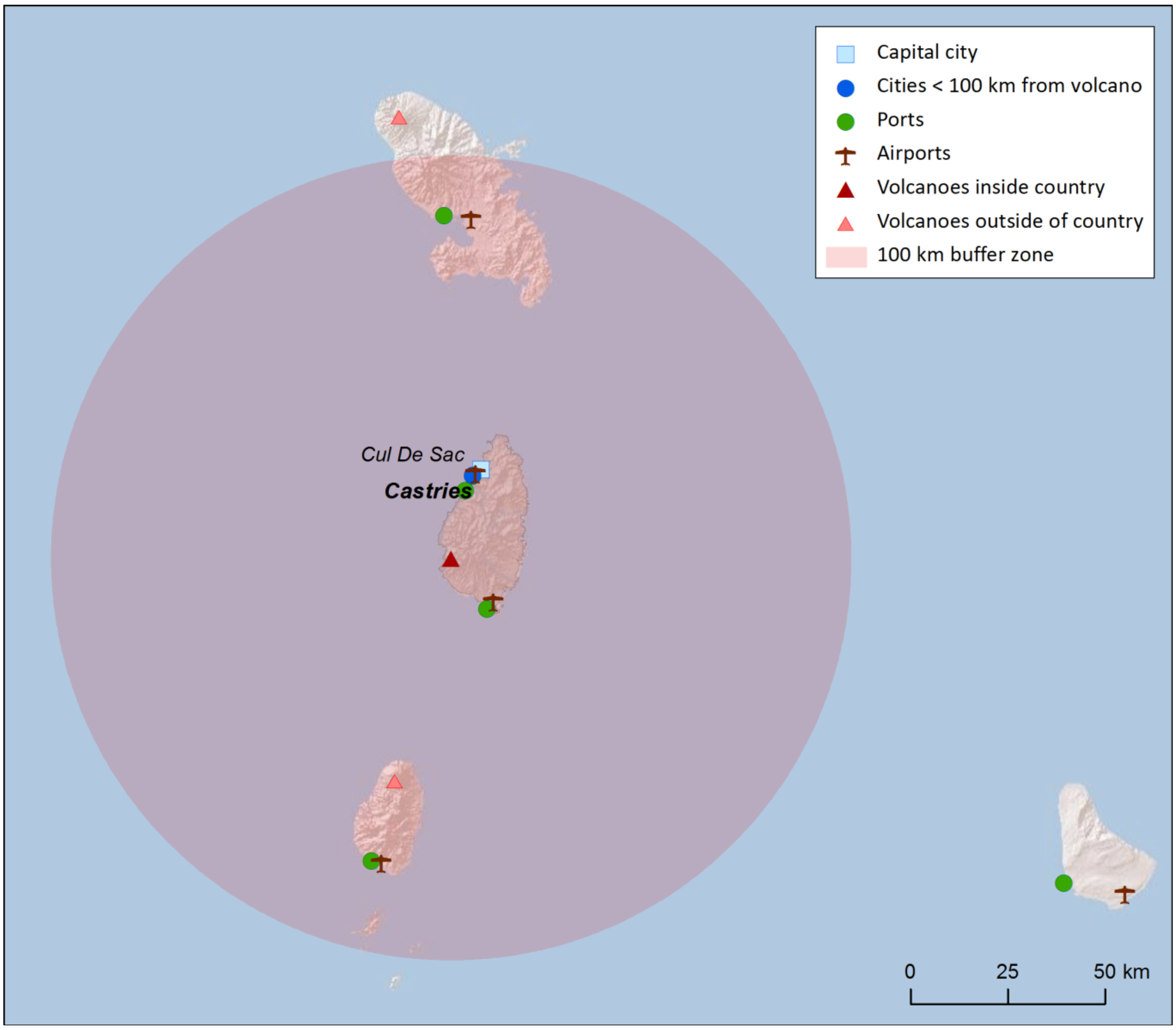

Figure 338: The location of St Lucia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Qualibou in St. Lucia has just one confirmed eruption recorded during the Holocene, with a VEI 1 event in 1766. This is insufficient to calculate the VHI and therefore a hazard level is not determined here. Qualibou has a high local population, and is classed at PEI 5 suggestive of a risk level of II to III.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**					**Qualibou**		
	U- HR							
	U- NHHR							
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 314: Identity of St. Lucia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

The University of the West Indies Seismic Research Centre monitors the historically active volcano Qualibou through a seismic network and multiple deformation stations.

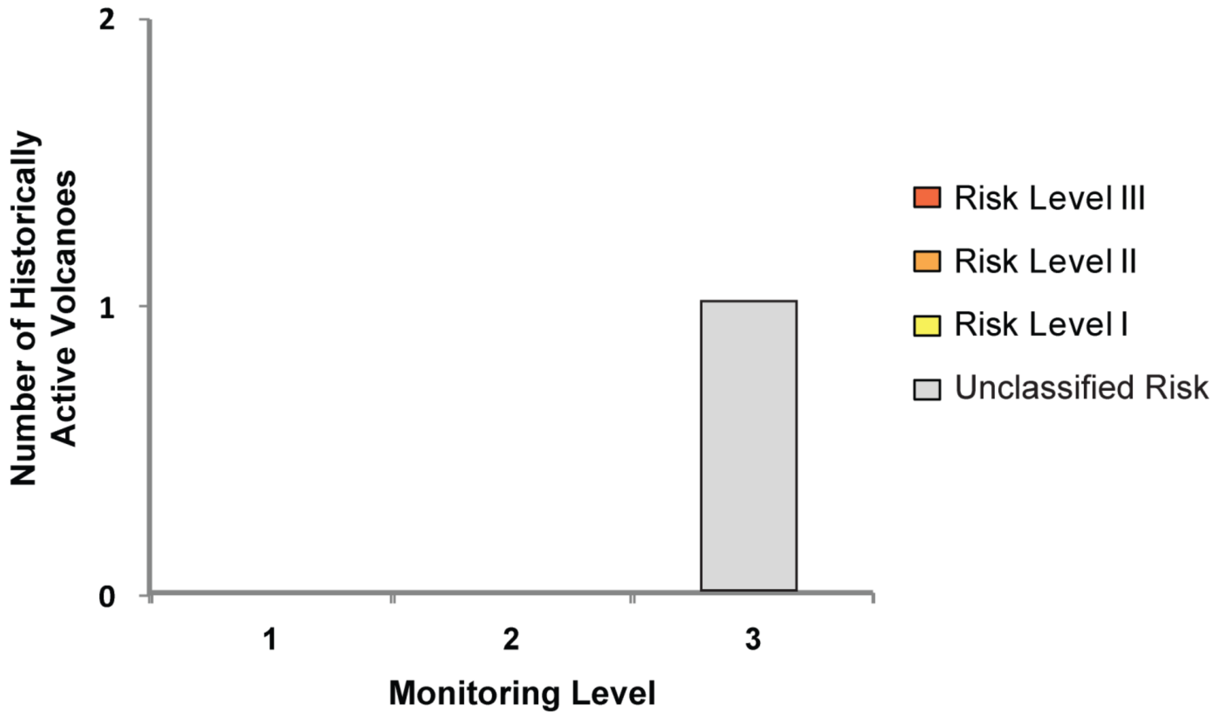

Figure 339: The monitoring and risk levels of the historically active volcanoes in St Lucia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

St Vincent and the Grenadines

Description

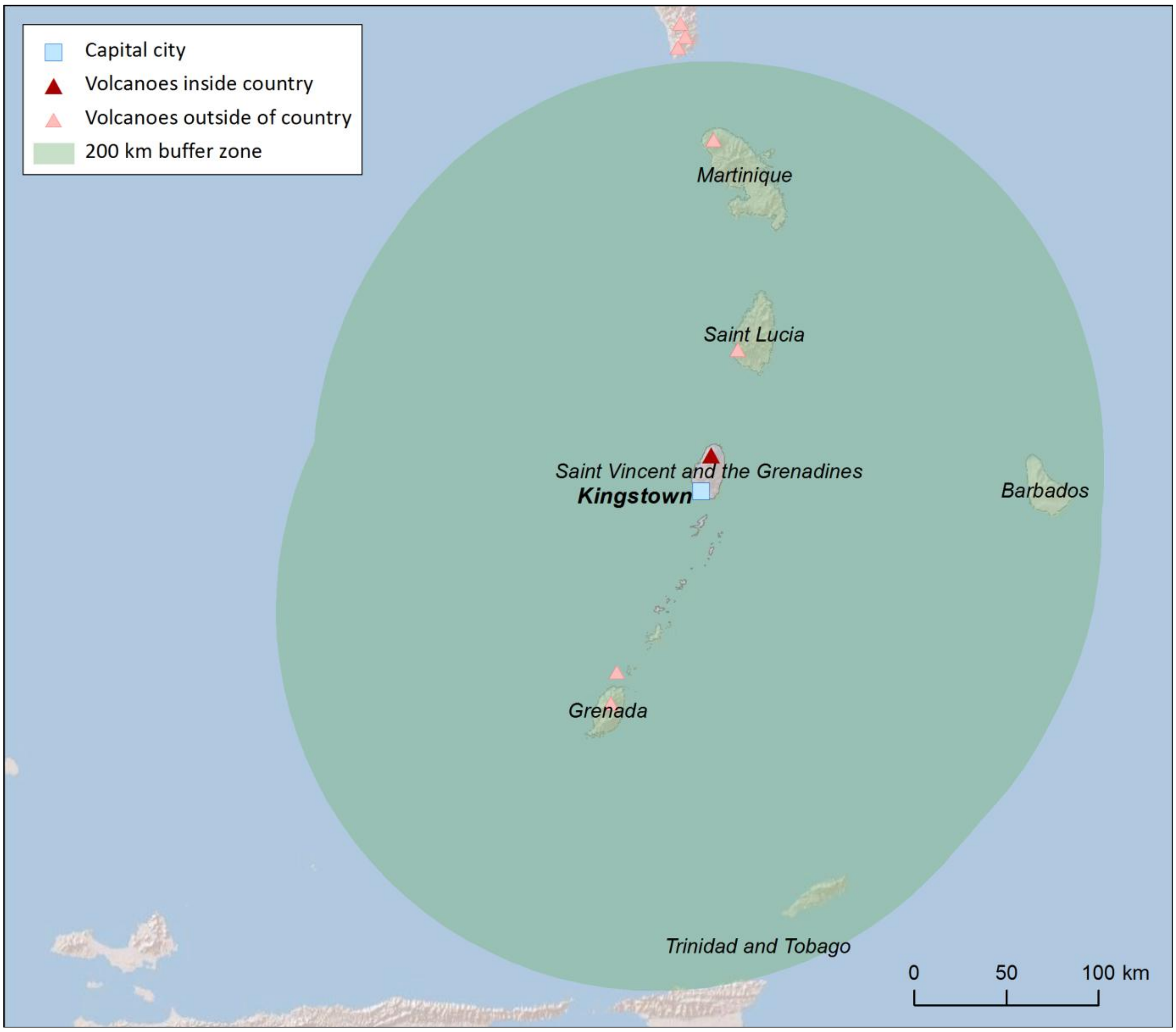

Figure 340: Location of St Vincent and the Grenadines' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect St Vincent and the Grenadines.

One Holocene volcano, Soufrière St. Vincent, is located in the north of the main island of St. Vincent and the Grenadines. This andesitic stratovolcano has developed as a result of the subduction of the Atlantic Ocean crust beneath the Caribbean Plate.

Twenty-one Holocene eruptions are confirmed at Soufrière St. Vincent, between 2380 BC and 1979 AD. These eruptions have varied in size from VEI 0 to 4, however all eruptions prior to the 1700s are of unknown magnitude. These eruptions however, all have records of producing explosive products including pyroclastic flows. Indeed 17 out of 21 eruptions recorded here have produced pyroclastic flows and much of the island is blanketed with deposits from these eruptions, indicating that explosive activity has been commonplace.

Two historical eruptions of VEI 4 are recorded here, including the VEI 4 eruption of 1902 which devastated much of the northern part of the island.

Being a relatively small island the whole population is located close to the volcano, with about a quarter of the population living within 10 km alone. Four eruptions have resulted in fatalities with about 1,700 recorded, of which most occurred during the 1902 eruption.

Robertson (2005) described eruption scenarios at Soufrière St. Vincent and presents integrated hazard maps for effusive dome-forming and explosive eruptions, showing much of the north of the island as Very High Hazard, with decreasing hazard moving southwards. See Robertson (2005) for full details.

The University of the West Indies Seismic Research Centre (SRC) is responsible for the monitoring of St. Vincent and the Grenadines' volcanoes. Indeed, they monitor the Soufrière St. Vincent with multiple dedicated ground-based systems. A monitoring alert system is in place. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre http://www.uwiseismic.com/

Robertson, R. (2005) St. Vincent, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	?1,741
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The M4.7 eruption of Soufrière St. Vincent in 1812 AD.
Number of Holocene eruptions	21 confirmed eruptions. 1 uncertain eruption.
Recorded Holocene VEI range	0 – 4 and unknown.
Number of historically active volcanoes	1

Number of historic eruptions	9

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Andesitic (1)

Table 315: The number of volcanoes in St Vincent and the Grenadines, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	110,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	9,482
Gross National Income (GNI) per capita (2005 PPP $)	9,367
Human Development Index (HDI) (2012)	0.733 (High)

Population Exposure

Capital city	Kingstown
Distance from capital city to nearest Holocene volcano	19.7 km
Total population (2011)	103,869
Number (percentage) of people living within 10 km of a Holocene volcano	24,415 (23.5%)
Number (percentage) of people living within 30 km of a Holocene volcano	100,414 (96.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	108,973 (>100%)

Largest cities, as measured by population, and populations:

Kingstown	24,518

Infrastructure Exposure

Number of airports within 100 km of a volcano	8
Number of ports within 100 km of a volcano	1

Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

Soufrière St. Vincent lies in the north of the main island of St. Vincent and the Grenadines. Being only a small island, the whole of St. Vincent lies within a short distance of this volcano, and the 100 km radius of this volcano extends to nearly fully encompass the islands of the Grenadines. This radius also extends to fully encompass and expose St. Lucia, and indeed, the 100 km radius of the Qualibou volcano on St. Lucia extends to encompass the whole of St. Vincent. All infrastructure is exposed here.

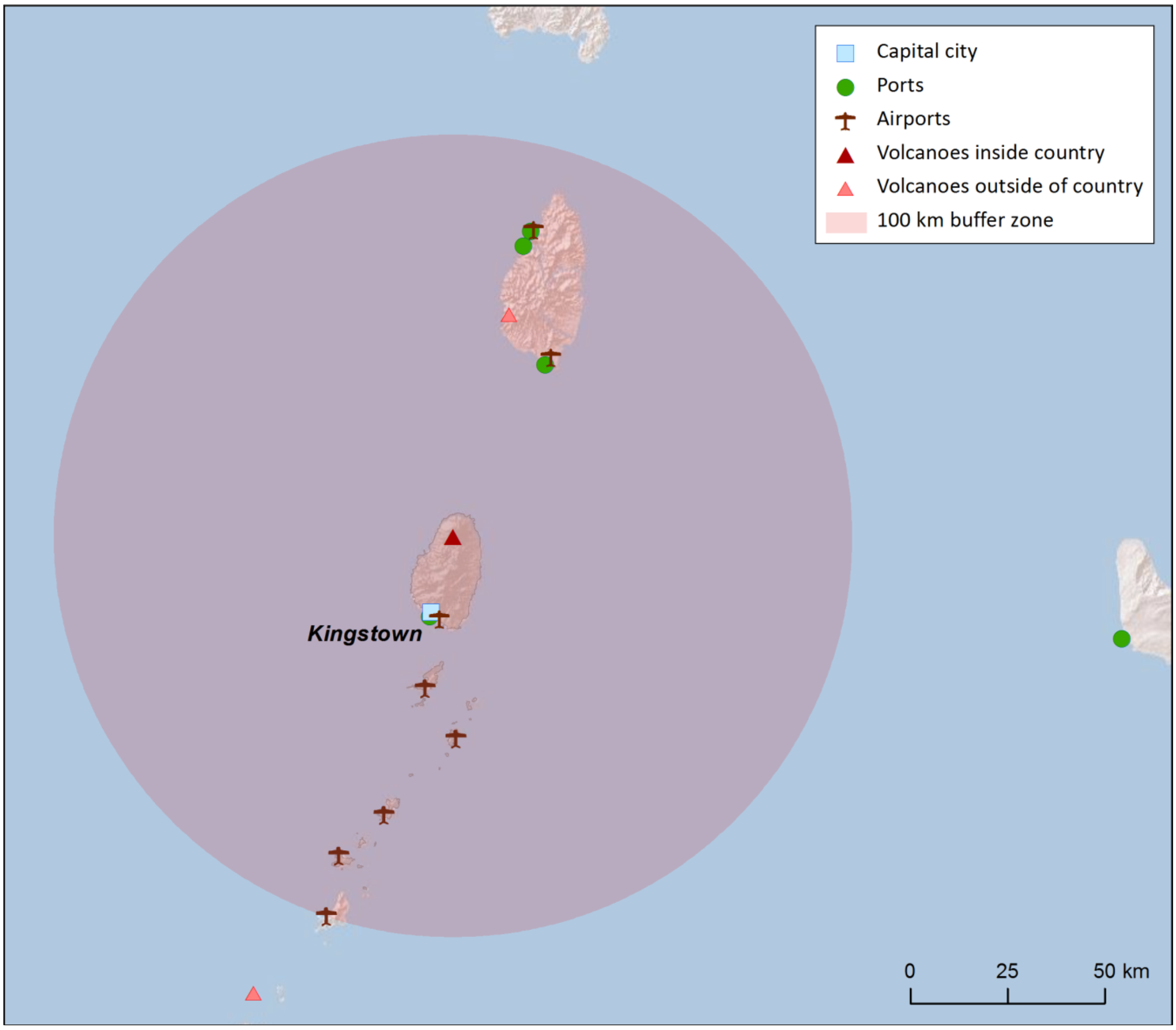

Figure 3416: The location of St Vincent and the Grenadines' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

With a Holocene record of 21 confirmed eruptions including seven with a known size, Soufrière St. Vincent has sufficient data available to determine the hazard level through the calculation of the

VHI. With a record of VEI 4 eruptions and explosive events producing pyroclastic flows, this volcano is classified at Hazard level III.

With a Hazard Level of III and a moderate PEI of 4, Soufrière St. Vincent is classed at Risk Level III.

CLASSIFIED	**Hazard III**				Soufrière St. Vincent			
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR							
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 316: Identity of the volcano of St. Vincent and the Grenadines and its Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Soufrière St. Vincent	4	III

Table 317: Classified volcanoes of St Vincent and the Grenadines ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 1 volcano.

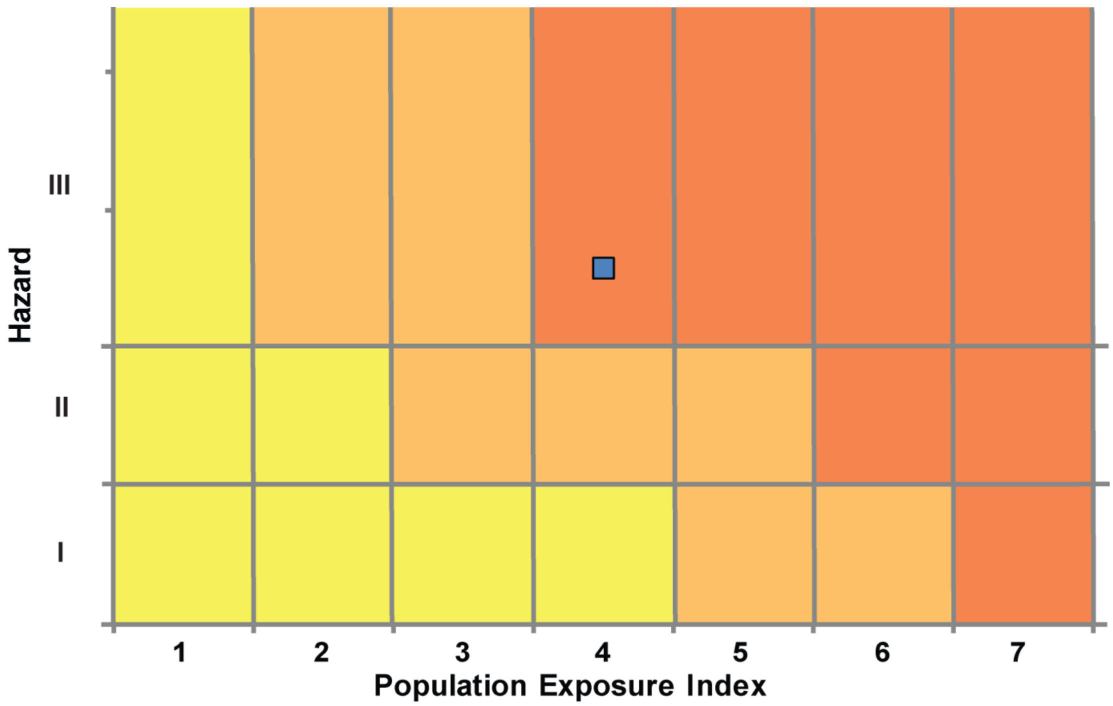

Figure 342: Distribution of St Vincent and the Grenadines' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The University of the West Indies Seismic Research Centre monitors the historically active Soufrière St. Vincent volcano through a seismic network and multiple deformation stations.

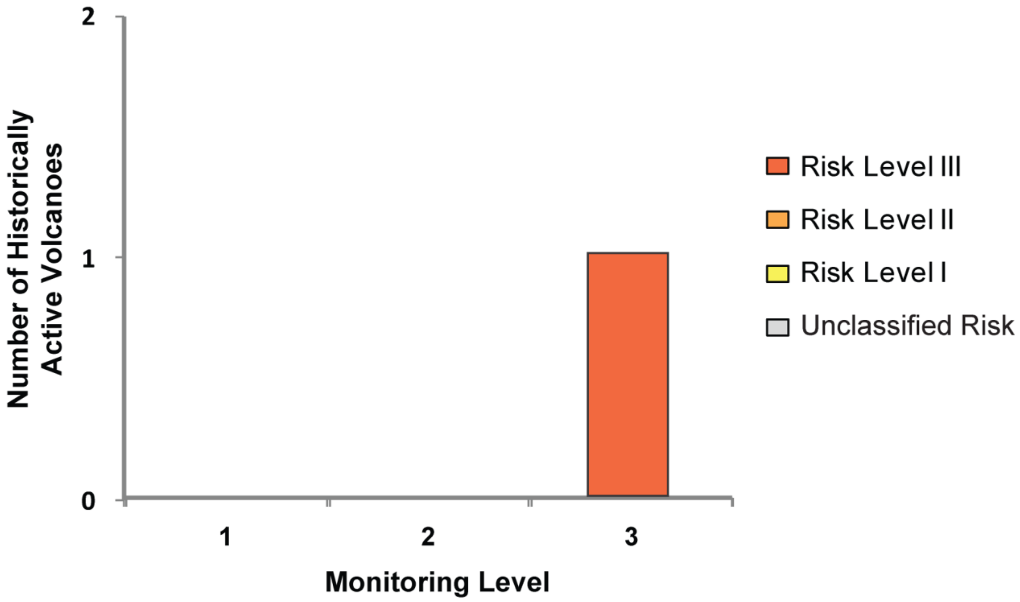

Figure 343: The monitoring and risk levels of the historically active volcanoes in St Viincent and the Grenadines. Monitoring Level 1indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

UK – Montserrat

Description

Montserrat is a British Overseas Territory. There is one Holocene volcano on Montserrat, Soufrière Hills volcano, located in the southern half of the island. It is an andesitic stratovolcano related to the subduction of the Atlantic Ocean crust beneath the Caribbean Sea.

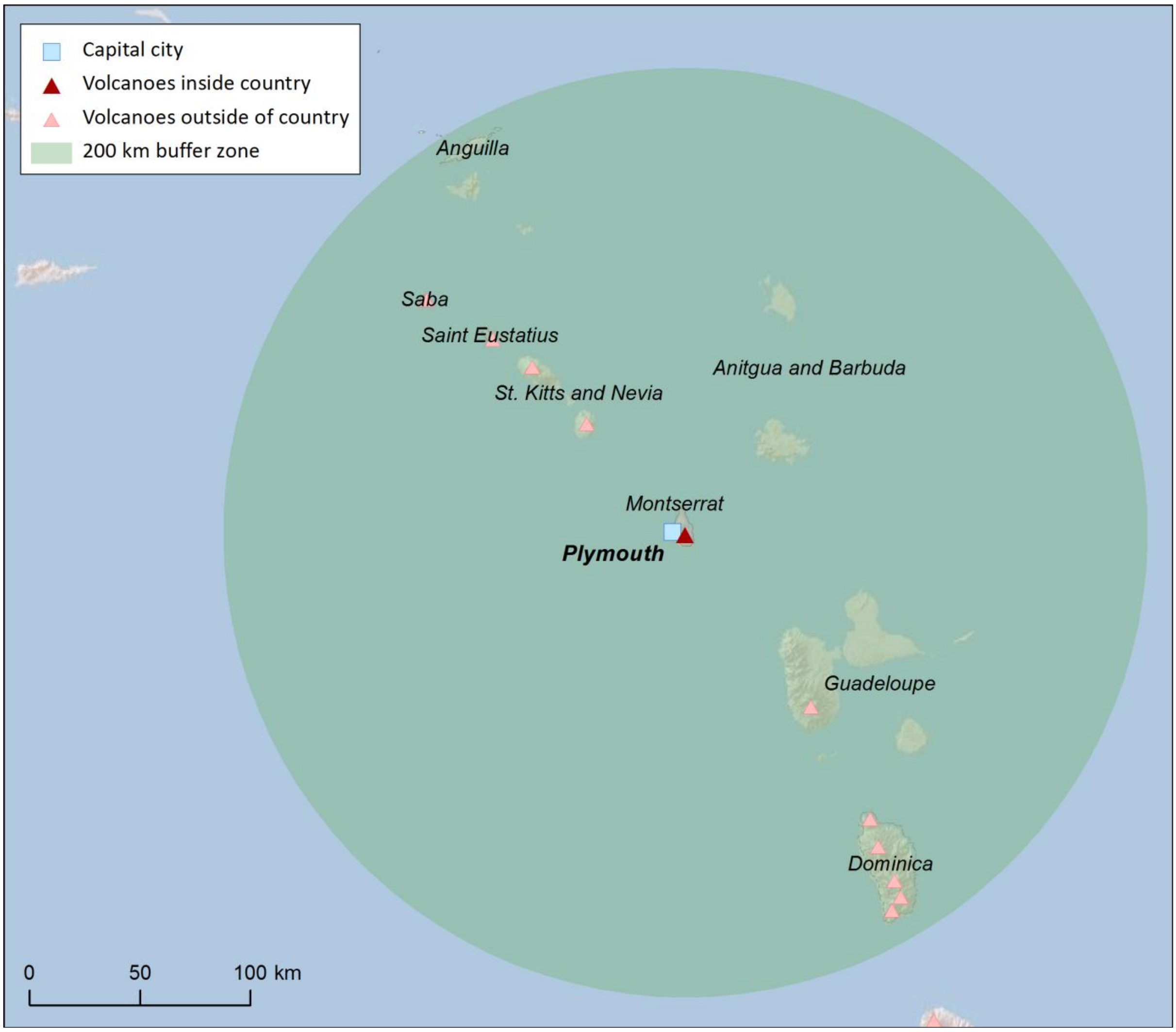

Figure 344: Location of Montserrat's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Montserrat.

Soufrière Hills volcano is currently active. Historic activity in the 17th Century produced the Castle Peak lava dome and seismic activity has occurred in swarms at 30 year intervals in the 20th Century. No other eruptions are recorded until the ongoing eruptions which started in August 1995. Eruptive activity is typified by lava dome growth followed by collapse resulting in pyroclastic density currents, lahars and ash plumes. Three VEI 3 eruptions were recorded in 1995, 2004 and 2005.

Parts of the southern half of the island were evacuated in 1995. In June 1997, 19 people were killed by pyroclastic density currents resulting from partial dome collapse. As a direct result of this the entire southern half of the island was made an exclusion zone. It remains an exclusion zone, with access being granted to certain areas dependant on activity and is revised on a daily basis.

By 1998, approximately 70% of the population had left the island (Kokelaar, 2002). The capital city of Plymouth has been destroyed by multiple ash fall and pyroclastic density current deposits. Montserrat is a small island with the whole population (c.5000) living within 12 km of the volcano.

Montserrat has a dedicated volcano observatory: Montserrat Volcano Observatory (MVO) run by the University of the West Indies Seismic Research Centre (SRC). MVO provides regular updates on alert levels and short-term hazard assessments. An international panel of scientists, practitioners and decision-makers, the Scientific Advisory Committee on Montserrat Volcanic Activity (SAC) provides hazard and risk assessments [CS18].

See also:

Montserrat Volcano Observatory – www.mvo.ms

Kokelaar, B. P. (2002). Setting, chronology and consequences of the eruption of Soufrière Hills Volcano, Montserrat (1995-1999). *Geological Society, London, Memoirs*, *21*(1), 1-43.

Wadge, G., Robertson, R.E.A., and Voight, B. (eds) (2014). The Eruption of Soufriere Hills Volcano, Montserrat from 2000 to 2010. Geological Society Memoir No.39.

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	19
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Three VEI 3 eruptions are recorded at Soufrière Hills in 1995, 2004 and 2005.
Number of Holocene eruptions	5 confirmed eruptions.
Recorded Holocene VEI range	3 and unknown.
Number of historically active volcanoes	1
Number of historic eruptions	4

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Andesitic (1)

Table 318: The number of volcanoes in Montserrat, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	5,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	-
Gross National Income (GNI) per capita (2005 PPP $)	-
Human Development Index (HDI) (2012)	-

Population Exposure

Capital city (Montserrat)	Plymouth
Distance from capital city to nearest Holocene volcano	5.4 km
Total population (2011)	5,140
Number (percentage) of people living within 10 km of a Holocene volcano	4,926 (95.8 %)
Number (percentage) of people living within 30 km of a Holocene volcano	5,001 (97.3%)
Number (percentage) of people living within 100 km of a Holocene volcano	5,001 (97.3%)

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	6
Total length of roads within 100 km of a volcano (km)	-
Total length of railroads within 100 km of a volcano (km)	-

The Soufriere Hills volcano is situated to the south of central Montserrat. Being a small island, all infrastructure and population here lies within 20 km of the volcano. Indeed the 100 km radius of Soufriere Hills extends to encompass much of Guadeloupe, St. Kitts and Nevis and Antigua and

Barbuda, exposing much of the infrastructure here. The 100 km radii of the volcanoes of Guadeloupe and St. Kitts and Nevis likewise extend to encompass the island of Montserrat.

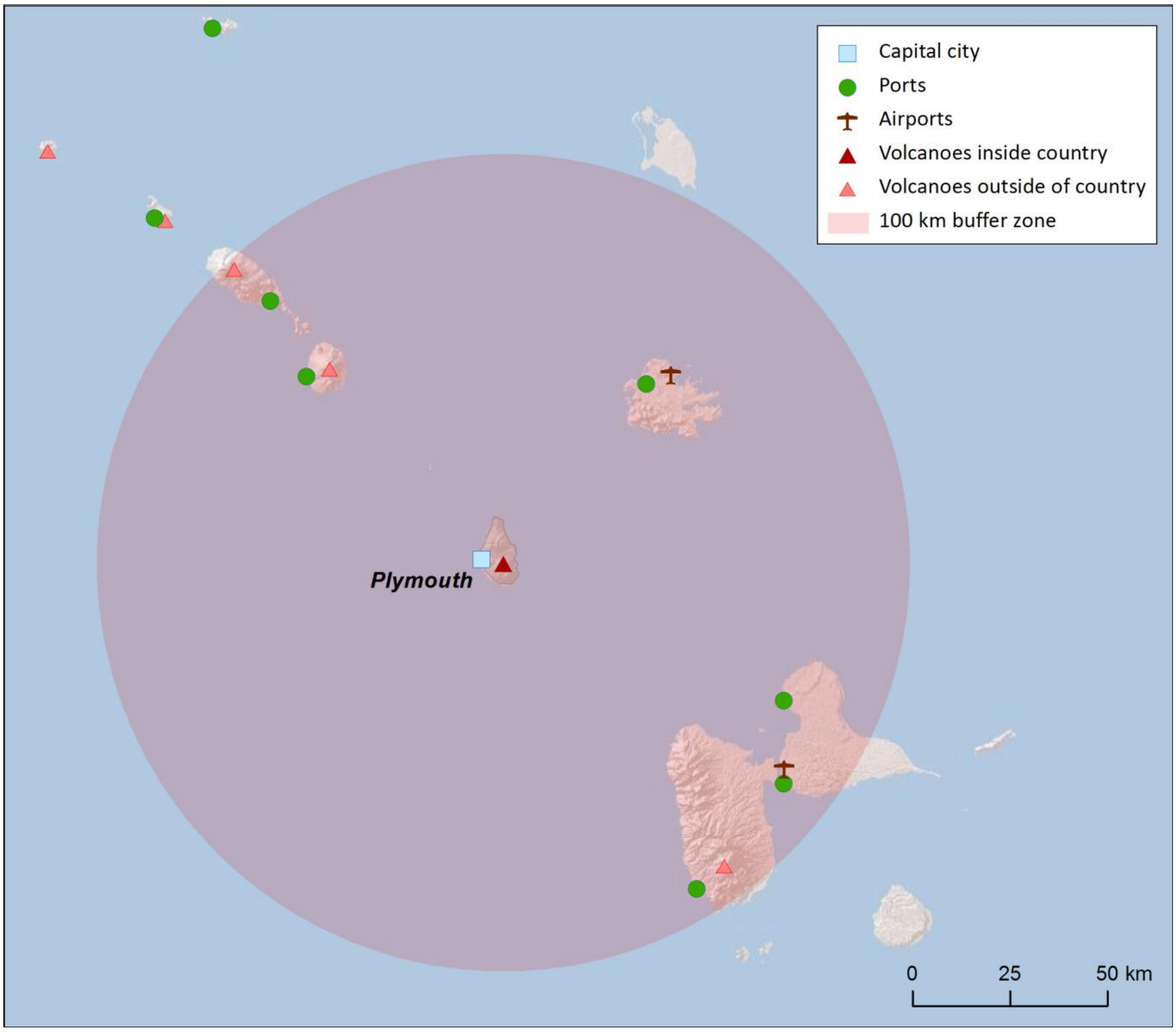

Figure 345: The location of Montserrat's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

With a Holocene record of five eruptions, three of which with a known size, the hazard level at Soufrière Hills volcano in Montserrat can be classified through the calculation of the VHI only when considering the recent long-duration activity as separate events. This is therefore classified at Hazard Level III with a history of VEI 3 eruptions accompanied by pyroclastic flows.

With the high Hazard Level and a moderate PEI of 4, Soufrière Hills Volcano is classed at Risk Level III.

CLASSIFIED	Hazard III				Soufrière Hills			
	Hazard II							
	Hazard I							
UNCLASSIFIED	U – HHR							
	U- HR							
	U- NHHR							
		PEI 1	PEI 2	PEI 3	PEI 4	PEI 5	PEI 6	PEI 7

*Table 319: Identity of Montserrat's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Soufrière Hills	4	III

Table 320: Classified volcanoes of Montserrat ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 1 volcano.

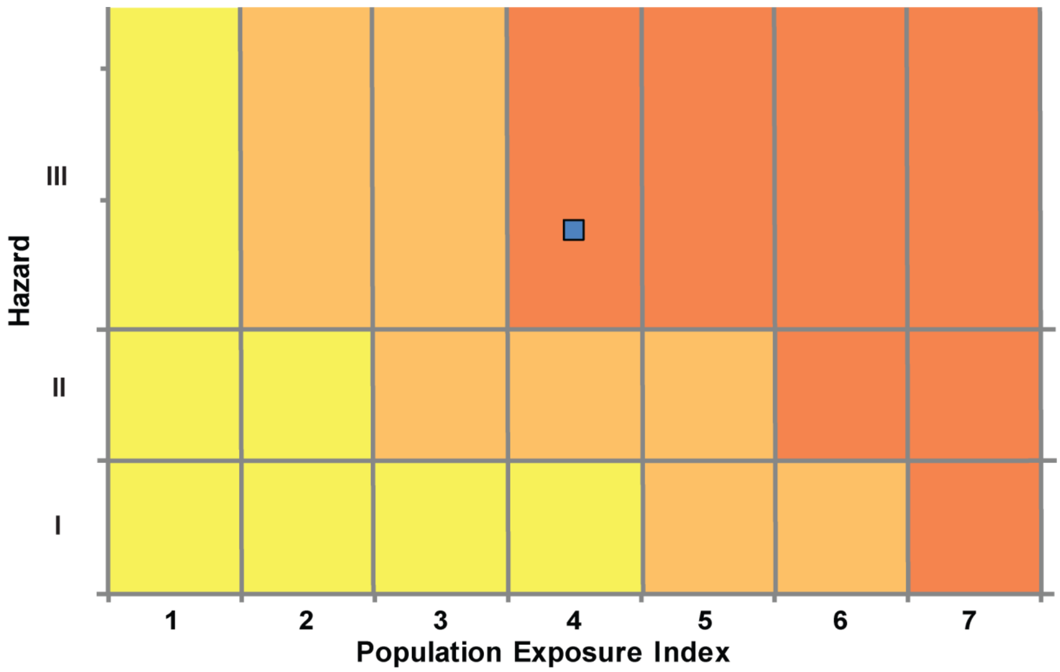

Figure 346: Distribution of Montserrat's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels: Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The historically active Risk Level III Soufrière Hills Volcano is monitored by the Montserrat Volcano Observatory. A dedicated seismic and deformation network is in place, and monitoring of the gases produced is also undertaken.

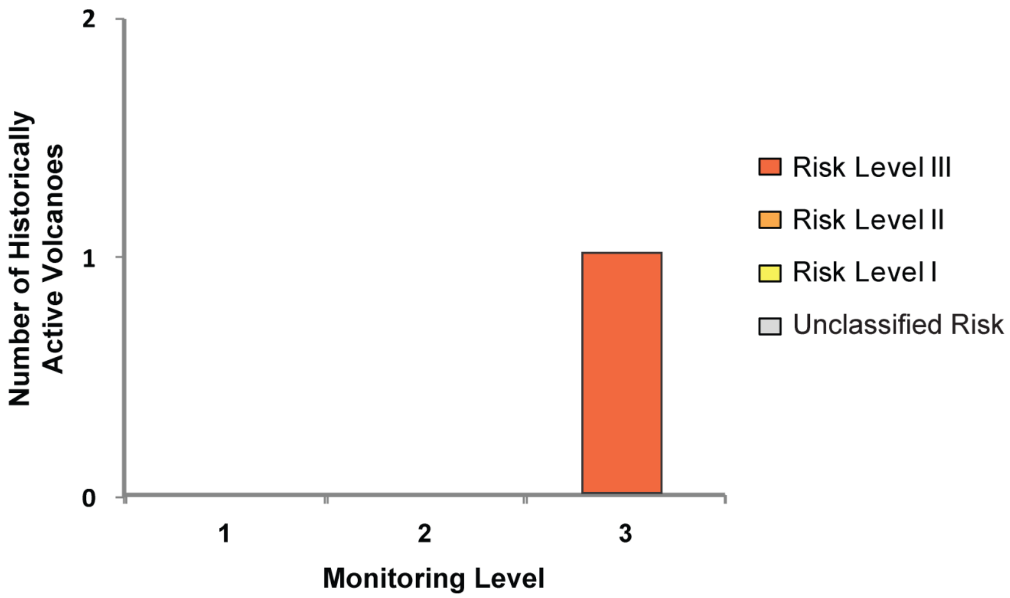

Figure 3477: The monitoring and risk levels of the historically active volcanoes in Montserrat. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 17: Iceland and Arctic Ocean

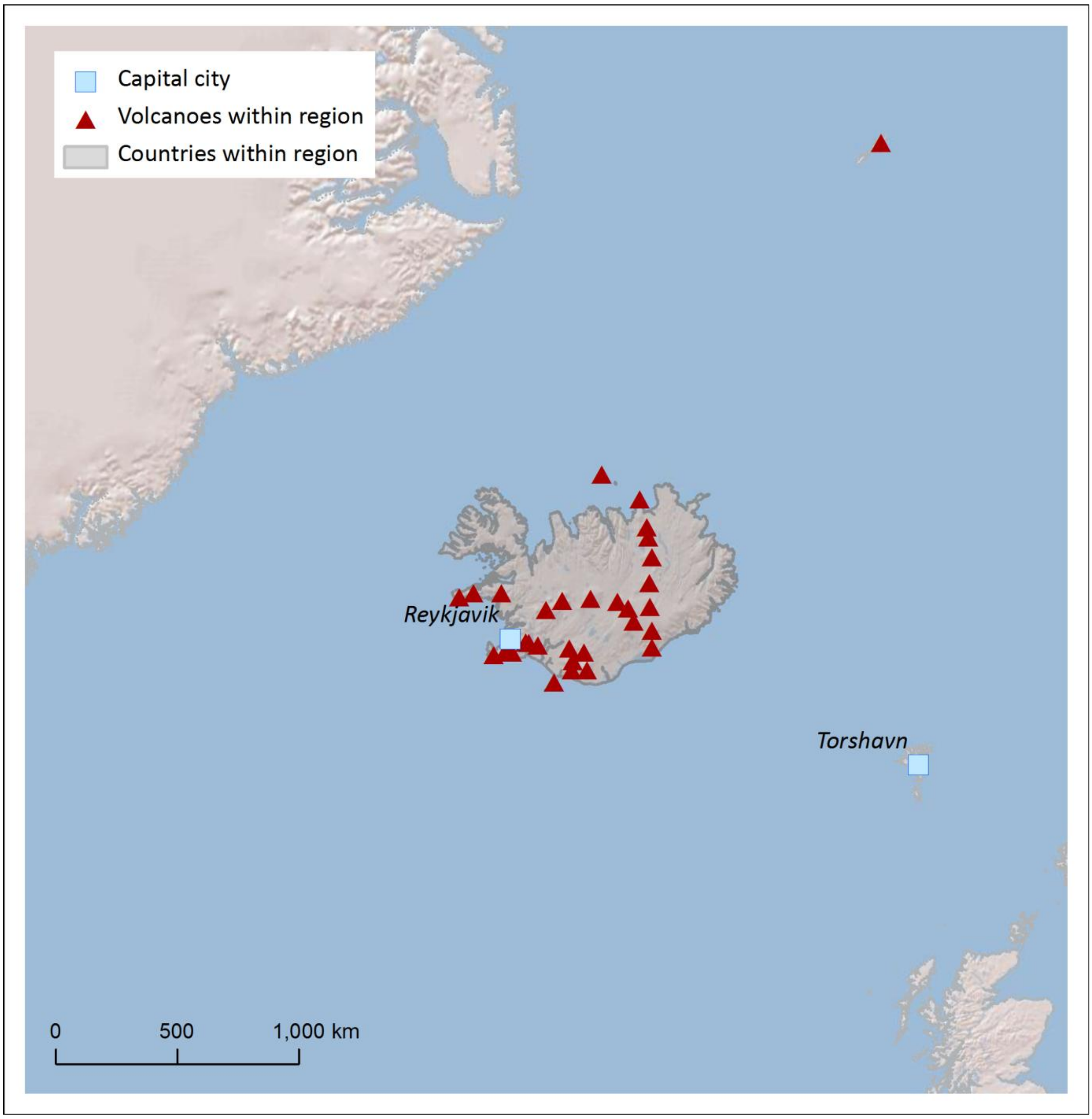

Figure 348: The distribution of Holocene volcanoes through the Iceland and Arctic region. The capital cities of the constituent countries are shown.

Description

Region 17: Iceland and Arctic Ocean comprises volcanoes in Iceland and Jan Mayen volcano in the northern Arctic, a volcano in Norwegian territories. Here we discuss all volcanoes of Region 17. The country profile for Norway includes Jan Mayen and two further Norwegian volcanoes in the southern Atlantic (Region 18).

Country	Number of volcanoes
Iceland	30
Norway	1 + 2 from Region 18

Table 321: The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

Thirty-three Holocene volcanoes are located in Iceland and the Arctic Ocean, comprising 30 volcanoes in Iceland. These volcanoes are the result of intra-plate hotspot activity with a mid-ocean ridge.

A range of volcano types are present here, though most are stratovolcanoes. The composition of all but four volcanoes is dominantly basaltic. A range of activity styles and eruption magnitudes are recorded through the Holocene, with a range of eruptions from VEI 0 to 6, with about 10% of all eruptions being VEI ≥4.

Fourteen volcanoes have historical records of 146 eruptions, about 81% of which were recorded through direct observations. 4% of historical events have involved the production of pyroclastic flows and lahars, with lava flows recorded in 32% of historical eruptions.

5% of eruptions have resulted in loss of life. The population of this region is small, and as such most are considered relatively low risk. However the hazard is unclassified at about half the volcanoes in this region.

Monitoring is undertaken at all historically active volcanoes in Iceland and the Arctic, with comprehensive monitoring at many of Iceland's volcanoes. See the Iceland country profile for details.

Volcano facts

Number of Holocene volcanoes	33
Number of Pleistocene volcanoes with M≥4 eruptions	6
Number of volcanoes generating pyroclastic flows	6 (16 eruptions)
Number of volcanoes generating lahars	1 (9 eruptions)
Number of volcanoes generating lava flows	22 (220 eruptions)
Number of eruptions with fatalities	12
Number of fatalities attributed to eruptions	10,315
Largest recorded Pleistocene eruption	The largest recorded Quaternary explosive eruption in this region is the Saksunarvatn eruption of Grímsvötn, Iceland in 10,180 BP.

	This eruption measured M6.6.
Largest recorded Holocene eruption	The largest recorded Holocene eruption in this region in LaMEVE is the 3050 BP H3 M5.8 eruption of Hekla.
Number of Holocene eruptions	503 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 6 and unknown.
Number of historically active volcanoes	14
Number of historical eruptions	146

Number of volcanoes	Primary volcano type	Dominant rock type
2	Caldera(s)	Basaltic (2)
14	Large cone(s)	Andesitic (1), Basaltic (11), Rhyolitic (1), Unknown (1)
2	Shield(s)	Basaltic (2)
7	Small cone(s)	Basaltic (7)
4	Subglacial	Basaltic (4)
4	Submarine	Basaltic (3), Unknown (1)

Table 322: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	2
Large (> VEI 3)	30

Table 323: Average recurrence interval (years between eruptions) for small and large eruptions in Iceland and the Arctic.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 ocurr in this region with an average recurrence interval (ARI) of about 2 years, whilst the ARI for large eruptions is longer, at about 30 years.

Eruption Size

Eruptions are recorded through the Iceland and Arctic region of VEI 0 to 6, representing a range of eruption styles from gentle effusive events, to large explosive eruptions. There is a wide spread of eruption sizes, with the most populous group being VEI 2, with nearly 20% of all Holocene eruptions classed as such. Just over 10% of eruptions here are explosive at VEI≥4.

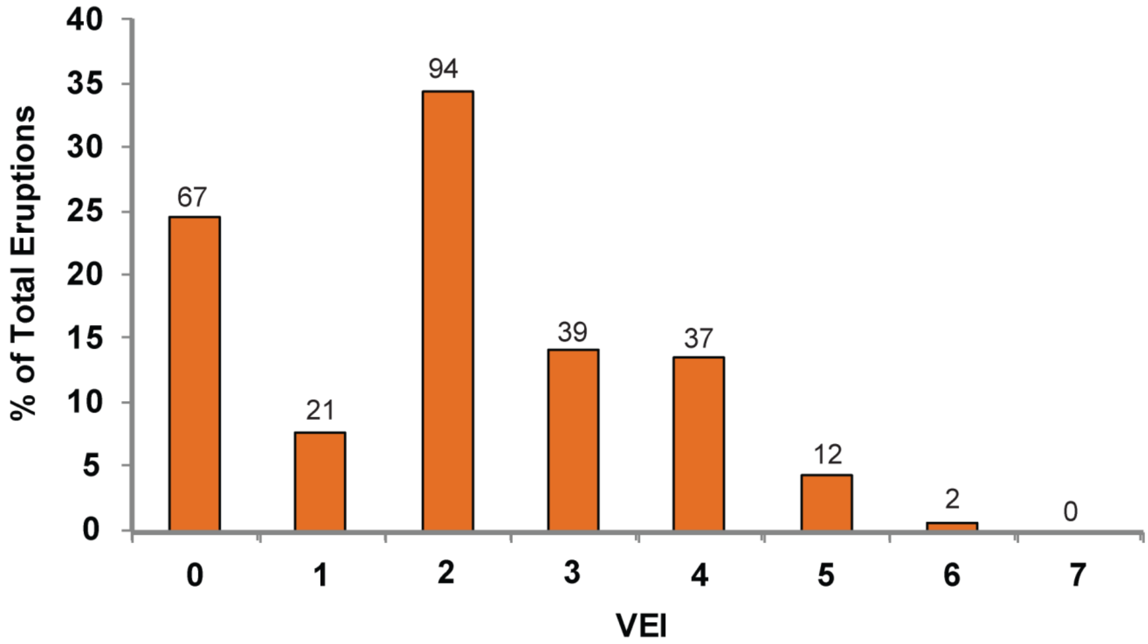

Figure 349: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 231 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	311,058
Gross Domestic Product (GDP) per capita (2005 PPP $)	33,618 (Iceland)
Gross National Income (GNI) per capita (2005 PPP $)	29,176 (Iceland)
Human Development Index (HDI) (2012)	0.906 (Very High, Iceland)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	7,255 (2.33 %)
Number (percentage) of people living within 30 km of a Holocene volcano	84,738 (27.24 %)
Number (percentage) of people living within 100 km of a Holocene volcano	286,832 (92.21 %)

<table>
<tr><td rowspan="3">CLASSIFIED</td><td>Hazard III</td><td></td><td>Hekla</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Hazard II</td><td>Jan Mayen</td><td>Katla; Grímsvötn; Bárdarbunga; Askja</td><td></td><td>Reykjanes</td><td></td><td></td><td></td></tr>
<tr><td>Hazard I</td><td></td><td>Snaefellsjökull; Ljósufjöll; Hveravellir; Kverkfjöll; Krafla</td><td>Hengill; Grímsnes</td><td></td><td>Krísuvík; Brennisteinsfjöll</td><td></td><td></td></tr>
<tr><td colspan="9"></td></tr>
<tr><td rowspan="3">UNCLASSIFIED</td><td>U – HHR</td><td></td><td>Vestmannaeyjar; Eyjafjallajökull; Tjörnes Fracture Zone; Öraefajökull; Kolbeinsey Ridge</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>U- HR</td><td>Bouvet</td><td>Prestahnukur; Torfajökull; Fremrinamur; Theistareykjarbunga</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>U- NHHR</td><td>Thompson Island</td><td>Helgrindur; Hofsjökull; Tindfjallajökull; Tungnafellsjökull; Esjufjöll</td><td>Hrómundartindur</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>PEI 1</td><td>PEI 2</td><td>PEI 3</td><td>PEI 4</td><td>PEI 5</td><td>PEI 6</td><td>PEI 7</td></tr>
</table>

*Table 324: Identity of the volcanoes in this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
2	5
1	4
3	3
24	2
3	1

Table 325: The number of volcanoes in Iceland and the Arctic Ocean classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
0	III
4	II
12	I
17	Unclassified

Table 326: The number of volcanoes in the Iceland and Arctic region classified at each Risk Level.

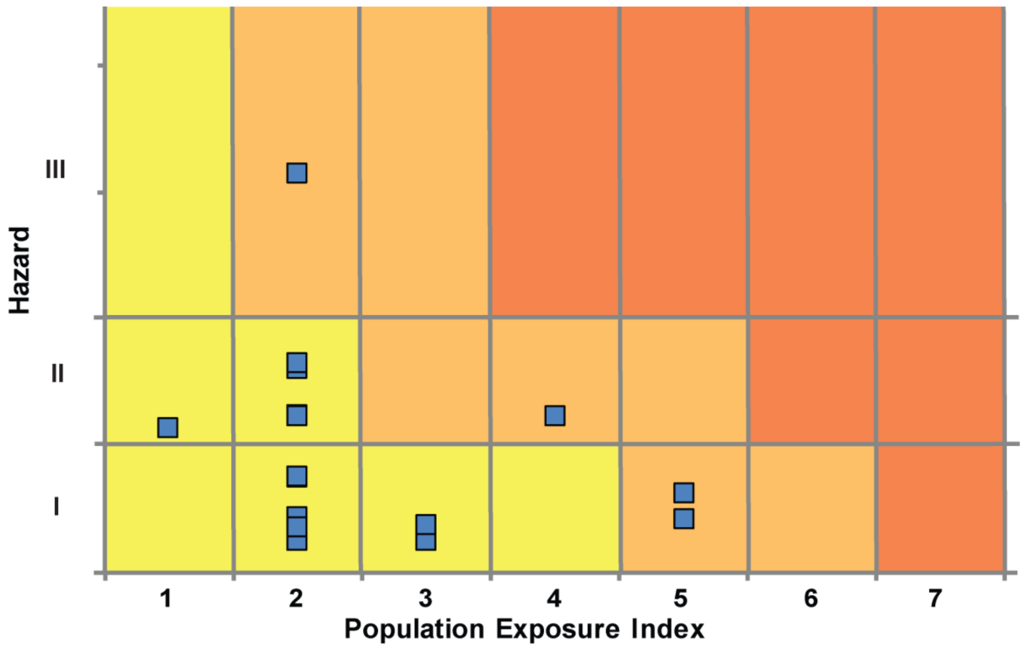

Figure 350: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

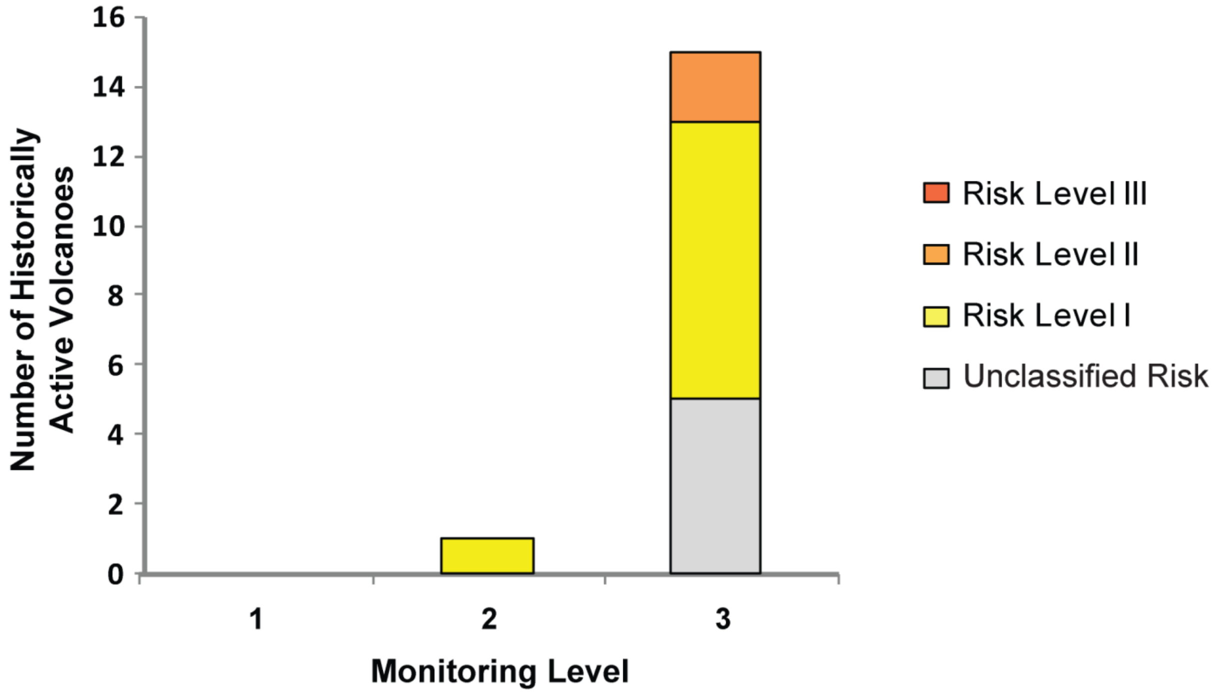

Figure 351: The monitoring and risk levels of the historically active volcanoes in Iceland. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Iceland

Description

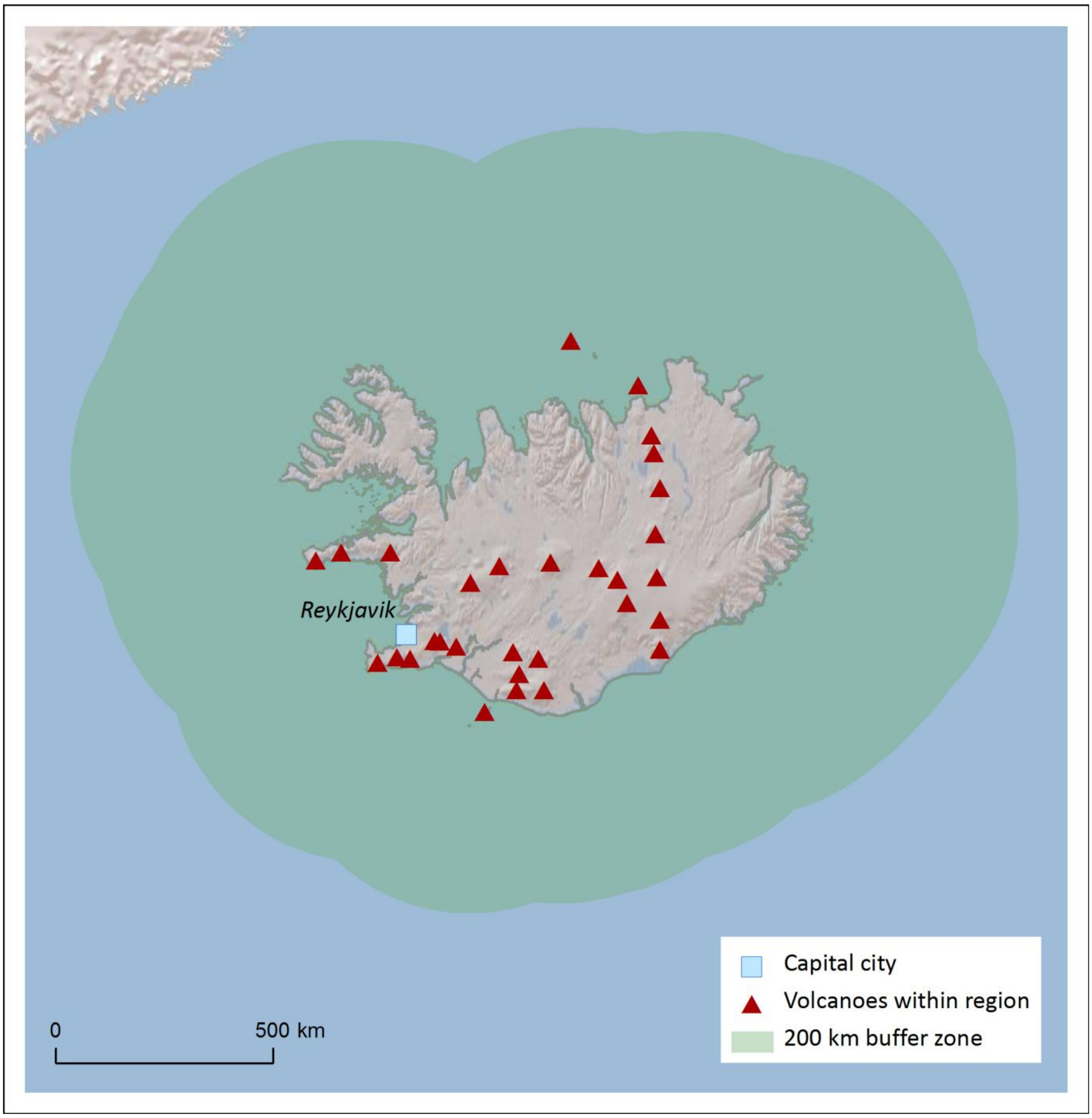

Figure 352: Location of Iceland's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Iceland.

Volcanism in Iceland is caused by divergence of two tectonic plates (European and North American), as well as a mantle-sourced 'hot-spot'. Active volcanic systems are located along the tectonic plate boundary which cuts through Iceland roughly from south-west to north-east. The most frequently active volcanoes in recent decades have been Grimsvötn and Hekla.

In Iceland, volcanically active areas are subdivided into volcanic systems. This classification works well for Iceland due to its unique volcano-tectonic setting. One volcanic system may consist of one or more so-called central volcanoes which may be linked through the sub-surface structure. The volcanic systems are 30-190 km long and 10-30 km wide. Some volcanic systems consist of a single central volcano (e.g. Öræfajökull), while others have a fissure swarm and no central volcano (e.g. Reykjanes). However, many volcanic systems have both (e.g. Hekla, Katla, Grimsvotn). Eruptions may take place in the central volcano and/or on the fissure swam. For example, the effusive Laki eruption in 1783-84 and the highly ash-rich 2011 Grimsvotn eruption were sourced from the same volcanic system but different parts.

Iceland has 28 Holocene volcanic systems listed in the GVP database. Several updates and new data on volcanic systems have been included in the Catalogue of Icelandic Volcanoes (CIV), which will be published by the Icelandic volcano observatory (IMO), University of Iceland, and Icelandic Civil Protection in the beginning of 2015. The CIV includes two additional Holocene volcanic systems, as well as one non-Holocene system which is nevertheless considered important for Icelandic volcanism.

Volcanic activity is highly varied and includes nearly all known types of eruption style, duration, products and composition. Eruptions are frequent with approximately 3 events per decade. It has been suggested that frequency of activity goes through cycles, and that we may be entering a more active interval. The majority of eruptions have been explosive due to the presence of glaciers on many volcanoes. Most of the frequently occurring eruptions are small (<0.1 km^3 DRE), while the largest flood-basalt eruptions (>10 km^3 DRE) have an approximately 500-1000 year repose interval. The largest explosive eruptions have reached VEI 6 (return period 1-2 per millennium), with the most recent one in 1362 CE.

The most frequent volcanic hazards include jökulhlaups (floods following an eruption under a glacier), tephra fall, and pollution of air and grazing pastures by ash, gases and aerosols. Damage due to lava flows is only likely if an eruption were to occur very close to inhabited areas, such as happened in the 1973 eruption in Vestmannaeyjar. Pyroclastic density currents and tsunamis are known to have occurred, but are relatively minor except in infrequent, large eruptions.

The most hazardous eruptions expected in Iceland are of two different types: (1) large effusive eruption, such as the Laki eruption 1783-84 CE which lasts weeks or months. It would cause severe pollution by gas and aerosol in Iceland, and impact air quality in the Northern hemisphere; (2) VEI 6 explosive eruption close to inhabited areas, such as the 1362 eruption of Öræfajökull, producing pyroclastic density currents and heavy tephra fall. Additionally, smaller ash-rich eruptions (VEI 3-4) which last weeks to months can significantly damage agriculture in Iceland and cause prolonged air space closures (e.g. Eyjafjallajökull in 2010). In addition, even moderately sized eruptions may be extremely hazardous if they melt through a thick glacier and cause large jökulhlaups.

Loss of life directly caused by volcanic eruptions has fortunately been very modest (<15 people since 1500 CE). However, eruptions have caused a number of fatalities through indirect impact. The 1783-84 Laki eruption caused severe famine due to pollution of graze land and loss of livestock, and over 8,500 people are estimated to have died as a consequence. It is possible that this eruption also caused increased mortality in Europe due to air pollution, but exact scale of impact is not known. In modern times, risk to life remains low. This is a combination of a developed economy, advanced volcano monitoring systems, well-defined civil protection procedures and frequently low proximal populations, with most Icelandic volcanoes categorised at a low PEI of 2. Damage to infrastructure and economy (in particular roads and bridges) is however, considerable.

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Gudmundsson, M. T., G. Larsen, A. Höskuldsson, and A. G. Gylfason (2008), Volcanic hazards in Iceland, *Jökull*, *58*, 251–268.

Larsen, G., M. T. Gudmundsson, and H. Björnsson (1998), Eight centuries of periodic volcanism at the center of the Iceland hotspot revealed by glacier tephrostratigraphy, *Geology*, *26*(10), 943 –946, doi:10.1130/0091-7613(1998)026<0943:ECOPVA>2.3.CO;2.

Volcano Facts

Number of Holocene volcanoes	30
Number of Pleistocene volcanoes with M≥4 eruptions	6
Number of volcanoes generating pyroclastic flows	6
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	21
Number of fatalities caused by volcanic eruptions	?>10,315
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	The M6.6 Saksunarvatn eruption of Grímsvötn at 10,180 BP.
Largest recorded Holocene eruption	The M5.8 H3 eruption of Hekla at 3,050 BP.
Number of Holocene eruptions	496 confirmed eruptions. 27 uncertain and 7 discredited eruptions.
Recorded Holocene VEI range	0 – 6 and unknown.
Number of historically active volcanoes	13
Number of historic eruptions	140

Number of volcanoes	Primary volcano type	Dominant rock type
2	Caldera(s)	Basaltic (2)
13	Large cone(s)	Andesitic (1), Basaltic (10), Rhyolitic (1), Unknown (1)
1	Shield(s)	Basaltic (1)
7	Small cone(s)	Basaltic (7)
4	Subglacial	Basaltic (4)
3	Submarine	Basaltic (3)

Table 327: The number of volcanoes in Iceland, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	326,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	33,618
Gross National Income (GNI) per capita (2005 PPP $)	29,176
Human Development Index (HDI) (2012)	0.906 (Very High)

Population Exposure

Capital city	Reykjavik
Distance from capital city to nearest Holocene volcano	24.9 km
Total population (2011)	311,058
Number (percentage) of people living within 10 km of a Holocene volcano	7,254 (2.3%)
Number (percentage) of people living within 30 km of a Holocene volcano	84,737 (27.2%)
Number (percentage) of people living within 100 km of a Holocene volcano	286,831 (92.2%)

Largest cities, as measured by population, and populations:

Reykjavik	113,906

Infrastructure Exposure

Number of airports within 100 km of a volcano	3
Number of ports within 100 km of a volcano	17
Total length of roads within 100 km of a volcano (km)	8,930
Total length of railroads within 100 km of a volcano (km)	0

The Holocene volcanoes are widespread through Iceland and as such, almost the entirety of the country is located within the 100 km radii of these volcanoes. Just small areas to the east and north-west lie beyond 100 km. This places much of the critical infrastructure and main cities, including the capital Reykjavik, within the 100 km exposure radii. Numerous ports, airports and an extensive road network are affected.

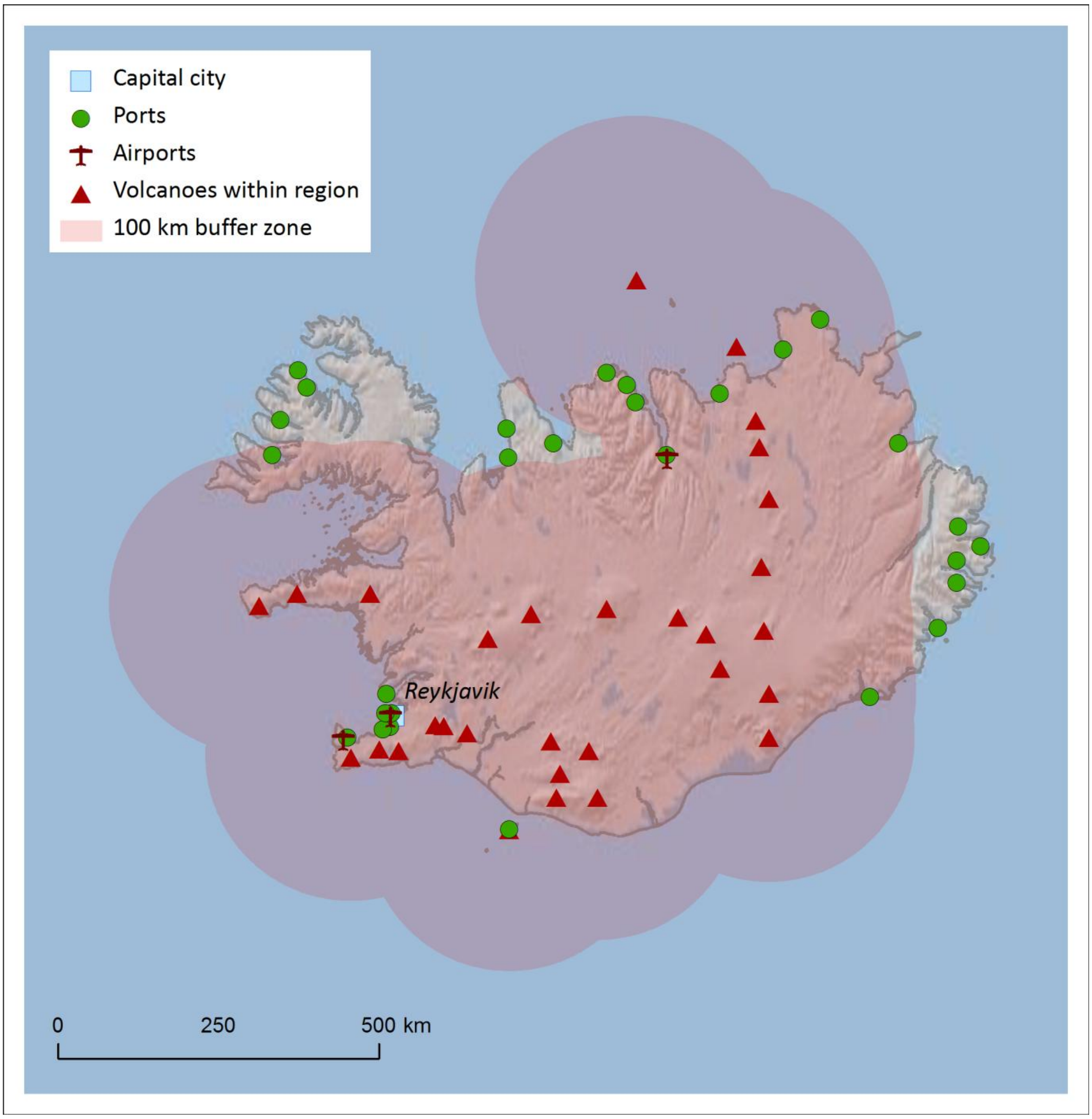

Figure 353: The location of Iceland's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The volcanoes of Iceland have varying levels of data available in the eruption record. 50% (15) of the volcanoes have appropriate eruptive histories to define the hazard. Eight of these have erupted since 1900. These volcanoes are classified across Hazard Levels I and II, with most at Level I.

Of the unclassified volcanoes, six have no confirmed Holocene age eruptions. The remaining volcanoes have a Holocene record, including five with historical activity.

In Iceland the PEI ranges from low to high, at PEI 2 to 5. With most volcanoes classed at PEI 2, the majority of Icelandic classified volcanoes are classed at Risk Level I, with just four being Risk Level II.

CLASSIFIED	**Hazard III**		Hekla					
	Hazard II		Katla; Grímsvötn; Bárdarbunga; Askja		Reykjanes			
	Hazard I		Snaefellsjökull; Ljósufjöll; Hveravellir; Kverkfjöll; Krafla	Hengill; Grímsnes		Krísuvík; Brennisteinsfjöll		
UNCLASSIFIED	**U – HHR**		**Vestmannaeyjar**; **Eyjafjallajökull**; Tjörnes Fracture Zone; Öraefajökull; Kolbeinsey Ridge					
	U- HR		Prestahnukur; Torfajökull; Fremrinamur; Theistareykjarbunga					
	U- NHHR		Helgrindur; Hofsjökull; Tindfjallajökull; Tungnafellsjökull; **Esjufjöll**	**Hrómundartindur**				
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 328: Identity of Iceland's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Krísuvík	5	II
Brennisteinsfjöll	5	II
Reykjanes	4	II
Hengill	3	I
Grímsnes	3	I
Hekla	2	II
Snaefellsjökull	2	I
Ljósufjöll	2	I
Hveravellir	2	I
Katla	2	I
Grímsvötn	2	I
Bárdarbunga	2	I
Kverkfjöll	2	I
Askja	2	I
Krafla	2	I

Table 329: Classified volcanoes of Iceland ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 11 volcanoes; Risk Level II – 4 volcanoes; Risk Level III – 0 volcanoes.

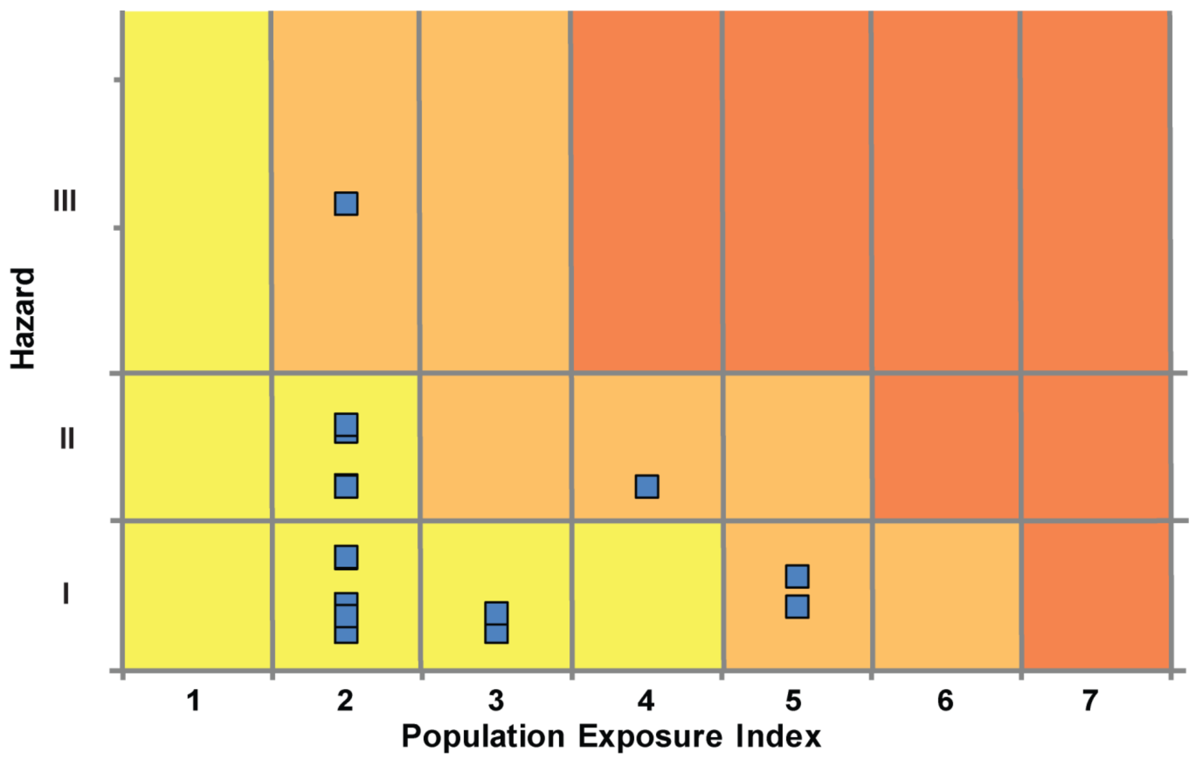

Figure 354: Distribution of Iceland's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Historical eruptions are recorded at 13 volcanoes in Iceland. All of these have dedicated ground-based monitoring systems in place, with monitoring conducted by the Iceland Meteorological Office

(IMO). Multiple monitoring systems are used, including seismic analysis and deformation, categorising these volcanoes at Monitoring Level 3. Many of the Holocene volcanoes with activity prior to 1500 AD are also monitored by the IMO.

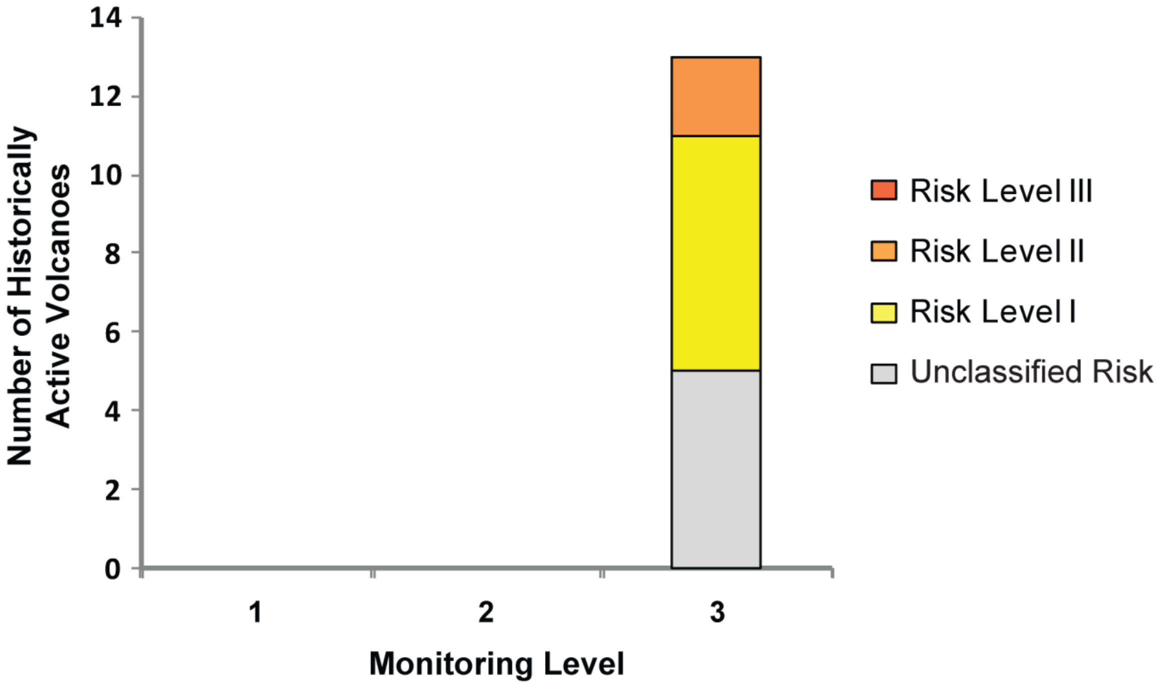

Figure 355: The monitoring and risk levels of the historically active volcanoes in Iceland. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Norway

Note that we include discussion of the remote Bouvet and Thompson Island volcanoes of the South Atlantic (Region 18) here.

Description

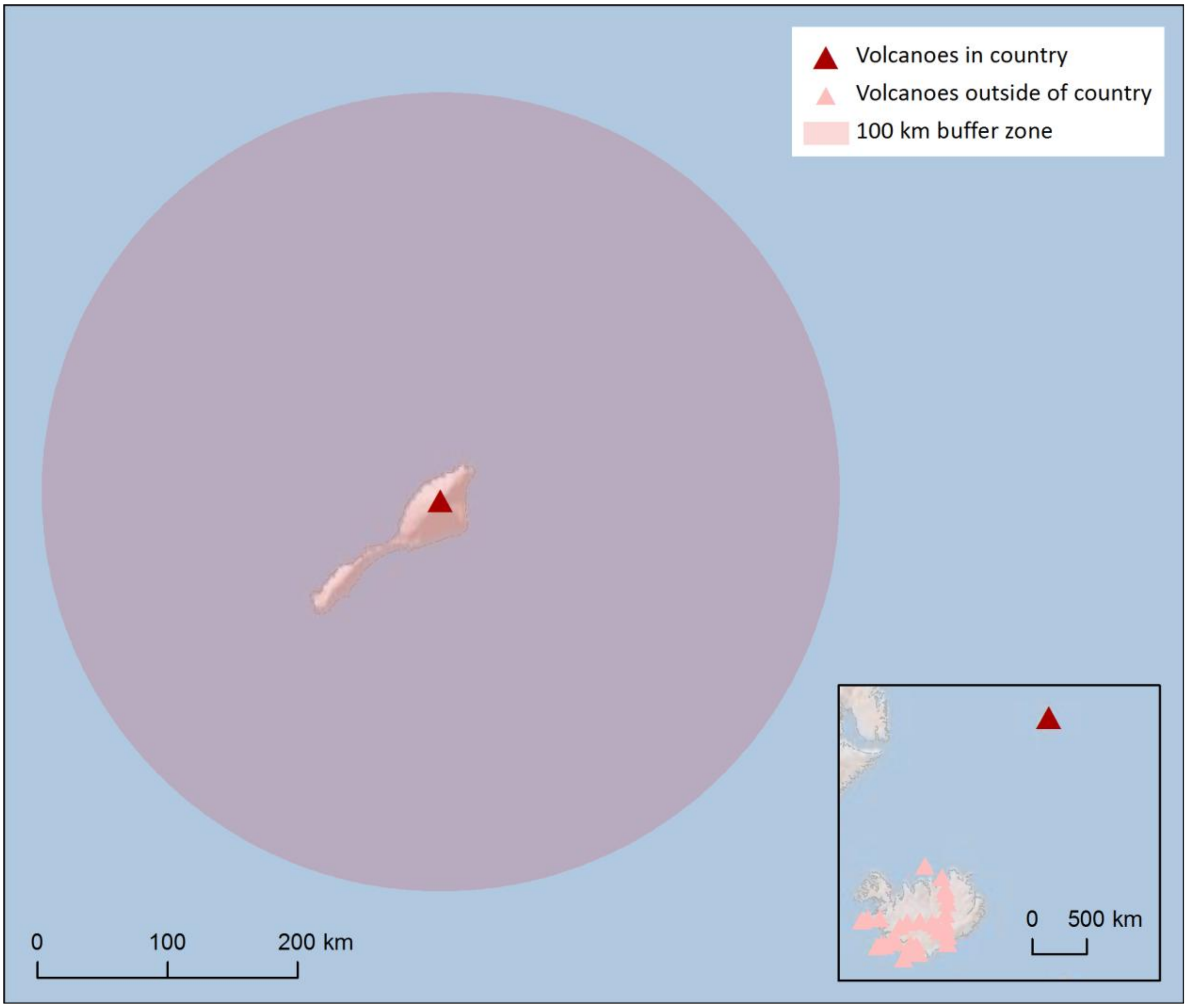

Figure 356: The location of Norway's volcano – Jan Mayen in the Iceland and Arctic Ocean region and the extent of the 100 km zone surrounding it.

There is no active volcanism on mainland Norway. An active volcano is found on a Norwegian island of Jan Mayen in the North Atlantic ocean. The small island (53 km long and 2-16 km wide) is situated approximately 550 km north of Iceland and 950 km west of Norway. The island has no residents other than temporary personnel working for the Norwegian Armed Forces or the Norwegian Meteorological Institute. Eighteen people spend the winter on the island, but the population may double (35) during the summer. Since 2010, the island has been closed to tourists.

The northern part of the island is dominated by a stratovolcano, Beerenberg, which is the northernmost active subaerial volcano on Earth. The upper part of Beerenberg is covered by an ice cap. The southern part of the island is a mountainous ridge made of scoria craters, scoria mounds, and lava domes.

Volcanic activity is sourced in a fairly unusual tectonic setting near the intersection of the Jan Mayen Fracture Zone (a transform fault) and the Mohn's mid-ocean ridge. Six eruptions have occurred between 1732 and 1985. All of these eruptions were on flank vents and produced lava flows and scoria cones. The most recent eruptions were in 1970, 1973, and 1985.

The 1970 eruption began on September 18 and continued to January 1971. Intense storms hid the onset of the eruption. A commercial pilot spotted the eruption cloud on September 20. The personnel was evacuated, but returned shortly. The eruption was large, erupting at least 0.5 km^3 of basalt from a 6 km long fissure that ran from sea-level to an elevation of 1,000 m. There were at least five active craters.

The 1985 eruption began on January 6, 1985 and lasted only 35-40 hours. The volume of lava was two orders of magnitude smaller than in 1970-71. Earthquakes with magnitudes up to 5 occurred during the eruption. The eruption was thought to be from a leaky fracture zone not the Jan Mayen magma system proper. The vent was 35 km from the settlement. Personnel were not evacuated.

The Department of Earth Science, University of Bergen has operated seismic stations on Jan Mayen (as part of the National Seismic Network of Norway) since 1961. The 3 stations on Jan Mayen are used to make daily locations of the local seismicity as well as recording distal earthquakes. The 1985 eruption was the first one to be observed with the local seismic network. Volcanic tremors and low-frequency events were observed on 5 January at 2230 h and 10 hours later the first large earthquake occurred. No visual confirmation of the eruption was made until 6 January at 1630 h. The local network hence provides an efficient tool for monitoring and warning of volcanic activity. However, since there was no change in the local seismicity in the days or months before the 1985 eruption, it seems to be difficult to make long-term predictions of flank eruptions without introducing additional monitoring techniques.

Another volcanic area under Norwegian dependency is Bouvet Island in the South Atlantic Ocean. It is a small (49 km^2) and uninhabited sub-Antarctic island. It lies at the southern end of the Mid-Atlantic Ridge and is the most remote island in the world, approximately 2,200 kilometres south-southwest of the coast of South Africa. There have been no historical eruptions on the island, but the eruption history is not known. The existence of Thompson Island volcano about 70 km north-northeast of Bouvet was reported in 1893 but since this time there is no evidence of its existence.

References:

http://www.jan-mayen.no/

Havskov, J. and Atakan, K. (1991), Seismicity and volcanism of Jan Mayen Island. Terra Nova, 3: 517–526. doi: 10.1111/j.1365-3121.1991.tb00187.x

Volcano Facts

Number of Holocene volcanoes	3
Number of Pleistocene volcanoes with M≥4 eruptions	-

Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	2
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Three eruptions of VEI 3 are recorded at Jan Mayen in 1732, 1818 and 1970.
Number of Holocene eruptions	8 confirmed eruptions. 2 uncertain and 1 discredited eruption.
Recorded Holocene VEI range	0 – 3 and unknown.
Number of historically active volcanoes	1
Number of historic eruptions	6

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Basaltic (1)
1	Shield(s)	Basaltic (1)
1	Submarine	Unknown (1)

Table 330: The number of volcanoes in Norway (Iceland and Arctic Ocean region and Atlantic Ocean region), their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2011)	4,691,849 (mainland Norway)
Gross Domestic Product (GDP) per capita (2005 PPP $)	47,626 (mainland Norway)
Gross National Income (GNI) per capita (2005 PPP $)	47,950 (mainland Norway)
Human Development Index (HDI) (2012)	0.955 (mainland Norway)

Population Exposure

Capital city	Oslo

Distance from capital city to nearest Holocene volcano	1110.7 km
Number (percentage) of people living within 10 km of a Holocene volcano	1 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	1 (<1%)
Number (percentage) of people living within 100 km of a Holocene volcano	1 (<1%)

Infrastructure Exposure

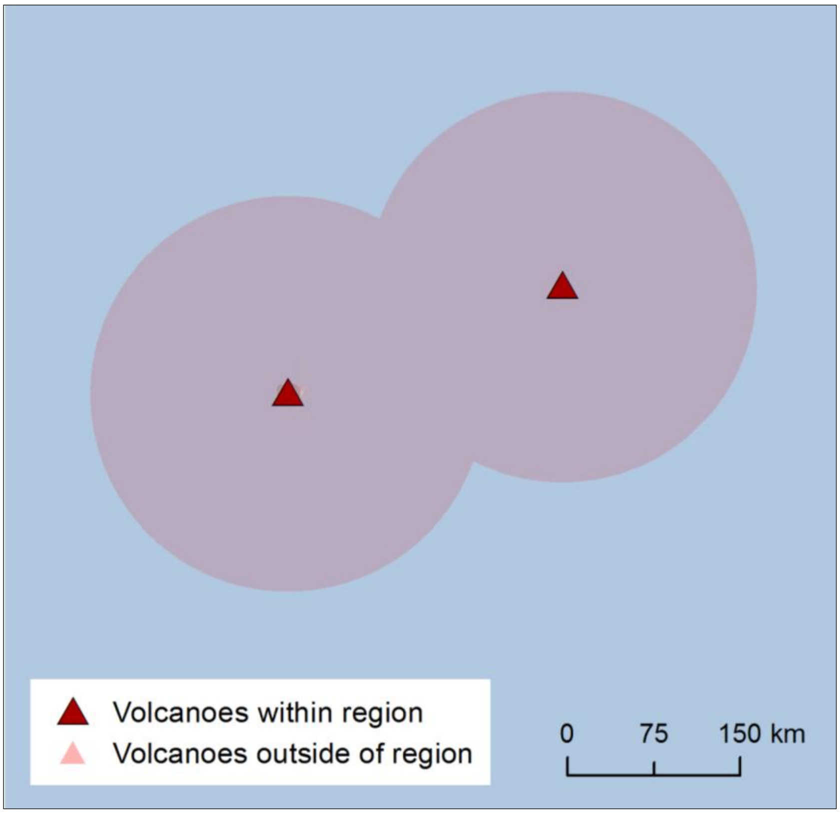

Figure 357: The Bouvet and Thompson Island volcanoes in the southern Atlantic Ocean, and the extent of the 100 km zone surrounding them.

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

Hazard, Uncertainty and Exposure Assessments

Of the three Norwegian volcanoes, just Jan Mayen has a sufficient eruption record to determine hazard through calculation of the VHI. This volcano is classified as Hazard Level II. With just one recorded Holocene eruption, Bouvet is unclassified, as is Thompson Island which has no confirmed Holcoene activity.

With no population living within 100 km of the Norwegian volcanoes the PEI is classified at PEI 1. This makes these volcanoes Risk Level I, with no potential to increase in Risk level despite the uncertainty in the Hazard.

CLASSIFIED	**Hazard III**							
	Hazard II	Jan Mayen						
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR	Bouvet						
	U- NHHR	Thompson Island						
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 331: Identity of Norway's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Jan Mayen	1	I

Table 332: Classified volcanoes of Norway ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

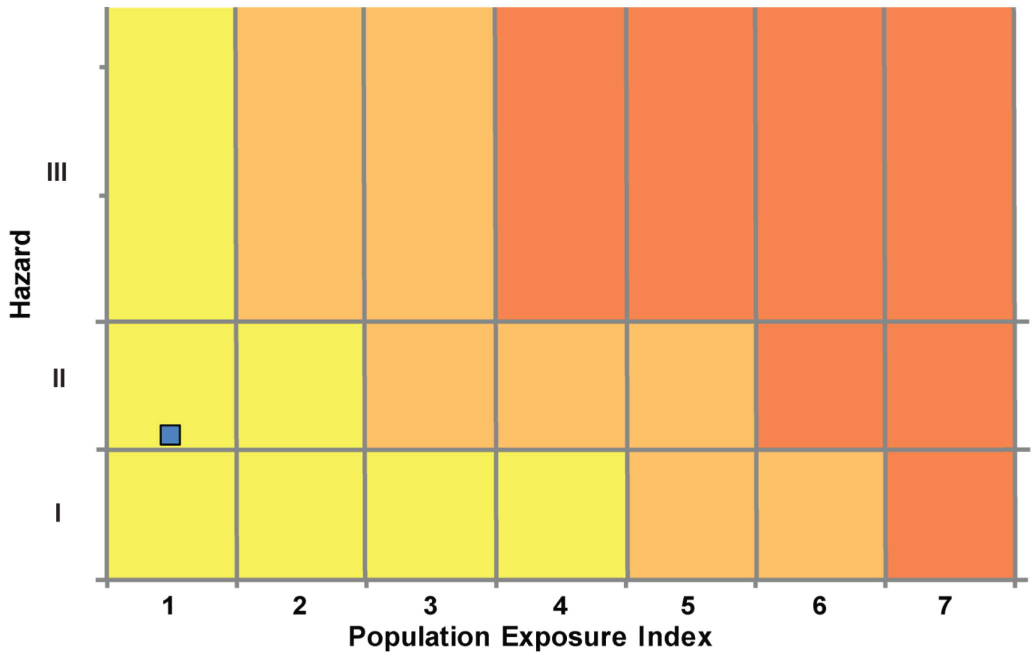

Figure 358: Distribution of Norway's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The University of Bergen operates a network of three seismometers on the island of Jan Mayen.

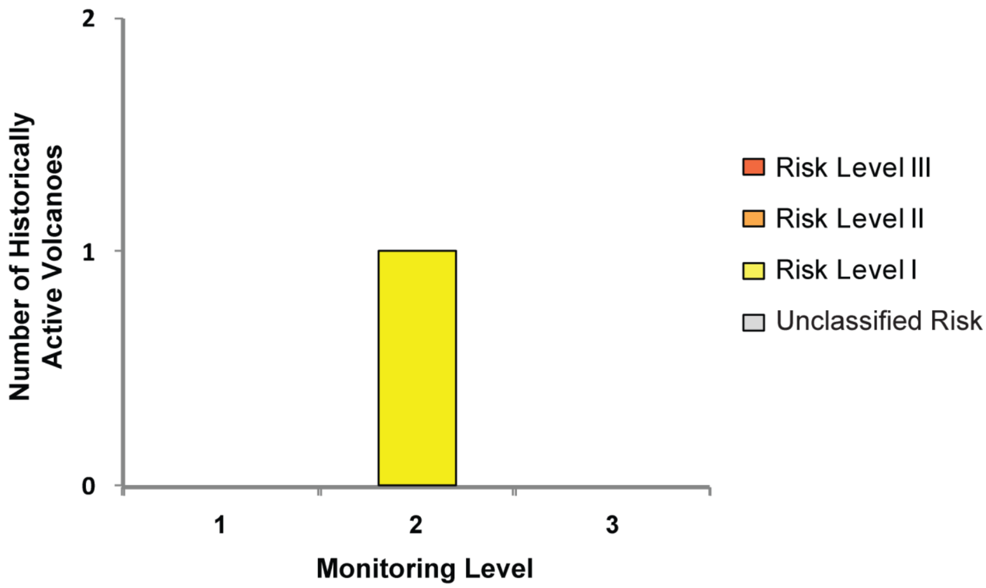

Figure 359: The monitoring and risk levels of the historically active volcanoes in Norway. Monitoring Level 1indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 18: Atlantic Ocean

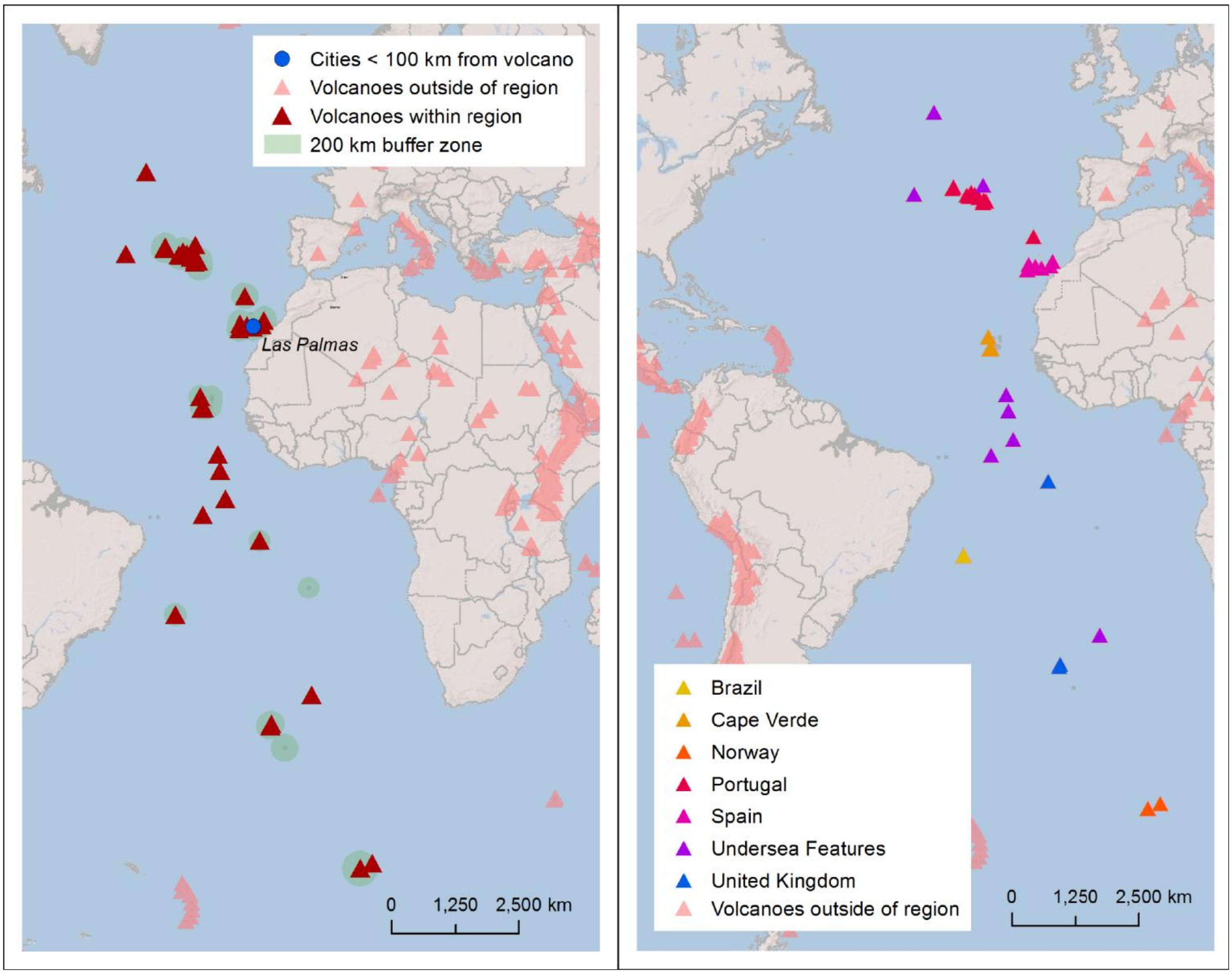

Figure 360: The distribution of Holocene volcanoes through the Atlantic Ocean region. The capital cities of the constituent countries are shown. The host countries are identified on the right.

Description

Region 18: the Atlantic Ocean comprises volcanoes throughout the Atlantic, from an unnamed seamount in the north to the Norwegian territory of Bouvet in the south. Six countries are represented here. All are included in this regional discussion, and individual country profiles are provided, however see Region 17 for the Norway profile.

Country	Number of volcanoes
Brazil	1
Cape Verde	3
Norway (See Region 17)	2
Portugal – Azores	14
Spain – Canary Islands	6
UK	3

Table 333: The countries represented in this region and the number of volcanoes. Volcanoes located on the borders between countries are included in the profiles of all countries involved. Note that countries may be represented in more than one region, as overseas territories may be widespread.

Thirty-seven Holocene volcanoes are located in the Atlantic Ocean. Most of these are in the Azores. Volcanism here is largely related to intra-plate hotspot processes in the ocean crust, with several volcanoes on or near the mid-Atlantic Ridge. Considerable submarine volcanism occurs at the mid-Atlantic ridge, where rifting processes generate voluminous basalt flows.

Excluding the submarine volcanism of the Mid-Atlantic Ridge, eleven volcanoes in this region are classed as submarine. The dominant volcano types are stratovolcanoes, with numerous such volcanoes present through the Azores and Cape Verde in particular. Five volcanoes comprise fissure vents and or pyroclastic cones, and four shield volcanoes are found. The rock type through this region is dominantly basaltic, though ranges from basaltic to trachytic.

A range of activity styles and eruption sizes are recorded throughout the Holocene, with eruptions of VEI 0 to 5. About 70% of eruptions here have been small, at VEI 0 to 2, however over 18% of eruptions have been large explosive VEI ≥4 events. These VEI ≥4 eruptions have largely been restricted to the Azores, with just one in the Canary Islands. Four VEI 5 eruptions are recorded at Agua de Pau and Furnas in the Azores, the most recent of which was the 1630 eruption of Furnas, which caused property damage and loss of life.

Twenty volcanoes have historical records of 58 eruptions, 95% of which were recorded through direct observations. 9% of historical events have involved the production of pyroclastic flows, whilst 57% produced lava flows.

Lives were lost in 16% of historical eruptions (9 events at 6 volcanoes – San Jorge, Furnas, Fayal, Pico in the Azores; La Palma in the Canary Islands and Fogo in Cape Verde). Most volcanoes have small to medium local populations, and as such most volcanoes in this region are classed at Risk Level II. However the hazard is not classified at about 80% of the region's volcanoes.

Of twenty historically active volcanoes in this region, 14 have one or more dedicated seismometer for volcano monitoring.

Volcano facts

Number of Holocene volcanoes	37
Number of Pleistocene volcanoes with M≥4 eruptions	6

Number of volcanoes generating pyroclastic flows	8 (17 eruptions)
Number of volcanoes generating lahars	3 (4 eruptions)
Number of volcanoes generating lava flows	16 (111 eruptions)
Number of eruptions with fatalities	9
Number of fatalities attributed to eruptions	541
Largest recorded Pleistocene eruption	The largest recorded eruption in this region during the Quaternary is the DHF I: Fasnia Formation (Lower Grey Member) eruption of Tenerife, Canary Islands. This M6.5 event occurred at 289 ka.
Largest recorded Holocene eruption	There are four eruptions of VEI 5 recorded at Agua de Pau and Furnas.
Number of Holocene eruptions	166 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 5 and unknown.
Number of historically active volcanoes	20
Number of historical eruptions	58

Number of volcanoes	Primary volcano type	Dominant rock type
17	Large cone(s)	Andesitic (1), Basaltic (8), Foiditic (3) Phonolitic (1), Trachytic /Andesitic (4)
4	Shield(s)	Basaltic (4)
5	Small cone(s)	Basaltic (5)
11	Submarine	Basaltic (1), Unknown (10)

Table 334: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	5
Large (> VEI 3)	230

Table 335: Average recurrence interval (years between eruptions) for small and large eruptions in the Atlantic Ocean.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 ocurr in this region with an average recurrence interval (ARI) of about 5 years, whilst the ARI for large eruptions is longer, at about 230 years.

Eruption Size

Eruptions are recorded through the Atlantic Ocean region of VEI 0 to 5, representing a range of eruption styles from gentle effusive events to large explosive eruptions. VEI 2 events dominate the record, with nearly 50% of all Holocene eruptions classed as such. Over 18% of eruptions here are explosive at VEI≥4.

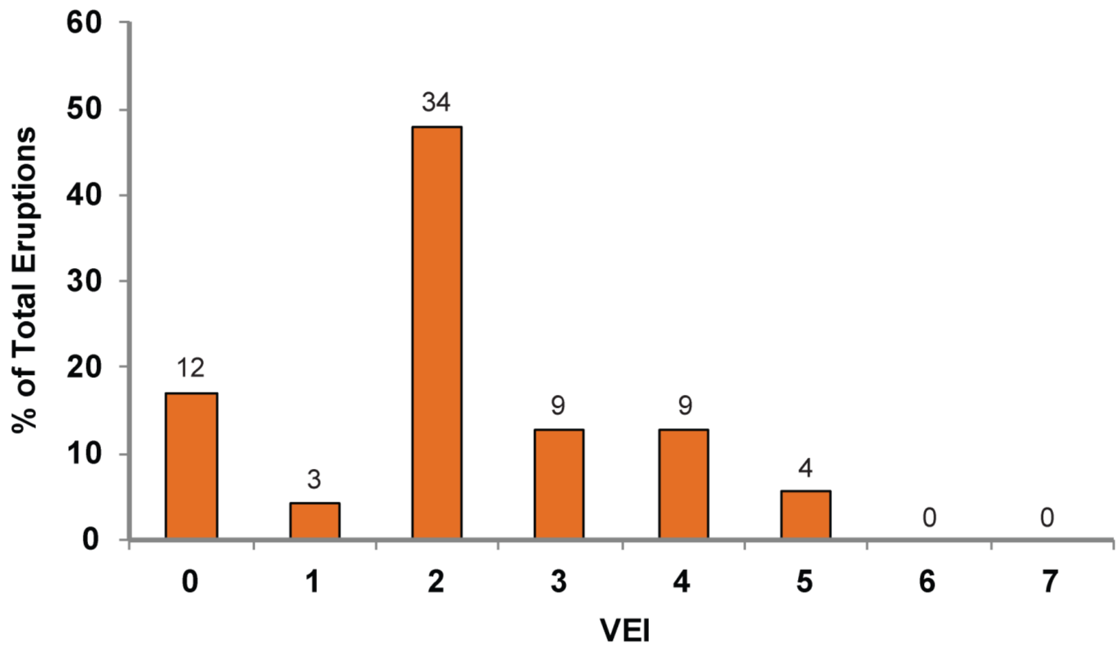

Figure 361: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 95 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Gross Domestic Product (GDP) per capita (2005 PPP $)	3,616 (Cape Verde)
Gross National Income (GNI) per capita (2005 PPP $)	3,609 (Cape Verde)
Human Development Index (HDI) (2012)	0.586 (Medium, Cape Verde)

Infrastructure Exposure

Number of airports within 100 km of a volcano	17
Number of ports within 100 km of a volcano	17
Total length of roads within 100 km of a volcano (km)	1,570
Total length of railroads within 100 km of a volcano (km)	0

CLASSIFIED	**Hazard III**			Furnas	Agua de Pau			
	Hazard II			San Jorge	Sete Cidades; La Palma; Tenerife			
	Hazard I				Fogo			
UNCLASSIFIED	**U – HHR**	Unnamed (381020); Unnamed (381040); **Unnamed (385052)**	**Don Joao de Castro Bank; Monaco Bank; Tristan da Cunha; Nightingale Island**	Pico	**Fayal; Terceira; Hierro**	Lanzarote	Picos Volcanic System	
	U- HR	Bouvet		Flores	Gran Canaria		Madeira	
	U-NHHR	Unnamed (381030); Unnamed (385010); Unnamed (385020); Unnamed (385030); Unnamed (385040); Trindade; Thompson Island	Corvo; Ascensión	Graciosa; **Brava**	Fuerteventura	Sao Vicente		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table **336**: Identity of the volcanoesin this region in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
2	6
2	5
10	4
6	3
6	2
11	1

Table 337: The number of volcanoes in the Atlantic Ocean classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
1	III
5	II
1	I
30	Unclassified

Table 338: The number of volcanoes in the Atlantic Ocean region classified at each Risk Level.

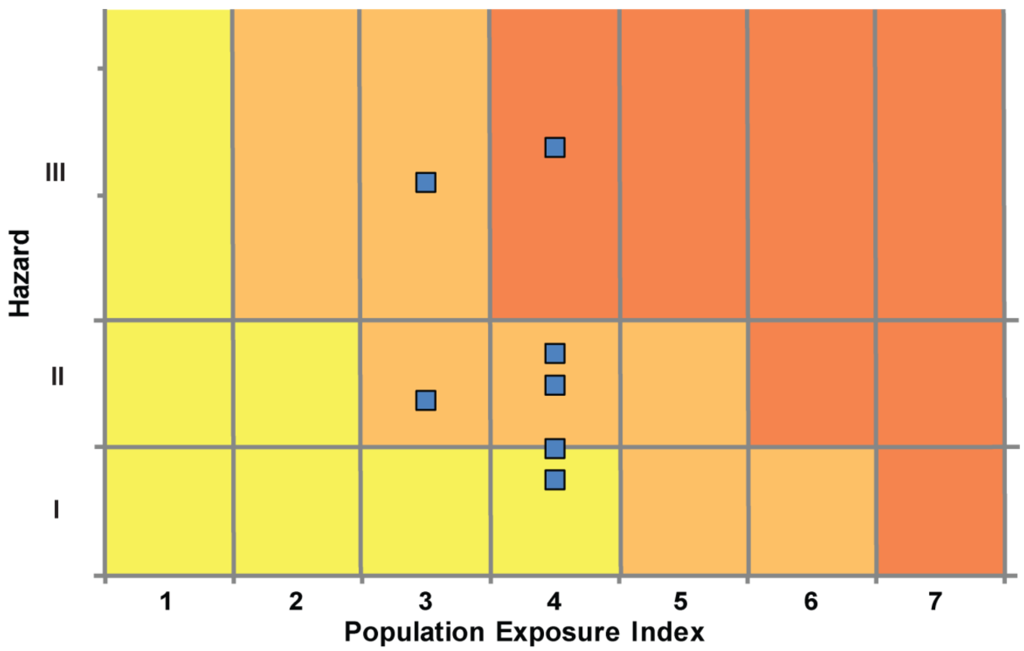

Figure 362: Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

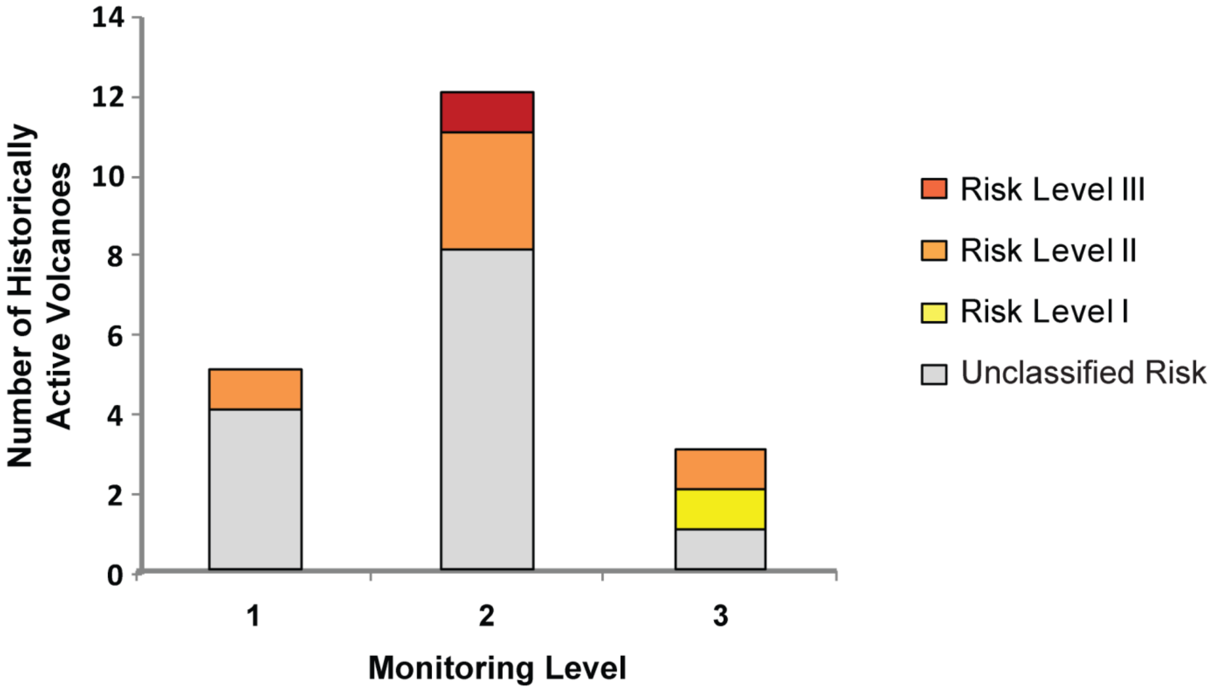

Figure 363: The monitoring and risk levels of the historically active volcanoes in the Atlantic Ocean. Monitoring Level 1indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Brazil

Description

One volcano, Trindade, forms an island of the same name lying about 1,100 km off the coast of Brazil. This volcano lies at the eastern end of a chain of submarine volcanoes extending from Brazil's coast and is related to intra-plate processes.

No Holocene eruptions are recorded at Trindade, however the youngest activity which constructed a pyroclastic cone and extensive lava flows, is considered no older than Holocene (Almeida, 1961 in VOTW4.22). With no detailed eruptive history, the hazard level of this volcano cannot be determined.

Only a small contingent of the Brazilian Navy resides on the island of Trindade, with no permanent population located here or within 100 km of the volcano.

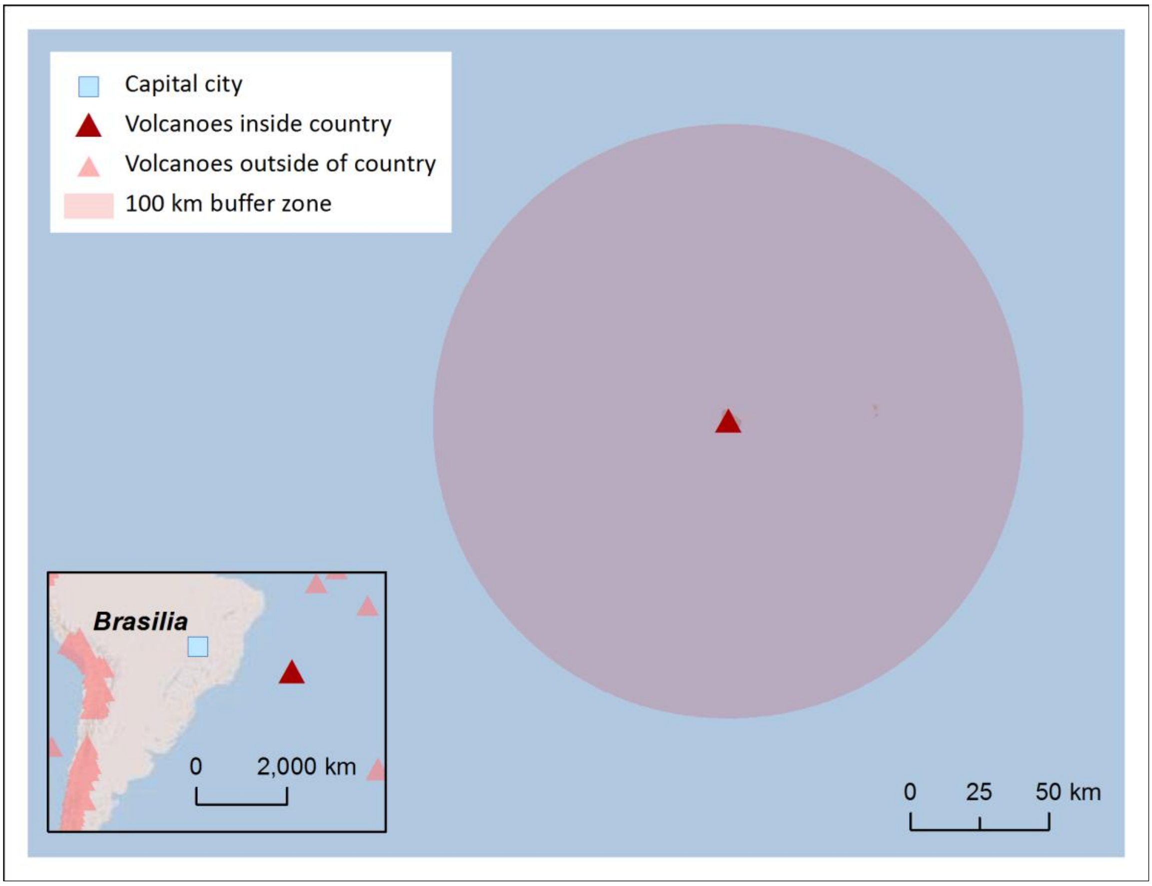

Figure 364: Location of Brazil's volcano, Trindade, and a 100 km radius surrounding it.

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-

Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Intra-plate
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	-
Number of Holocene eruptions	-
Recorded Holocene VEI range	-
Number of historically active volcanoes	-
Number of historic eruptions	-

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Foiditic (1)

Table 339: The number of volcanoes in Brazil, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	198,833,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	10,278
Gross National Income (GNI) per capita (2005 PPP $)	10,152
Human Development Index (HDI) (2012)	0.730 (High)

Population Exposure

Capital city	Brasília
Distance from capital city to nearest Holocene volcano	2013.6 km
Total population (2011)	203,429,773
Number (percentage) of people living within 10 km of a Holocene volcano	0 (0%)
Number (percentage) of people living within 30 km of a Holocene volcano	0 (0%)

Number (percentage) of people living within 100 km of a Holocene volcano	0 (0%)

Ten largest cities, as measured by population, and populations:

Sao Paulo	10,021,295
Rio de Janeiro	6,023,699
Salvador	2,711,840
Fortaleza	2,400,000
Belo Horizonte	2,373,224
Brasilia	2,207,718
Curitiba	1,718,421
Manaus	1,598,210
Recife	1,478,098
Porto Alegre	1,372,741

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	0
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The Trindade volcano is located at over 1000 km off the coast of Brazil, thus no areas of mainland Brazil lie within 100 km of a Holocene volcano. The Trindade and Martim Vaz islands are small and hence lie in their entirety within 100 km of the Trindade volcano, and as such all infrastructure here is exposed. No permanent settlements exist here, however a Brazilian Navy Base is located on Trinidade < 5 km from the volcano.

Hazard, Uncertainty and Exposure Assessments

With no confirmed Holocene eruptions recorded at Trindade volcano in Brazil hazard assessment through the calculation of the VHI cannot be undertaken and this volcano is therefore unclassified.

There is no permanent population living within 100 km of Trindade with the exception of a small contingent of the Brazilian Navy, hence a PEI of 1. Despite the absence of a hazard classification, this points to this volcano being ranked at Risk level I.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR	Trindade						
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 340: Identity of Brazil's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

No volcanoes in Brazil have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Brazil.

Cape Verde

Description

There are three Holocene volcanoes in Cape Verde as listed in VOTW4.0: Brava, Fogo and Sao Vicente. Fogo was most recently active in 1995. Recent dating of rocks on Brava suggests that Holocene eruptions occurred here. Holocene lavas are described on Sao Vicente by Mitchell-Thorne, 1976 in VOTW4.0), however Holm et al. (2008) date activity here at 6.6 to 0.3 Ma. We include Sao Vicente in analysis here due to its inclusion in VOTW4.0. In their investigations of volcanic hazard in Cape Verde, Faria and Fonseca (2014) do not consider Sao Vicente as an active volcano, instead considering Santo Antão, north of Sao Vicente, as a potentially active centre, though the last dated activity here was about 90,000 years ago. Whilst Sao Vicente and Santo Antão are in the north, Brava and Fogo are in the south. All are stratovolcanoes related to a mantle hotspot.

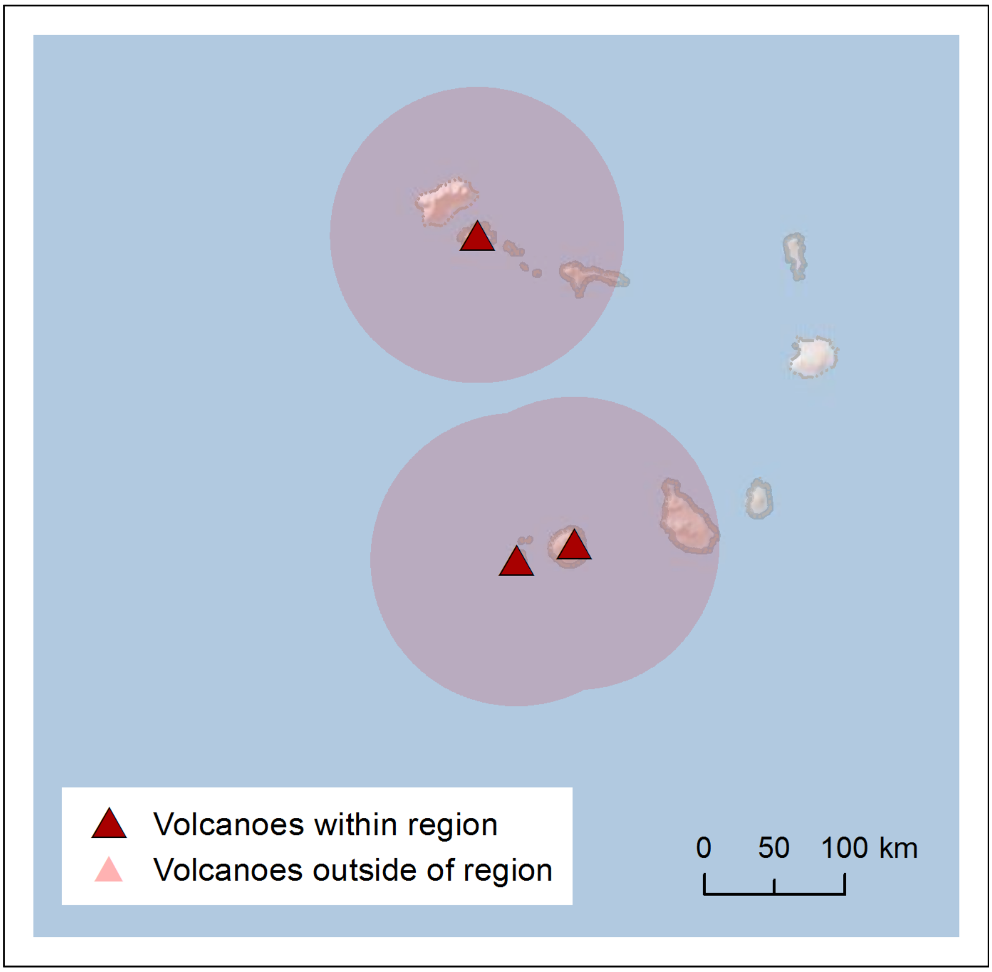

Figure 365: The location of the Cape Verde volcanoes and a 100 km buffer zone surounding them.

Brava is the westernmost island of the southern Cape Verde Islands. The age of the last eruption is unknown; however, frequent seismic swarms suggest the island is still active. Carbonantite lavas and pyroclastic deposits are also present on Brava, which are presumed to be Holocene to Pleistocene in age (Mourão et al., 2010).

Fogo is the only historically active volcano in the Cape Verde Islands. Fogo is a stratovolcano with a 9 km wide collapse structure just NE of the centre of the island. The caldera is open to the east and has a 1 km high horse-shoe shape wall. Within the caldera is a steep-sided cone, Pico, rising >1 km above the caldera floor. Pico had a period of very frequent eruptions from the time of Portuguese settlement in 1500 until about 1760, which are not listed individually in VOTW4.22, however the National Institute for Meteorology and Geophysics has identified separate sixteen separate events in this time, including a large eruption in 1680. Since then, 9 historical eruptions have been recorded with lava flows sometimes reaching the eastern coast. Its last known eruption was in 1995.

Only Fogo has a record of historic eruptions, however both Brava and Santa Antão have had historic felt seismicity and recorded seismic and geothermal activity. These latter volcanoes have a geological record of eruptions, including some explosive events. Faria and Fonseca (2014) consider the volcanic hazard levels to be highest on Fogo, Brava and Santa Antão and hence monitoring efforts are focussed here. They describe the lava flow hazard on Fogo as being particularly high within the caldera and in the eastern coast. In Brava they describe the volcanic hazard awareness among the population and authorities as very low due to the absence of historical eruptions.

The National Institute for Meteorology and Geophysics (INMG) of the Cape Verde Government monitors the Fogo, Brava and Santa Antão volcanoes using networks of broadband seismometers (7 on Fogo, 2 on Brava, 4 on Santo Antão, 1 on Sao Vicente and 1 on Sal) and, on Fogo, three tiltmeters. Monitoring and civil protection were established on Fogo Volcano after the 1995 eruption. In 2010, it was recognised that Brava may pose a threat and monitoring was established.

Faria and Fonseca (2014) describe how a warning system is operational on Fogo, using an alert level system of five levels. If anomalous activity is detected, a warning is sent to the National Civil Protection Service, which is responsible for risk management in Cape Verde. Were unrest or activity to increase at the other volcanoes, as detected through the monitoring network, then warning systems would be established for these.

See also:

Faria, B., and Fonseca, J.F.B.D. (2014) Investigating volcanic hazard in Cape Verde Islands through geophysical monitoring: network description and first results. Nat. Hazards Earth Syst. Sci. 14, 485-499.

Holm, P.M., Grandvuinet, T., Friis, J., Wilson, J.R., Barker, A.K. and Plesner, S. (2008) An 40Ar-39Ar study of the Cape Verde hot spot: Temporal evolution in a semistationary plate environment. Journal of Geophysical Research, 113, B08201.

Mourão, C., Mata, J., Doucelance, R., Madeira, J., Silveira, A. B. D., Silva, L. C., & Moreira, M. (2010). Quaternary extrusive calciocarbonatite volcanism on Brava Island (Cape Verde): a nephelinite-carbonatite immiscibility product. *Journal of African Earth Sciences*, *56*(2), 59-74.

Volcano Facts

Number of Holocene volcanoes	3
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	No lahars are recorded in VOTW4.22 however lahar deposits are observed in Fogo (considered likely to be historical), Brava and Sao Antão.
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	?15
Tectonic setting	Intraplate
Largest recorded Pleistocene eruption	The M5.7 Cão Grande pumice of Santo Antão at 200 ka.
Largest recorded Holocene eruption	7 eruptions of VEI 2 are recorded at Fogo between 1785 AD and 1995 AD. An eruption identified in 1680 at Fogo does not have an attributed size and is not considered separately in VOTW4.22, however it is considered to have been a large explosive event.
Number of Holocene eruptions	11 according to VOTW4.22, with a further 15 identified by the INMG.
Recorded Holocene VEI range	1 – 2 and unknown.
Number of historically active volcanoes	1 (Fogo)
Number of historic eruptions	11 according to VOTW4.22, with a further 15 identified by the INMG.

Number of volcanoes	Primary volcano type	Dominant rock type
3	Large cone(s)	Basaltic (1), Foiditic (2)

Table 341: The number of volcanoes in Cape Verde, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	496,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	3,616
Gross National Income (GNI) per capita (2005 PPP $)	3,609
Human Development Index (HDI) (2012)	0.586 (Medium)

Population Exposure

Capital city	Praia
Distance from capital city to nearest Holocene volcano	87.1 km
Total population (2011)	516,100
Number (percentage) of people living within 10 km of a Holocene volcano	96,368 (18.7%)
Number (percentage) of people living within 30 km of a Holocene volcano	144,129 (27.9%)
Number (percentage) of people living within 100 km of a Holocene volcano	462,061 (89.5%)

Largest cities, as measured by population, and populations:

Praia	113,364

Infrastructure Exposure

Number of airports within 100 km of a volcano	3
Number of ports within 100 km of a volcano	5
Total length of roads within 100 km of a volcano (km)	>100 km
Total length of railroads within 100 km of a volcano (km)	0

The three Holocene volcanoes of the Cape Verde islands are located on separate small islands, which are fully within the 100 km radius of each volcano. Not all Cape Verde islands are within 100 km distance of these volcanoes, however, the main island and capital, Praia, lies within 100 km of the southernmost two volcanoes. Although not described in the table here, an extensive road network is therefore affected and much of the critical infrastructure in the Cape Verde islands. The Pleistocene volcano of Santa Antão is home to about 44,000 people and hence significant infrastructure.

Hazard, Uncertainty and Exposure Assessments

Of Cape Verde's volcanoes, only Fogo has a sufficiently extensive eruption record to determine the hazard through the calculation of the VHI without significant associated uncertainties. This volcano is classified at Hazard Level I, with a historical record dominated by VEI 2 eruptions.

Neither Brava nor Sao Vicente have any confirmed Holocene eruptions on record, and as such these are unclassified. Brava has recorded unrest since 1900 AD, with the occurrence of minor seismicity.

The PEI in Cape Verde ranges from moderate to high. Despite the largest population within 100 km, with a PEI of 4 and Hazard Level I, Fogo is classed at Risk Level I. The risk is unclassified at Brava and Sao Vicente due to the absence of a hazard classification.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I				Fogo			
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR			**Brava**		Sao Vicente		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 342: Identity of Cape Verde's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in ***bold*** *have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Fogo	4	I

Table 343: Classified Volcanoes of Cape Verde ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

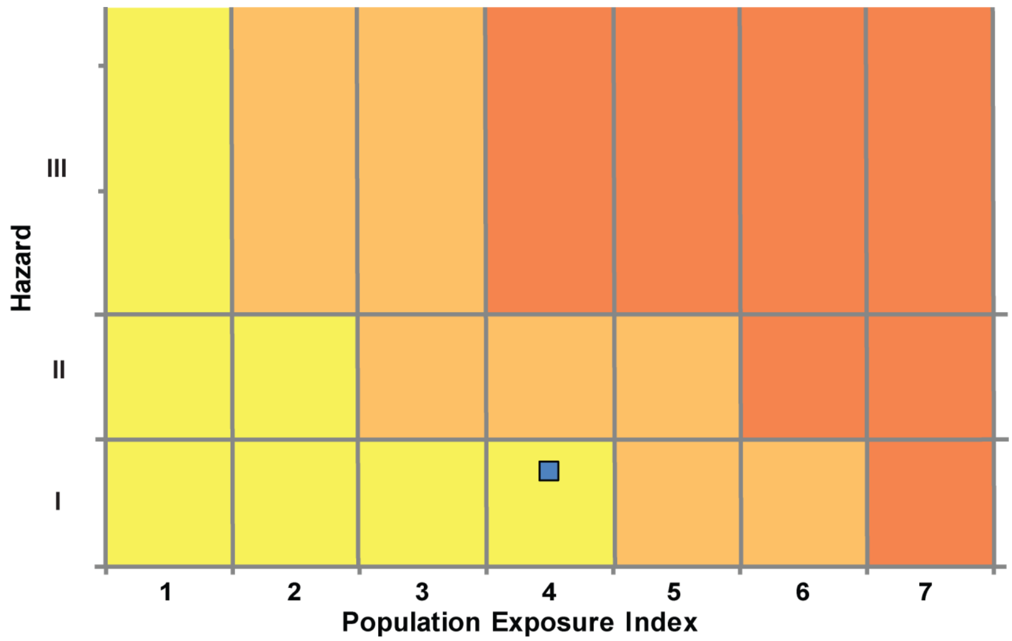

Figure 366: Distribution of Cape Verde's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels: Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The historically active Fogo is monitored by the Instituto Nacional de Meteorologia e Geofísica (National Institute for Meteorology and Geophysics) using a network of seismometers and tiltmeters. 15 seismometers are distributed throughout Cape Verde, focussed on the three largest islands Fogo, Santa Antão and Brava, considered with greatest Hazard by Faria and Fonseca (2014).

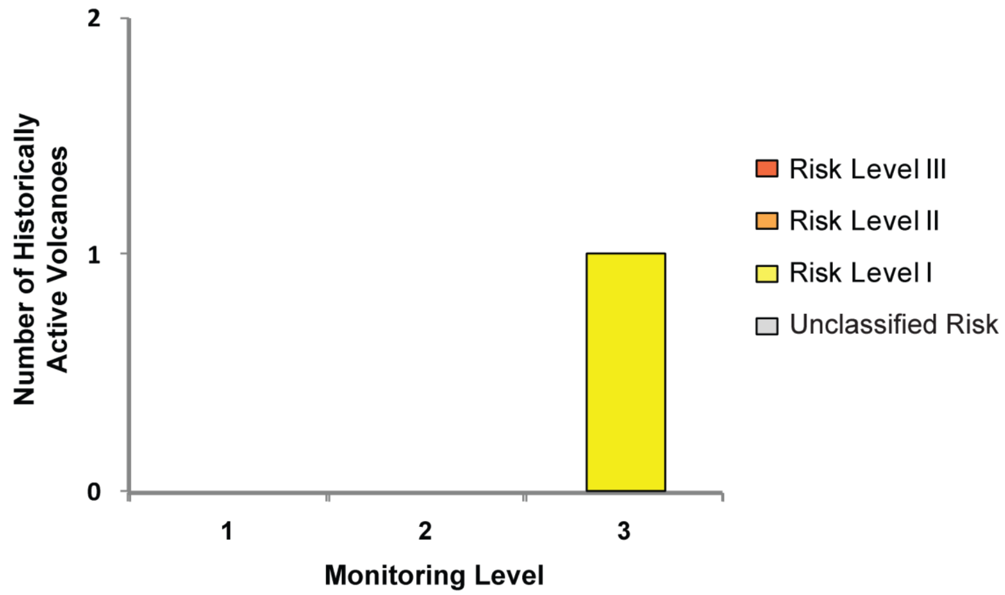

Figure 367: The monitoring and risk levels of the historically active volcanoes in Cape Verde. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Portugal - The Azores

Description

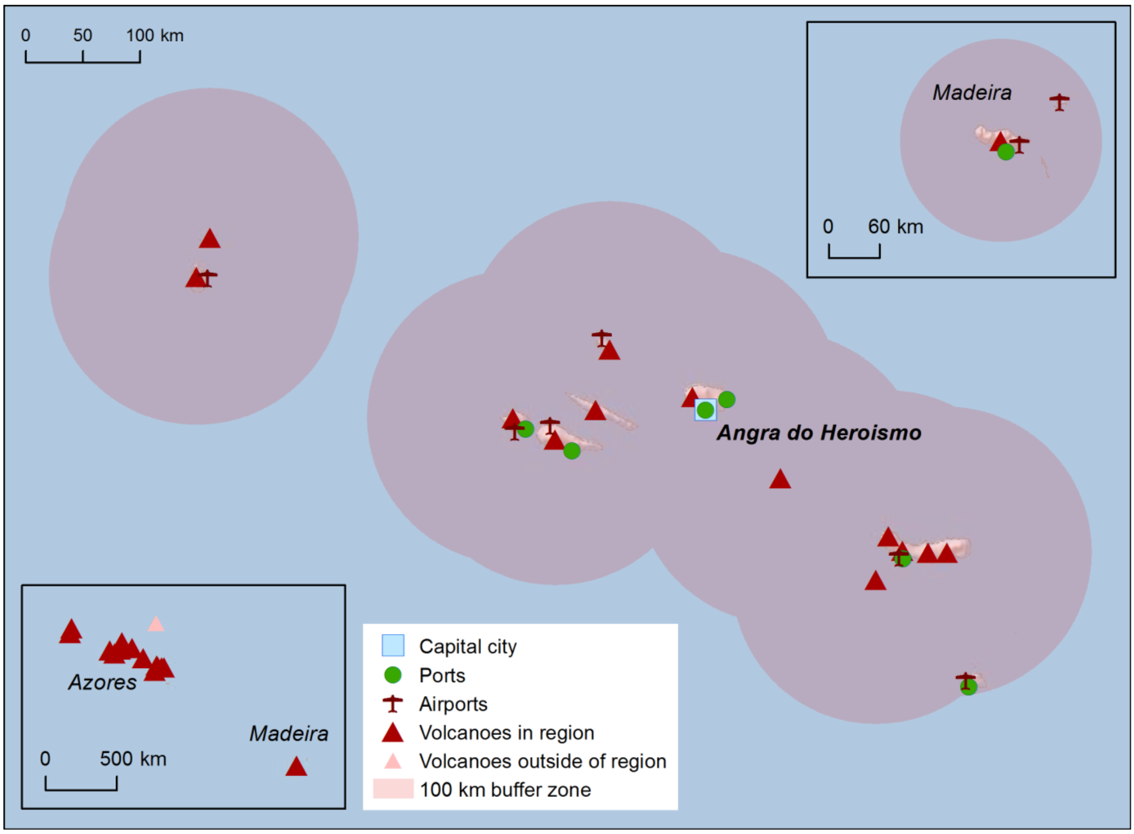

Figure 368: Location of the volcanoes in the Azores and a 100 km radius zone (pink) surrounding each volcano.

Fourteen Holocene volcanoes are located in the Azores. Volcanism here is due to the presence of a mantle plume intra-plate processes and tensional processes due to the presence of the Mid-Atlantic Ridge. Most volcanoes here are stratovolcanoes, and the composition of the rocks is most commonly basaltic.

Seventy-four eruptions of Holocene age are recorded, at VEI 0 to 5, indicating a range of activity from mild to large explosive events. Twenty-eight of these eruptions were recorded post-1500 AD.

One of the largest Holocene eruptions here was the VEI 5 eruption of Furnas in 1630. This produced pyroclastic flows and tephra fall, and resulted in significant damage and loss of life. Most activity has been dominated by Strombolian and Hawaiian eruption styles producing scoria and lava flows (Gaspar et al., 2011).

The size of the local population varies at each volcano, but throughout the Azores about 240,000 people live within 10km of a Holocene volcano.

The Centre for Volcanology and Geological Risk Assessment (CVARG) of the Azores University advises the regional and local civil protection authorities on volcanic issues. The Observatório Vulcanológico e Sismológico da Univ. dos Açores (CIVISA) is responsible for monitoring of the volcanoes here, using geophysical, geodetic and geochemical monitoring networks.

A permanent seismic network is operational and additional mobile seismometers are available. Permanent and temporary geodetic stations are also available. If unrest or eruptions are detected, the CVARG Crisis cabinet is activated and data is transmitted to the regional and local civil protection authorities.

See also:

Gaspar, J.L., Queiroz, G., Ferreira, T., Amaral, P., Viveiros, F., Marques, R., Silva, C., and Wallenstein, N. (2011) Geological hazards and monitoring at the Azores (Portugal), Earthzine, http://www.earthzine.org/2011/04/12/geological-hazards-and-monitoring-at-the-azores-portugal/

Observatório Vulcanológico e Sismológico da Univ. dos Açores: http://www.cvarg.azores.gov.pt/Paginas/home-cvarg.aspx

Volcano Facts

Number of Holocene volcanoes	14
Number of Pleistocene volcanoes with M≥4 eruptions	4
Number of volcanoes generating pyroclastic flows	7
Number of volcanoes generating lahars	3
Number of volcanoes generating lava flows	8
Number of fatalities caused by volcanic eruptions	?>525
Tectonic setting	11 Rift zone, 3 intra-plate
Largest recorded Pleistocene eruption	The M6.1 Caldera forming eruption of 24,691 BP at Sete Cidades.
Largest recorded Holocene eruption	The M6 Seara Cerrado da Ladeira (A) eruption of Sete Cidades at 5 ka and the M6 eruptions of Units C and E at Furnas at 1,784 and 1,300 BP respectively.
Number of Holocene eruptions	74 confirmed eruptions. 3 uncertain eruptions.
Recorded Holocene VEI range	0 – 5 and unknown.
Number of historically active volcanoes	10
Number of historic eruptions	28

Number of volcanoes	Primary volcano type	Dominant rock type
9	Large cone(s)	Andesitic (1), Basaltic (5), Trachytic /Andesitic (3)
1	Shield(s)	Basaltic (1)
2	Small cone(s)	Basaltic (2)
2	Submarine	Basaltic (1), Unknown (1)

Table 344: The number of volcanoes in the Azores, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Gross Domestic Product (GDP) per capita (2005 PPP $)	21,317
Gross National Income (GNI) per capita (2005 PPP $)	20,557
Human Development Index (HDI) (2012)	0.816

Population Exposure

Capital city (Azores)	Ponta Delgada, Angra do Heroísmo, Horta
Distance from capital city to nearest Holocene volcano	<5 km
Total population (2011, source: Instituto Nacional de Estatistica, Statistics Portugal: censos.ine.pt)	514,557 (including the Azores and Madeira)
Number (percentage) of people living within 10 km of a Holocene volcano	240,349 (46.6%)
Number (percentage) of people living within 30 km of a Holocene volcano	487,994 (94.8%)
Number (percentage) of people living within 100 km of a Holocene volcano	498,308 (96.8%)

Infrastructure Exposure

Number of airports within 100 km of a volcano	8
Number of ports within 100 km of a volcano	7
Total length of roads within 100 km of a volcano (km)	1,270
Total length of railroads within 100 km of a volcano (km)	0

The islands of the Azores are volcanic, meaning that the numerous towns and infrastructure of the Azores are located close to volcanic centres, including numerous ports and airports and an extensive road network.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of the volcanoes in the Azores. Just four volcanoes, <30%, have a sufficiently detailed record to define the hazard. These volcanoes are classified across hazard levels II and III, all with Holocene eruptions of VEI ≥3. San Jorge is the only classified volcano with activity since 1900 AD.

The remaining ten volcanoes are unclassified. Of these two, Corvo and Graciosa, have no confirmed Holocene eruptions on record. All others have a Holocene record, including historical activity at Don Joao de Castro Bank, Pico,Picos Volcanic System, Fayal, Terceira and Monaco Bank, including eruptions since 1900 AD at the latter three volcanoes.

The PEI ranges from 2 to 6, low to high in the Azores, with the largest populations and highest PEI found at Picos Volcanic System and Madeira. At a PEI of 4, the Hazard Level III volcano Agua de Pau is classed with the highest Risk Level in the Azores at III. The remaining classified volcanoes are Risk Level II.

CLASSIFIED	**Hazard III**			Furnas	Agua de Pau			
	Hazard II			San Jorge	Sete Cidades			
	Hazard I							
UNCLASSIFIED	**U – HHR**		**Don Joao de Castro Bank; Monaco Bank**	Pico	**Fayal; Terceira**		Picos Volcanic System	
	U- HR			Flores			Madeira	
	U- NHHR		Corvo	Graciosa				
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 345: Identity of the Azores' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Agua de Pau	4	III
Sete Cidades	4	II
Furnas	3	II
San Jorge	3	II

Table 346: Classified volcanoes of the Azores ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 3 volcanoes; Risk Level III- 1 volcano.

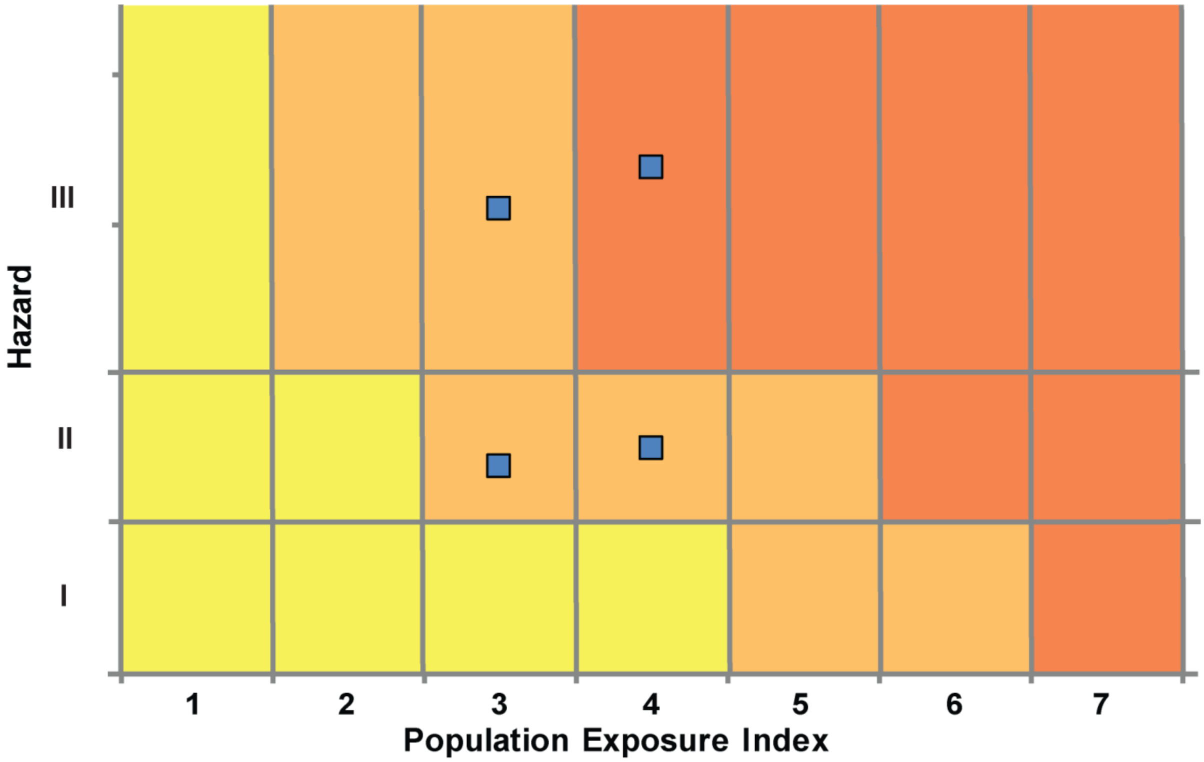

Figure 369: Distribution of the Azores' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Ten volcanoes have records of historical activity in the Azores. The Observatório Vulcanológico e Sismológico da Univ. dos Açores (CIVISA) is responsible for monitoring of the volcanoes here, using seismic and deformation stations. At the time of the writing of this report the specifics of equipment at individual volcanoes are not known.

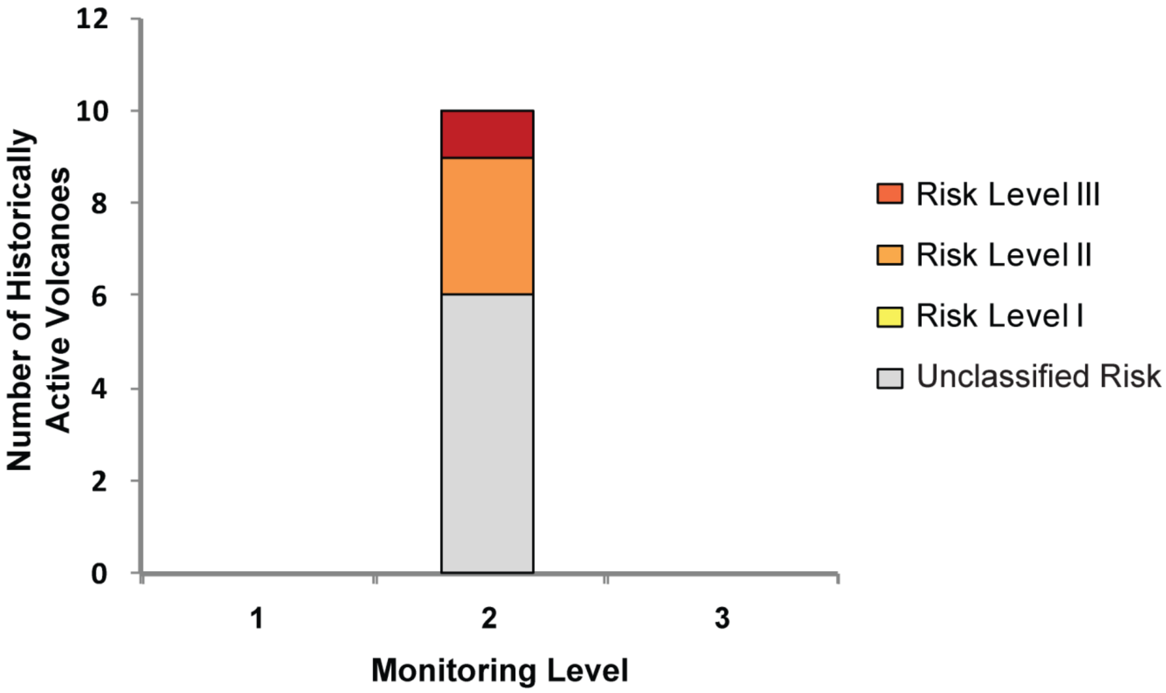

Figure 370: The monitoring and risk levels of the historically active volcanoes in the Azores. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Spain – Canary Islands

Description

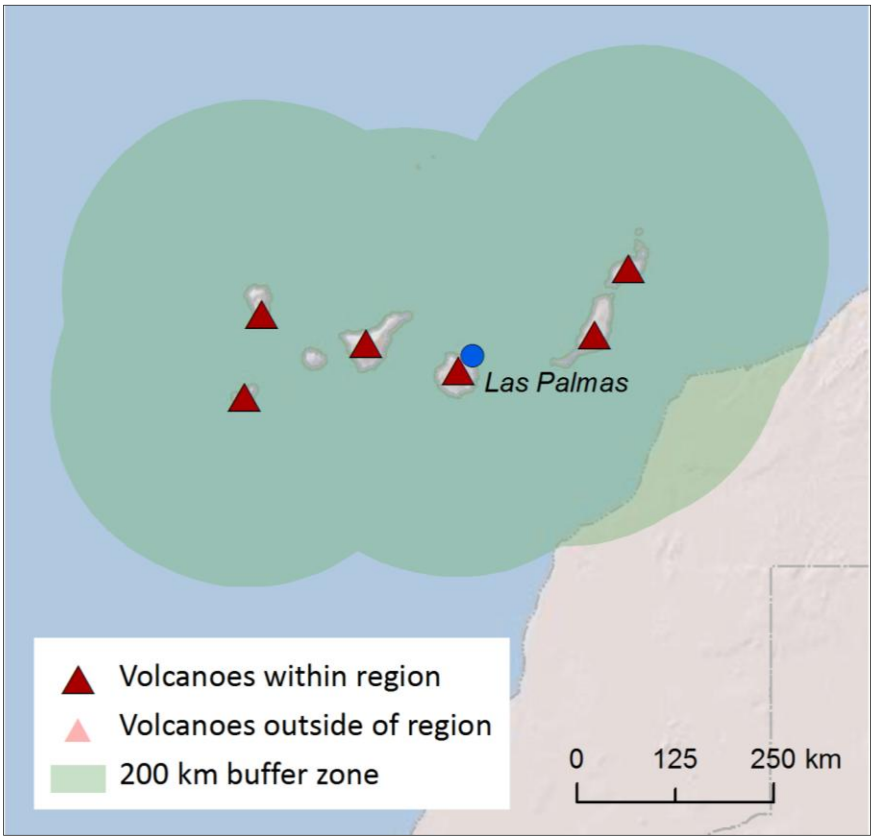

Figure 371: Location of volcanoes in the Canary Islands and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Canary Islands.

Six Holocene volcanoes are located in the Canary Islands. Volcanism here is due to intra-plate processes which have produced these basaltic centres. Volcano form varies, with two stratovolcanoes, a shield volcano and three fissure vents.

Seventy-four confirmed eruptions of Holocene age are recorded from five volcanoes. Fuerteventura has undated activity of suspected late Holocene age. These Holocene eruptions were of VEI 0 to 4, with mild to large explosive eruptions. The largest Holocene eruption was that of Tenerife about 2,000 years ago. The size of most Holocene eruptions (80%) is unknown.

In addition to a few unconfirmed eruptions, four volcanoes – La Palma, Tenerife, Lanzarote and El Hierro – have produced thirteen historical eruptions. These events are recorded as VEI 2, though violent Strombolian episodes are suspected. The submarine 2011 eruption of El Hierro is the exception, with no attributed size. This is the most recent eruption in the Canary Islands, and began with about three months of increased seismicity and deformation, prior to the submarine eruption.

The record is such that the hazard assessment for most of the Canary Island volcanoes is associated with considerable uncertainty and most volcanoes here are unclassified. Given the nature of volcanic islands, much of the population lives in close proximity to the volcanoes.

The Instituto Geografico Nacional (IGN) is the official monitoring organisation in the Canary Islands, responsible for a national seismic network and volcano monitoring system. The IGN uses a monitoring alarm system that is triggered by earthquakes of magnitude 2.5 and above for regional seismicity. In the active volcanic islands the threshold magnitude is much lower, at <1.5. Additionally on El Hierro and Tenerife a dense deformation monitoring network of GPS monitors are in place, allowing daily and sub-daily velocity determinations with millimetre resolution. The IGN has been funded by the Spanish government for volcano monitoring since 2004.

In addition to the IGN, several research teams at different institutions and universities also conduct research and monitoring in the Canary Islands. The Consejo Superior de Investigaciones Cientificas (CSIC) and Laboratory of Astronomy and Geodesy (LAG-UCA; Cadiz University) maintain monitoring networks at El Hierro, Tenerife and Lanzarote. INVOLCAN is the National Centre for Volcanology, the Canary Islands Volcanological Institute, who aims to improve volcanic risk management in the Canary Islands.

Volcanic activity levels are determined by the monitoring and research teams and communicated to the decision-makers who decide on and communicate alert levels. The authorities are the Dirección General de Protección Civil del Gobierno de Canarias, at the regional level) and the Spanish Government (Dirección General de Protección Civil y Emergencias). The IGN is officially responsible for declaring alerts but is the Civil Defence and the decision makers whose publish the alerts and set the Emergency Response Levels and the colour of the Volcanic Traffic Light, according to the scientific information received. There is a non-official Volcanic Activity Level (VAL), developed and managed by IGEO-CSIC and LAG-UCA teams during the El Hierro volcanic process.

Several different systems are currently used in the Canary Islands and the Volcanic Emergency Plan is currently under revision. A clear set of protocols and response plans may be beneficial here.

See also:

IGN: http://www.ign.es/ign/main/index.do

INVOLCAN: http://www.involcan.org/

CSIC: http://www.csic.es/web/guest/historia

Marti, J., Geyer, A., Andujar, J., Teixido, F., and Costa, F. (2009) Assessing the potential for future explosive activity from Teide-Pico Viejo stratovolcanoes (Tenerife, Canary Islands). Journal of Volcanology and Geothermal Research, 178: 529-542

Marti, J., Sobradelo, R., Felpeto, A., and Garcia, O. (2012) Eruptive scenarios of Phonolitic volcanism at Teide-Pico Viejo volcanic complex (Tenerife, Canary Islands). Bull. Vulcanol. 74:767-782

Volcano Facts

Number of Holocene volcanoes	6
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	1

Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	5
Number of fatalities caused by volcanic eruptions	?16
Tectonic setting	Intraplate
Largest recorded Pleistocene eruption	The M6.5 eruption of the DHFI Fasnia Formation Lower Grey Member at Tenerife at 289 ka.
Largest recorded Holocene eruption	The M4.7 Montaña Blanca, Pico Viejo eruption of Tenerife at 2,030 BP.
Number of Holocene eruptions	74 confirmed eruptions. 6 uncertain eruptions, 1 discredited.
Recorded Holocene VEI range	0 – 4 and unknown.
Number of historically active volcanoes	4
Number of historic eruptions	13

Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Basaltic (1), Phonolitic (1)
1	Shield(s)	Basaltic (1)
3	Small cone(s)	Basaltic (3)

Table 347: The number of volcanoes in the Canary Islands, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2013) (Instituto Nacional de Estadistica)[i]	2,092,826

Population Exposure

Capital city (Canary Islands)	Santa Cruz, Las Palmas
Distance from capital city to nearest Holocene volcano	<40 km
Number (percentage) of people living within 100 km of a Holocene volcano	2,092,826 (100%)

Largest cities, as measured by population, and populations:

Las Palmas	378,495

Infrastructure Exposure

Number of airports within 100 km of a volcano	6
Number of ports within 100 km of a volcano	5
Total length of roads within 100 km of a volcano (km)	300
Total length of railroads within 100 km of a volcano (km)	0

The volcanic Canary Islands are small, each measuring no more than 100 km across, meaning that the 100 km radii around the volcanoes here covers this island group in its entirety. This therefore places all the towns, ports and critical infrastructure proximal to the volcanoes, inclusive of the capitals.

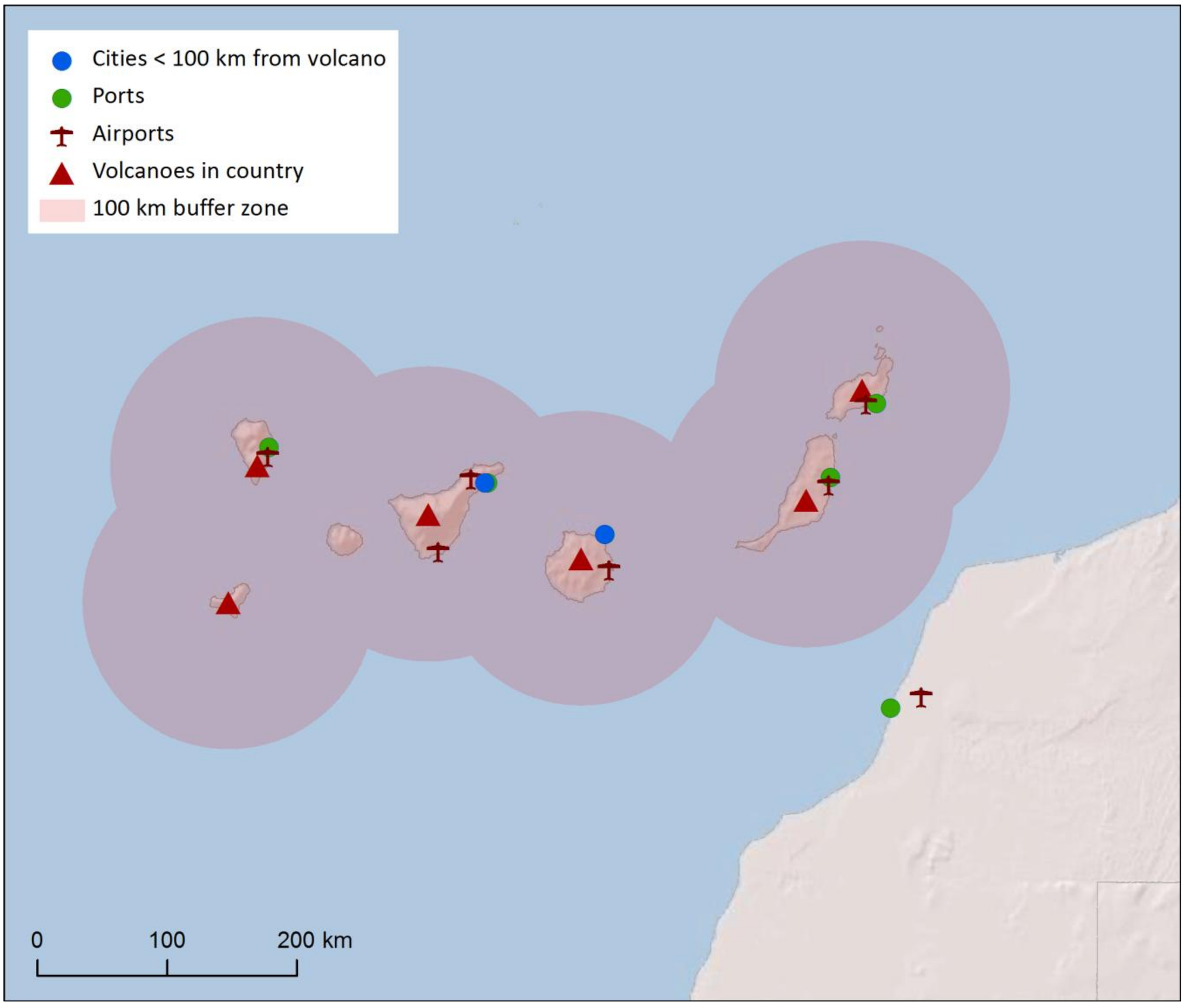

Figure 372: The location of the Canary Island volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The amount of data available in the eruption records of the Canary Island volcanoes is variable. La Palma and Tenerife have sufficient details to define the hazard through the calculation of the VHI without large associated uncertainties. The remaining five volcanoes cannot have a hazard level classified. These unclassified volcanoes include Fuertoventura, which has no confirmed Holocene activity, and Hierro and Lanzarote which both have historical eruptions, including the 2011 eruption of Hierro.

La Palma has a higher hazard score than Tenerife here due to more frequent historical eruptions, including one which produced a pyroclastic flow. However, no eruptions of greater than VEI 2 are recorded at La Palma, whilst Tenerife has a record of VEI 3 and VEI 4 events. Indeed, Marti et al. (2008) describe how explosive events have occurred at central and flank vents of Tenerife and Marti et al. (2012) calculate the volcanic threat at Tenerife using the NVEWS method, which designates this as a 'very high threat volcano', and calculate a probability of a large explosive eruption of magnitude 4 or above of 13.6% for the next 100 years using Extreme value theory.

The population of the Canaries is such that the volcanoes have moderate to high PEI levels at 4 and 5. The two classified volcanoes are classed at Risk Level II. Although here the population residing in the Canaries is considered, the tourist population must also be considered, with Marti et al. (2011) determining a mean daily hotel occupancy rate in 2009 of 52,000 on Tenerife alone. It must also be stressed that here the population is considered in concentric circles around the volcanoes, where as topographic features in particular are recognised for controlling the extent of the hazards and in Tenerife the hazard is recognised as particularly focussed on the northern side of the volcano, with the southern flank of Tenerife protected by the Cañadas caldera wall which would act to restrain propagation of flows in this direction.

CLASSIFIED	**Hazard III**							
	Hazard II				La Palma; Tenerife			
	Hazard I							
UNCLASSIFIED	**U – HHR**				**Hierro**	Lanzarote		
	U- HR				Gran Canaria			
	U- NHHR				Fuerteventura			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 348: Identity of the Canary Island volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without

*sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
La Palma	4	II
Tenerife	4	II

Table 349: Classified volcanoes of the Canaries ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given. Risk level I – 0 volcanoes; Risk Level II – 2 volcanoes; Risk Level III – 0 volcanoes.

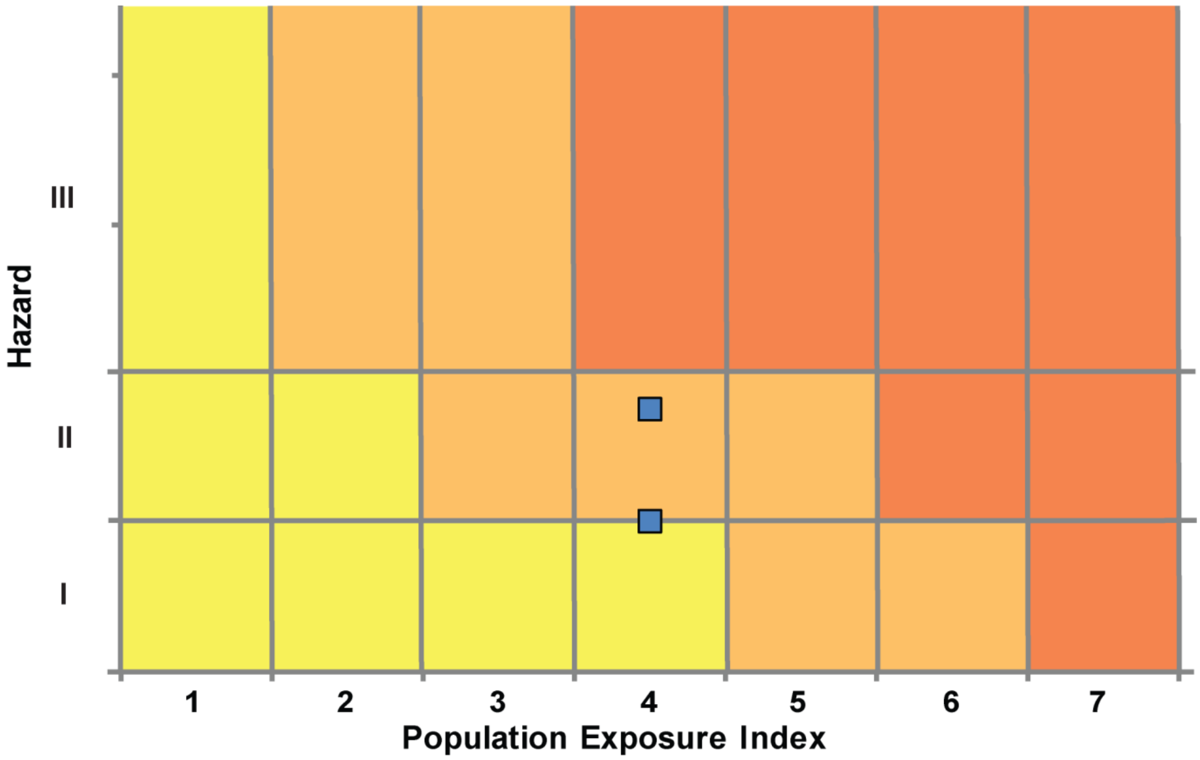

Figure 373: Distribution of the Canary Island classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Four volcanoes in the Canary Islands have records of historical activity. Monitoring is undertaken by a number of different groups in the Canaries. The official monitoring institution is the National Geographic Institute (Instituto Geografico Nacional, IGN) maintain permanent volcano monitoring networks comprising seismic and deformation stations on all of the islands, with dense monitoring networks on El Hierro and Tenerife. The other islands have seismic stations of the national seismic network. However, the Institute of Geosciences (IGEO-CSIC) in collaboration with the Laboratory of Astronomy and Geodesy (LAG-UCA, Cadiz University) manage networks at El Hierro and Tenerife (seismic and deformation) and seismic stations on Lanzarote. INVOLCAN and ITER (the Institute of Technology and Renewable Energies) operate a network of GPS stations throughout the Canary Islands as well as a geochemical network. INVOLCAN, ITER and the Andalusian Institute of Geophysics of the University of Grenada have plans for installation of a seismic network.

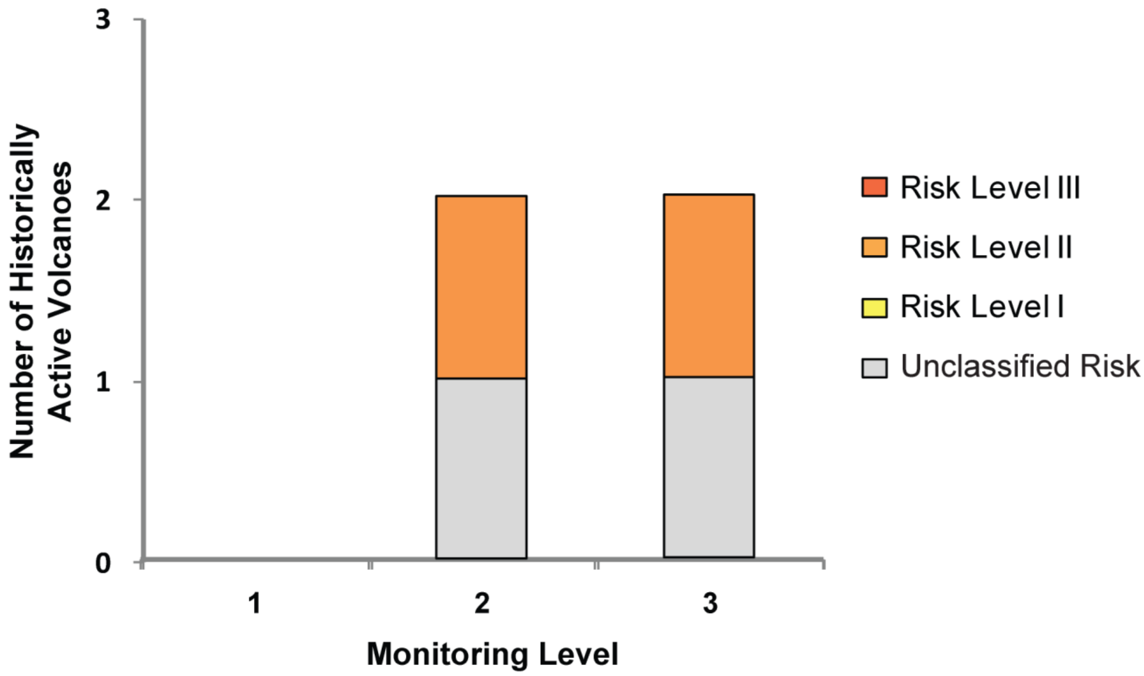

Figure 374: The monitoring and risk levels of the historically active volcanoes in the Canary Islands. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

UK – Tristan da Cunha, Nightingale Island, Ascension

Description

Tristan da Cunha and Ascension are part of the British Overseas Territory of St Helena, Ascension and Tristan da Cunha. Tristan da Cunha comprises a group of islands: Tristan da Cunha Island, Nightingale Island, Inaccessible Island and Gough Island. The islands are the surface expression of volcanic edifices related to the Mid-Atlantic spreading Ridge.

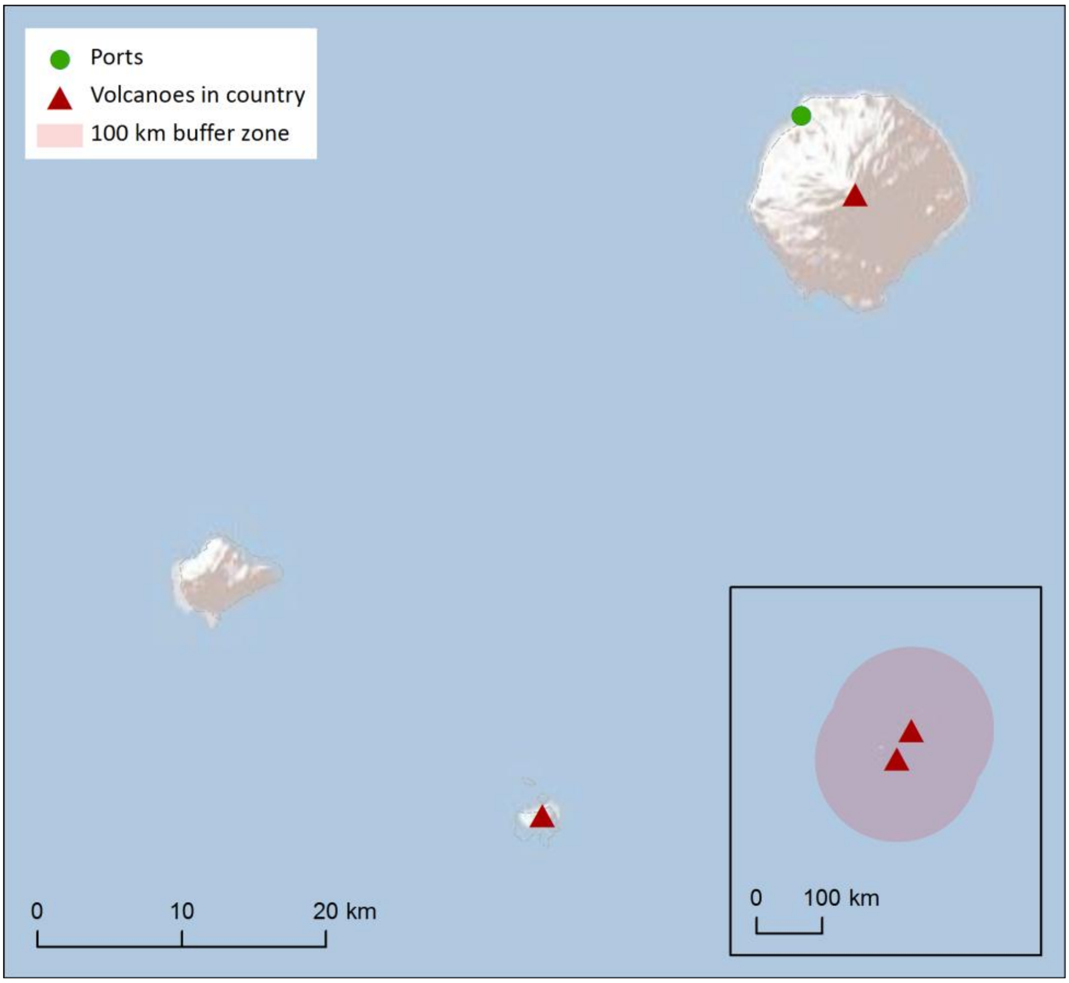

Figure 375: The location of the south Atlantic UK volcanoes of Tristan da Cunha and Nightingale Island. (Inset) A 100 km radius is seen around the volcanoes.

The overseas territory has three Holocene volcanoes: Tristan da Cunha, Nightingale and Ascension. Tristan da Cunha's last eruption occurred in 1961-62 with the formation of a lava dome and lava flow in the north-west of the island close to the settlement of Edinburgh-of-the-Seven-Seas. Tristan da Cunha is a trachy-balastic shield volcano with numerous parasitic cones on its flanks. The youngest summit lava has been dated at 5±1 ka and the youngest parasitic cone is 3±1 ka (Hicks et al., 2012).

Nightingale Island is part of the Tristan da Cunha archipelago and is located approximately 30 km to the southwest of Tristan da Cunha Island. Nightingale is a trachy-andesitic stratovolcano. In 2004 a seismic swarm was felt by islanders on Tristan da Cunha between the end of July and December. Pumice rafts were seen by fishermen and some eventually washed up on some of Tristan da Cunha's beaches. The events were located to a submarine eruption 37-55km south-southeast of Tristan da Cunha and is assumed to be a flank eruption of Nightingale volcano (O'Mongain et al., 2007).

Ascension Island is 3750 km north of Tristan da Cunha and lies just 90 km west of the Mid-Atlantic Ridge (MAR). Ascension is a basaltic stratovolcano predominantly comprising lava flows, pyroclastic deposits and scoria. A felsic complex in the centre and east of Ascension comprises a series of predominantly trachytic with some rhyolitic and basaltic lava flows and domes. The lower relief southern, western and northern parts of the island are dominated by mafic lava flows punctuated by numerous scoria cones. There has been no historical volcanic activity recorded on Ascension Island. The last eruption is unknown; however, it is proposed to have been late Holocene in age (Jicha et al., 2013).

Currently, the only monitoring stations on Tristan da Cunha are two CTBTO hydro-acoustic stations and an IRIS seismometer installed on Tristan to detect nuclear explosions and global tectonic earthquakes respectively. The British Geological Survey acts as a de facto remote volcano observatory for the South Atlantic but there is no contract or dedicated sustainable resource for this role beyond the BGS 'national capability' funding. As such, there is currently no dedicated volcano monitoring in the British Overseas Territory of St Helena, Ascension Island and Tristan da Cunha. The helicorder plots are checked daily by BGS staff for unusual activity. Should likely volcanic earthquakes be detected, BGS staff would communicate with FCO, CCS, the Islands' Administration Office and arrange to visit to check for evidence of volcanic activity on the island and potentially enhance monitoring capacity.

As the islands of Tristan da Cunha, Nightingale and Ascension are small, the entire populations live within 10 km of the volcanoes. Nightingale has no settlement; however, it is only c.40 km from the settlement on Tristan da Cunha, therefore an eruption on Nightingale would impact Tristan da Cunha islanders. The permanent population on Tristan da Cunha is 264. There is no permanent population on Ascension Island, with the majority of islanders (880 as of 2010) under a contract of employments to stay on the island.

See also:

O'Mongain, A., Ottemoller, L., Baptie, B., Galloway, D., and Booth, D., 2007, Seismic activity associated with a probable submarine eruption near Tristan da Cunha, July 2004-July 2006: Seismological Research Letters, v. 78, p. 375-382.

Hicks, A., Barclay, J., Mark, D.F., and Loughlin, S., 2012, Tristan da Cunha: Constraining eruptive behavior using the 40Ar/39Ar dating technique: Geology, v. 40, p. 723-726.

Jicha, B.R., Singer, B.S., and Valentine, M.J., 2013, 40Ar/39Ar Geochronology of Subaerial Ascension Island and a Re-evaluation of the Temporal Progression of Basaltic to Rhyolitic Volcanism: Journal of Petrology, v. 54, p. 2581-2596.

Volcano Facts

Number of Holocene volcanoes	3
Number of Pleistocene volcanoes with M≥4 eruptions	-

Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Rift zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The 1961 VEI 2 eruption of Tristan da Cunha.
Number of Holocene eruptions	3 confirmed eruptions.
Recorded Holocene VEI range	0 – 2 and unknown.
Number of historically active volcanoes	2
Number of historic eruptions	3

Number of volcanoes	Primary volcano type	Dominant rock type
2	Large cone(s)	Basaltic (1), Trachytic/Andesitic (1)
1	Shield(s)	Basaltic (1)

Table 350: The number of volcanoes in the UK islands of the south Atlantic, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	?<300
Gross Domestic Product (GDP) per capita (2005 PPP $)	-
Gross National Income (GNI) per capita (2005 PPP $)	-
Human Development Index (HDI) (2012)	-

Population Exposure

Capital city	Edinburgh of the Seven Seas (settlement on Tristan da Cunha), Georgetown (Ascension)
Distance from capital city to nearest Holocene volcano	<10 km
Number (percentage) of people living within 10 km of a	100%

Holocene volcano

Number (percentage) of people living within 30 km of a Holocene volcano	100%
Number (percentage) of people living within 100 km of a Holocene volcano	100%

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

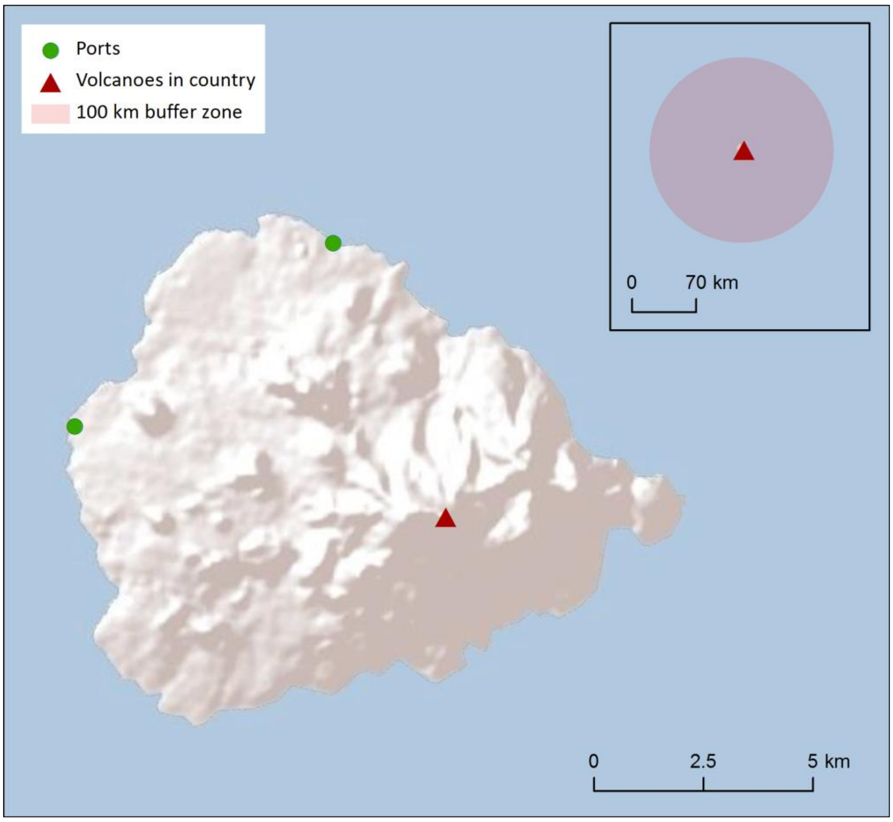

Figure 376: The location of Acension's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure which may be exposed to volcanic hazards.

The islands of Tristan da Cunha, Nightingale Island and Ascension are remote outposts of the UK in the central and southern Atlantic. Settlements on Tristan da Cunha and Ascension lie within 10 km of the volcanoes, and hence all infrastructure on these islands is exposed within the 100 km radii of the volcanoes.

Hazard, Uncertainty and Exposure Assessments

The eruption records for the UK volcanoes of the Atlantic Ocean are not sufficiently extensive to permit the calculation of the VHI and the determination of hazard levels. These volcanoes are therefore unclassified. Ascension has no confirmed Holocene activity, however both Tristan da Cunha and Nightingale Island have post-1900 AD eruptions.

The small population close to the three volcanoes here makes these PEI 2, a low population exposure index.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**		**Tristan da Cunha; Nightingale Island**					
	U- HR							
	U- NHHR		Ascensión					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 351: Identity of volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Both Tristan da Cunha and Nightingale Island have records of historical activity. No information is available at the time of the writing of this report to indicate the presence of dedicated ground-based monitoring at Nightingale Island, however one British Geological Survey monitored seismometer is used at Tristan da Cunha.

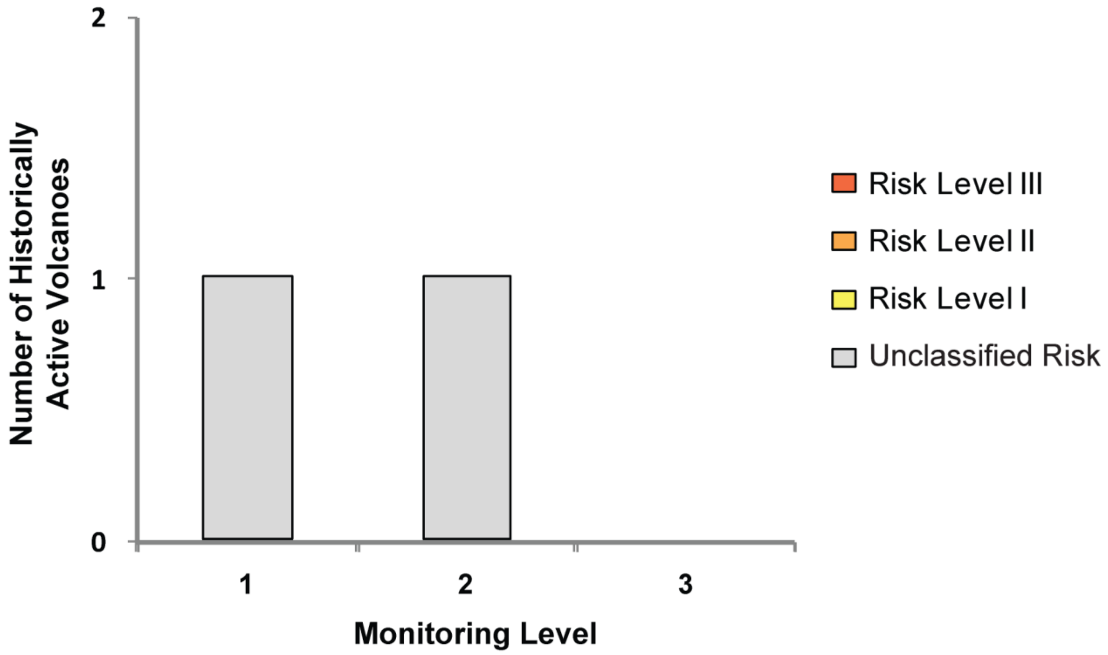

Figure 377: The monitoring and risk levels of the historically active volcanoes in Tristan da Cunha and Nightingale Island. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 19: Antarctica

Description

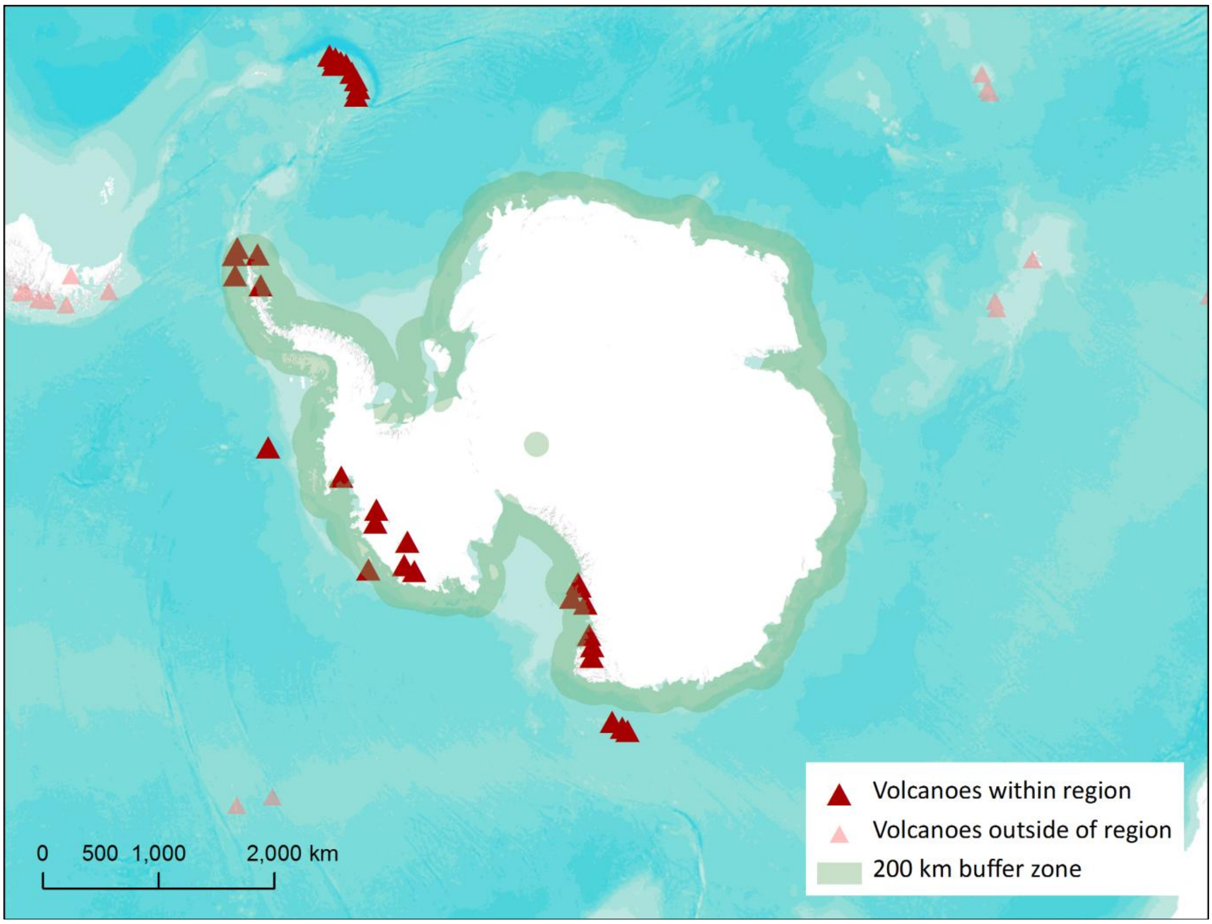

Figure 378: The distribution of Holocene volcanoes through the Antarctica region. A zone extending 200 km beyond the region's borders shows other volcanoes whose eruptions may directly affect Antarctica.

Thirty-two Holocene volcanoes are located in Antarctica. Half of these volcanoes have no confirmed eruptions recorded during the Holocene, and therefore the activity state is uncertain. A further volcano, Mount Rittmann, is not included in this count as the most recent activity here was dated in the Pleistocene, however this is geothermally active as discussed in Herbold et al. (2014). The region includes the South Sandwich Islands (a British Overseas Territory) and other island groups adjacent to Antarctica. Note that the volcanoes included and discussed here are described as country "Antarctica" and "UK" in VOTW4.0. Many of these volcanoes are related to rift and extension in the West Antarctic Rift System. Holocene volcanoes on the Antarctic continent except those on the northern tip of the Antarctic Peninsula are located in the West Antarctic Rift System. Those in the South Sandwich Islands are related to subduction processes. The range of tectonic settings here results in a range of compositions and volcano morphologies.

Eighty confirmed Holocene eruptions of VEI 0 - 4 are recorded in Antarctica, indicating mild activity to large explosive events, with small VEI 0 events with associated lava flows dominating the record. Although few large explosive eruptions are recorded in the Holocene, there is a record of VEI ≥4 eruptions in the Pleistocene, with the largest recorded Quaternary eruption occurring at 1.7 Ma with the M7 Eltanin eruption of Young Island. Fifty-two of these Holocene eruptions are recorded in historical times (since 1500 AD), however over 90% of these have in fact been recorded since 1800 AD, due to an increase in exploration and visual observations.

No permanent population resides in Antarctica, with only a transitory population of workers (mainly researchers) which grows to its maximum of a few thousand in the summer months. Due to this low population no eruptions have reported fatalities and the volcanoes are all low risk, however the hazard is still poorly understood at many of Antarctica's volcanoes.

Mount Erebus has long-term lava lake activity with occasional explosions and larger Strombolian activity. This activity, ongoing since at least 1972, has led to the establishment of the Mount Erebus Volcano Observatory (MEVO) with research undertaken primarily by the New Mexico Institute of Mining and Technology. Seismic and gas monitoring is undertaken and GPS and tiltmeters are used to investigate the deformation of the volcano. Although there is no permanent population here, the US base of McMurdo and the New Zealand Scott Base are located within 40 km of Erebus.

The Observatory Volcanologico Decepcion (OVD) was established by the Argentine Antarctic Institute, University of Buenos Aires and Higher Council for Scientific Research (CSIC), Spain, to study and monitor Deception volcano. Ground monitoring activities take place in the summer of each year, when seismic, gas, deformation and additional monitoring is undertaken. Monitoring and research is undertaken gain a better understanding of activity here and to provide forecasts of activity. No permanent population resides here, but significant numbers of scientists and tourists visit.

Mount Melbourne has been monitored by the Italian Antarctic Program in the past and the Korea Polar Research Institute plans to undertake monitoring here (P. Kyle, pers. comm. 2014).

See also:

Observatorio Volcanologico Decepcion: http://www.dna.gov.ar/CIENCIA/OVD/INDEX.HTM

Mount Erebus Volcano Observatory: http://erebus.nmt.edu/index.php/general-information

Herbold, C.W., McDonald, I.R., and Cary, S.C. (2014) Microbial Ecology of Geothermal Habitats in Antarctica. In: D.A. Cowan (ed) Antarctic Terrestrial Microbiology, Springer-Verlag, Berlin Heidelberg.

Volcano facts

Number of Holocene volcanoes	32
Number of Pleistocene volcanoes with M≥4 eruptions	3
Number of volcanoes generating pyroclastic flows	0
Number of volcanoes generating lahars	1

Number of volcanoes generating lava flows	4
Number of eruptions with fatalities	0
Number of fatalities attributed to eruptions	0
Tectonic settings	3 Rift zone, 20 Intra-plate, 9 Subduction zone
Largest recorded Pleistocene eruption	The M7 Eltanin eruption of Young Island at 1.7 Ma is the largest recorded Quaternary eruption in this region.
Largest recorded Holocene eruption	The largest Holocene eruption recorded in LaMEVE is the M4.7 eruption of the Hudson Mountains in 2160 BP.
Number of Holocene eruptions	80 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 4 and unknown
Number of historically active volcanoes	12
Number of historical eruptions	52

Number of volcanoes	Primary volcano type	Dominant rock type
1	Caldera(s)	Basaltic (1)
16	Large cone(s)	Andesitic (4), Basaltic (10), Phonolitic (1), Trachytic/Andesitic (1)
9	Shield(s)	Basaltic (5), Phonolitic (1), Trachytic/Andesitic (3)
4	Small cone(s)	Andesitic (1), Basaltic (3)
2	Submarine	Rhyolitic (1), Unknown (1)

Table 352: The volcano types and dominant rock types of the volcanoes of this region according to VOTW4.0.

Eruption Frequency

VEI	Recurrence Interval (Years)
Small (< VEI 4)	3
Large (> VEI 3)	

Table 353: Average recurrence interval (years between eruptions) for small and large eruptions in Antarctica.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about 3 years.

Eruption Size

Eruptions are recorded through Antarctica of VEI 0 to 4, representing a range of eruption styles from gentle effusive events, to explosive eruptions. VEI 0 and 2 events dominate the record, with about 80% of all Holocene eruptions classed as such. Fewer than 2% of eruptions here are explosive at VEI≥4.

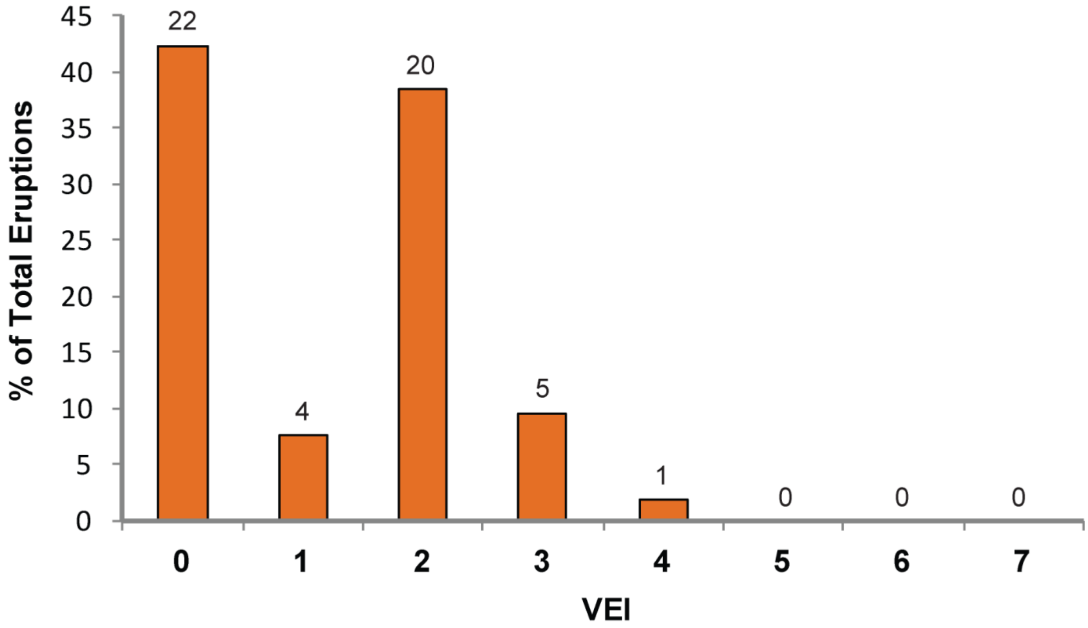

Figure 379: Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 28 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	No permanent residents. 1,100 staff in research stations during the winter, 4000 in the summer, 1000 additional offshore workers[ii].
Gross Domestic Product (GDP) per capita (2005 PPP $)	-
Gross National Income (GNI) per capita (2005 PPP $)	-
Human Development Index (HDI) (2012)	-

Population Exposure

Number (percentage) of people living within 10 km of a Holocene	0 (0%)

volcano	
Number (percentage) of people living within 30 km of a Holocene volcano	0 (0%)
Number (percentage) of people living within 100 km of a Holocene volcano	0 (0%)

Infrastructure Exposure

Number of airports within 100 km of a volcano	0
Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	0
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes of Antarctica are widespread. Three ports are located within 100 km of the volcanoes here, but otherwise, with no permanent population living on Antarctica, there is little infrastructure exposed to the volcanic threat.

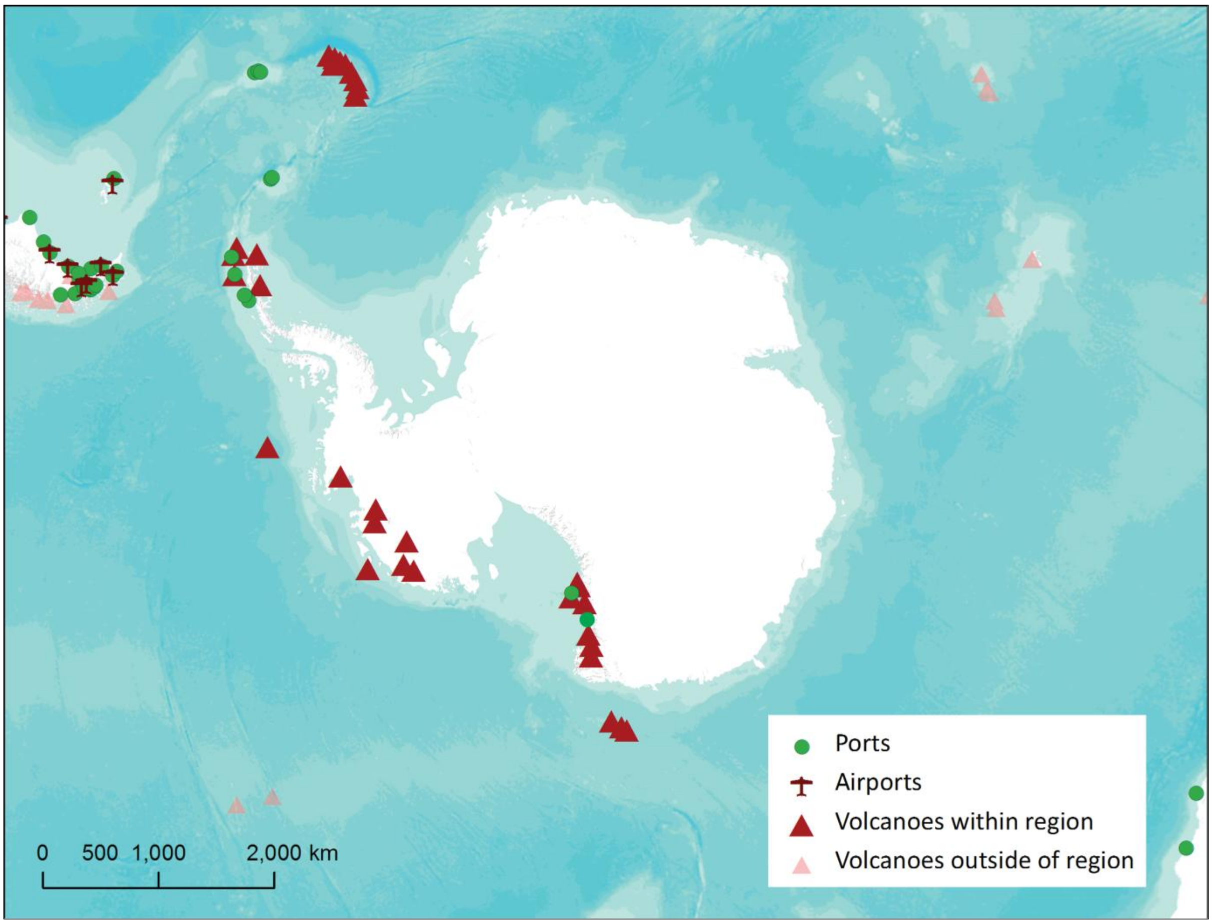

Figure 380: The location of Antarctica's volcanoes and ports.

Hazard, Uncertainty and Exposure Assessments

Of the 32 volcanoes in Antarctica, just four have assigned hazard levels: Deception Island, Erebus, Bristol Island and Michael. These volcanoes have a history of dominantly VEI 0 – 2 eruptions, frequently producing lava effusions and as such these are classed at Hazard Levels I and II.

The absence of extensive eruption records at the remaining volcanoes prevents hazard assessment without large uncertainties, and these are therefore unclassified. Of these, 16 have no confirmed Holocene eruptions. Eight unclassified volcanoes have records of historical eruptions, five of which have had eruptions since 1900: Penguin Island, Thule Islands, Montagu Island, Candlemas Island and Protector Shoal. Four unclassified volcanoes have experienced unrest above background levels since 1900.

With no permanent population in Antarctica, all volcanoes are classed as PEI 1 which therefore would categorise these as Risk level I, regardless of the Hazard Level.

CLASSIFIED	**Hazard III**							
	Hazard II	Deception Island						
	Hazard I	Erebus; Bristol Island; Michael						
UNCLASSIFIED	**U – HHR**	Buckle Island; **Melbourne**; **Penguin Island; Thule Islands**; **Montagu Island**; **Candlemas Island**; Zavodovski; **Protector Shoal**						
	U- HR	Pleiades, The; Berlin; Takahe; Hudson Mountains						
	U- NHHR	Young Island; Sturge Island; Unnamed; Unnamed; Morning, Mount; Royal Society Range; **Andrus**; Waesche; Siple; Toney Mountain; Peter I Island; Bridgeman Island; Paulet; **Seal Nunataks Group**; Hodson; **Leskov Island**						
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table **354**: Identity of Antarctica's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed "classified" (top). Those without sufficient data are "Unclassified" (Bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900AD, and those in red have records of at least one Holocene VEI≥4 eruption.*

Population Exposure Index

Number of Volcanoes	Population Exposure Index
0	7
0	6
0	5
0	4
0	3
0	2
32	1

Table 355: The number of volcanoes in Antarctica classed in each PEI category.

Volcano	Population Exposure Index	Risk Level
Bristol Island	1	I
Deception Island	1	I
Erebus	1	I
Michael	1	I

Table 356: Classified Volcanoes of Antarctica ordered by descending Population Exposure Index (PEI). Risk Levels determined through the combination of the Hazard Level and PEI are given.

Risk Levels for Classified volcanoes

Number of Volcanoes	Risk Level
0	III
0	II
4	I
28	Unclassified

Table 357: The number of volcanoes in the Antarctica region classified at each Risk Level.

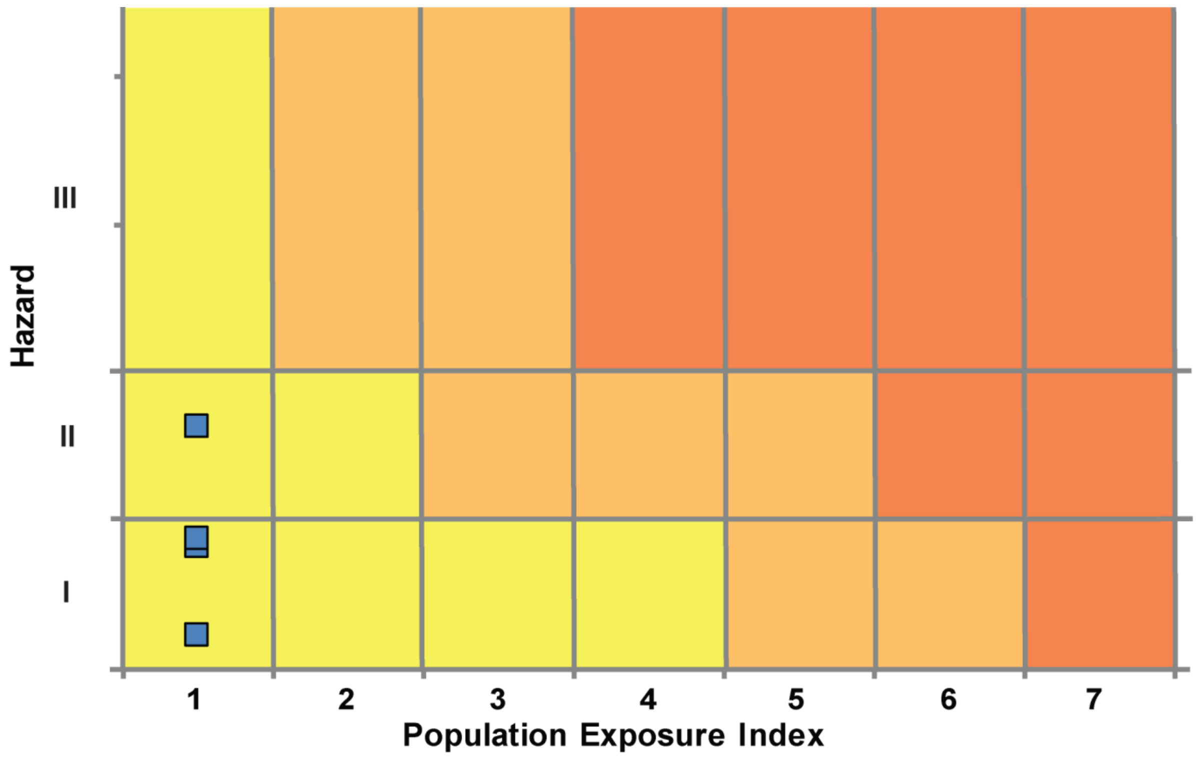

Figure 381: Distribution of the classified volcanoes of Antarctica across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Four Risk Level I volcanoes in Antarctica have records of historic activity. Of these Erebus and Deception have regular dedicated ground-based monitoring, including the use of seismic networks, gas and deformation monitoring. These systems are operated by the Mount Erebus Volcano Observatory and Observatory Volcanológico Deception. A further eight unclassified volcanoes (with no local populations) have historical records of activity but no current monitoring.

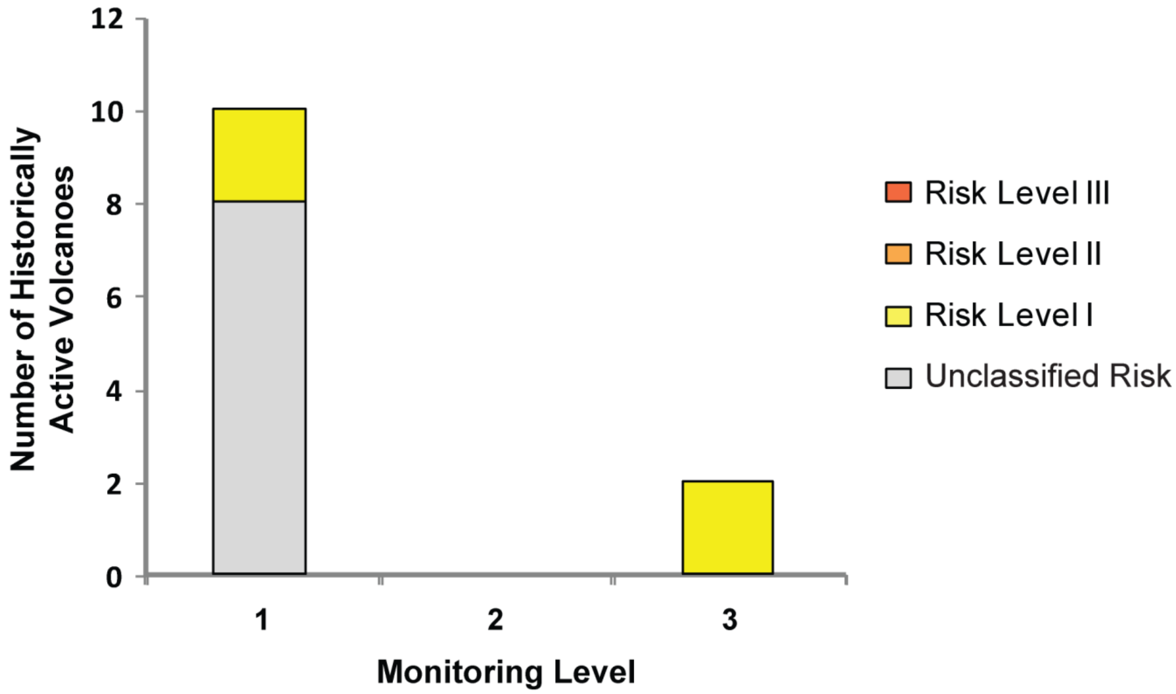

Figure 382: The monitoring and risk levels of the historically active volcanoes in Antarctica. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

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[i] http://www.ine.es/jaxi/tabla.do
[ii] https://www.cia.gov/library/publications/the-world-factbook/geos/ay.html