Appendix B

Country and regional profiles of volcanic hazard and risk (Part One)

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Appendix B

Country and regional profiles of volcanic hazard and risk

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Contents

1 Introduction

This report 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.

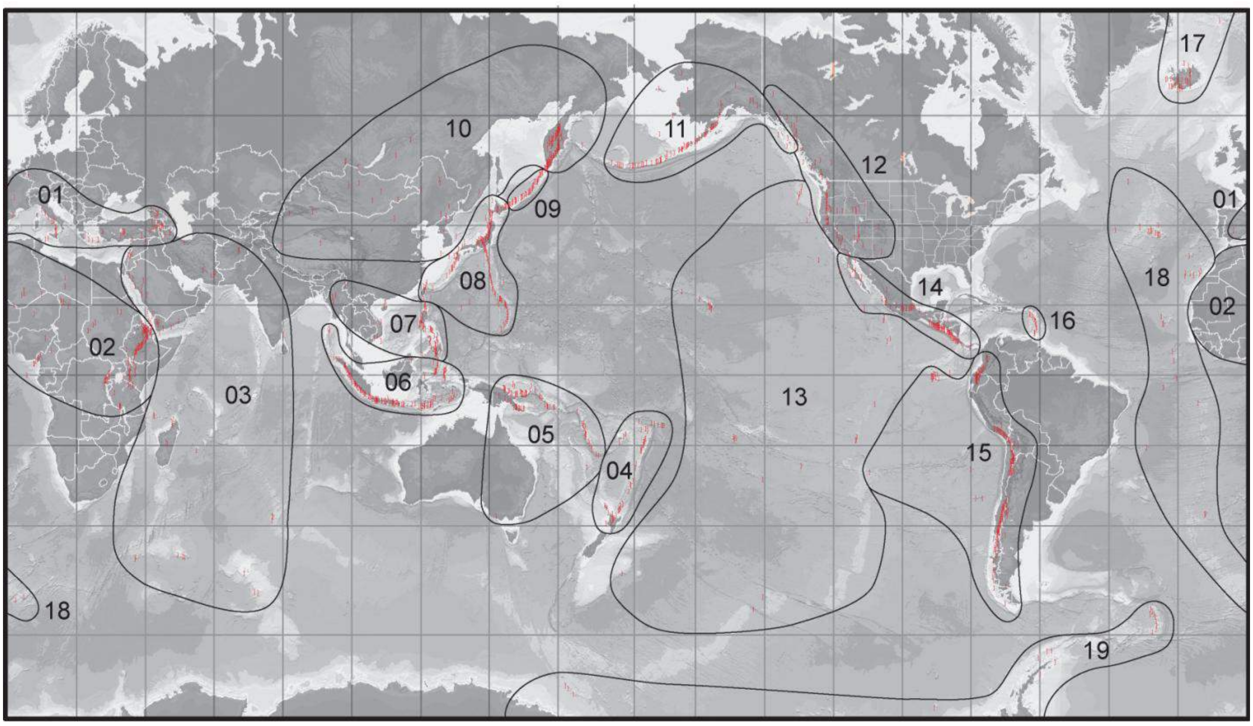

Figure 1 The 19 regions in Siebert et al. (2010) in which all Holocene volcanoes are located. The location of volcanoes is given in VOTW4.0 (2013) to include region, sub-region and country.

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 Chapter 22). 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 Chapter 4) 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, Chapter 22 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.

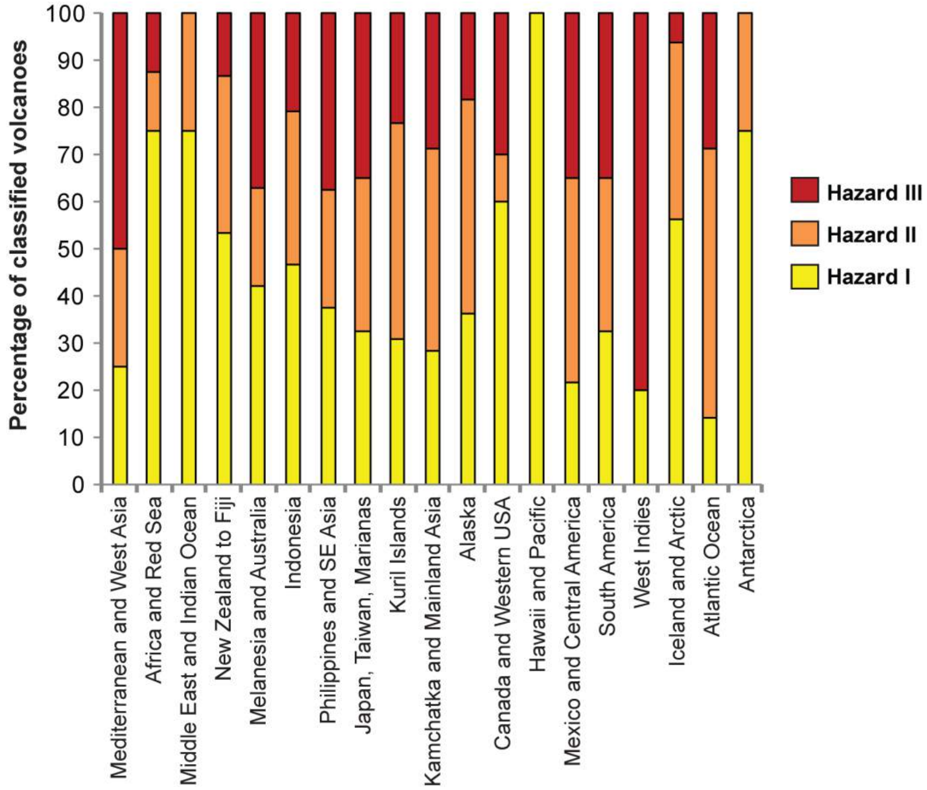

Figure 2 The percentage of volcanoes in each region with a classified score categorised into hazard levels.

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

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: for example 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.

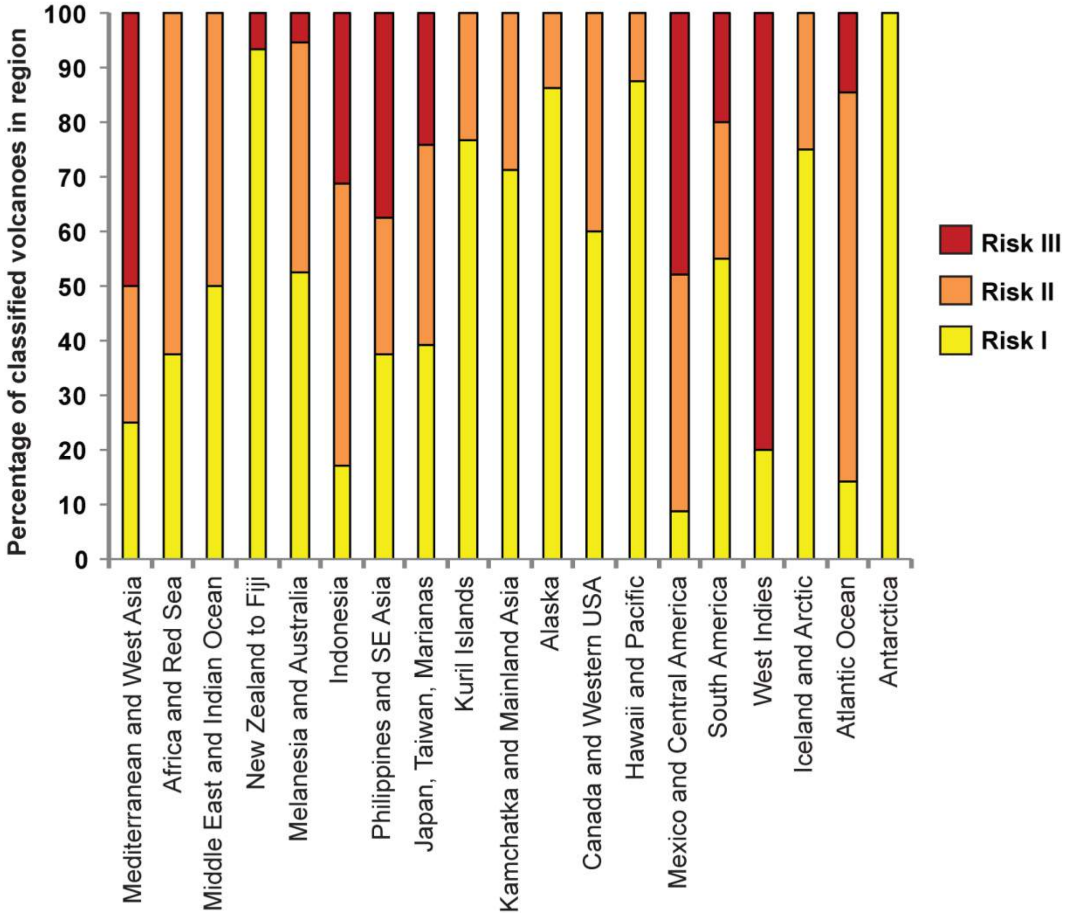

Figure 3: Percentage of classified volcanoes in regions at each Risk Level category.

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 Chapter 23.

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. There are 397 confirmed historical eruptions 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, Chapter 15) 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 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 seismic signals, e.g. 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.

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 1) and include '?' before the value:

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

Table 1 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 2).

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 2 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 3.

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 3 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; Chapter 22). Many volcanoes lack a detailed eruption history and hence only 328 volcanoes are classified with a VHI. See Chapter 22 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; Chapter 4) 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 Chapter 4 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).

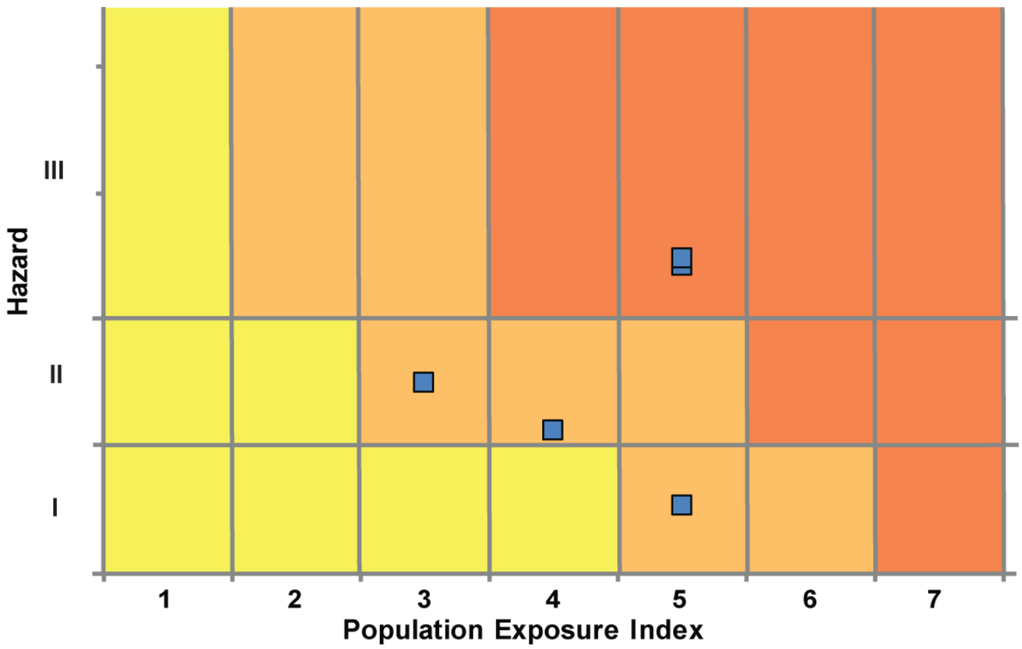

Figure 4 An example matrix combining VHI and PEI levels to indicate level of risk. Each volcano is represented by a point plotted using its hazard score and PEI level. The warming of the colouring of the matrix squares represents increasing risk (Risk Level I is yellow; Risk Level II is orange; Risk 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 4). 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 1900 AD, 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 4 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; Chapter 19). 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 Chapter 15) 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:

   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: 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: 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: 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: 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:

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

4. Ports

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

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

3 References

Aspinall, W., Auker, M., Hincks, T.K., Mahony, S., Nadim, F., Pooley, J., Sparks, R.S.J., and Syre, E. (2011) Volcano hazard and exposure in GFDRR priority countries and risk mitigation measures – GFDRR Volcano Risk Study. Bristol University Cabot Institute and NGI Norway for the World Bank: NGI Report 20100806, Bristol, 3 May 2011.

Auker, M.R., Sparks, R.S.J., Siebert, L., Crosweller, H.S., and Ewert, J. (2013) A statistical analysis of the global historical volcanic fatalities record. *Journal of Applied Volcanology*, 2:2.

Brown, S.K., Crosweller, H.S., Sparks, R.S.J., Cottrell, E., Deligne, N.I., Ortiz Guerrero, N., Hobbs, L., Kiyosugi, K., Loughlin, S.C., Siebert, L., and Takarada, S. (2014) Characterisation of the Quaternary eruption record: analysis of the Large Magnitude Explosive Volcanic Eruptions (LaMEVE) database. *Journal of Applied Volcanology*, 3:5.

Crosweller, H.S., Arora, B., Brown, S.K., Cottrell, E., Deligne, N.I., Guerrero, NO., Hobbs, L., Kiyosugi, K., Loughlin, S.C., Lowndes, J., Nayembil, M., Siebert, L., Sparks, R.S.J., Takarada,S., Venzke, E. (2012) Global database on large magnitude explosive volcanic eruptions (LaMEVE). *Journal of Applied Volcanology* 1(4):1-13, www.bgs.ac.uk/vogripa, LaMEVE Version 2.

Deligne, N.I., Coles, S.G., and Sparks, R.S.J. (2010) Recurrence rates of large explosive volcanic eruptions. *Journal of Geophysical Research*, 115, B06203.

Furlan, C. (2010) Extreme value methods for modelling historical series of large volcanic magnitudes. *Stat. Model.* 10(2): 112-132.

Human Development Reports, United Nations Development Programme 2013, hdr.undp.org/en/opendata/ Accessed October 2013.

Jenkins, S., Magill, C., McAneney, J., and Blong, R. (2012) Regional ash fall hazard I: a probabilistic assessment methodology, *Bulletin of Volcanology*, 74: 1699-1712.

Mead, S.R., and Magill, C. (2014) Determining change points in data completeness for the Holocene eruption record, *Bulletin of Volcanology*, In Press.

Siebert, L., Simkin, T., and Kimberly, P. (2010) *Volcanoes of the World*, 3rd ed. Smithsonian Institution, University of California Press.

Simkin, T.A., Siebert, L., Blong, R. (2001) Volcano fatalities – lessons from the historical record. *Science*, 291 (5502):255.

United Nations Population Division, United Nations, Department of Economic and Social Affairs, esa.un.org/undp/wpp/Excel-Data/population.htm Accessed October 2013.

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

4 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
	Tonga
	USA – American Samoa
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 (North Korea)
	Mongolia
	Republic of Korea (South 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
Region 14	**Mexico and Central America**
	Costa Rica
	El Salvador
	Guatemala
	Honduras

	Mexico
	Nicaragua
	Panama
Region 15	**South America**
	Argentina
	Bolivia
	Chile
	Colombia
	Ecuador
	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

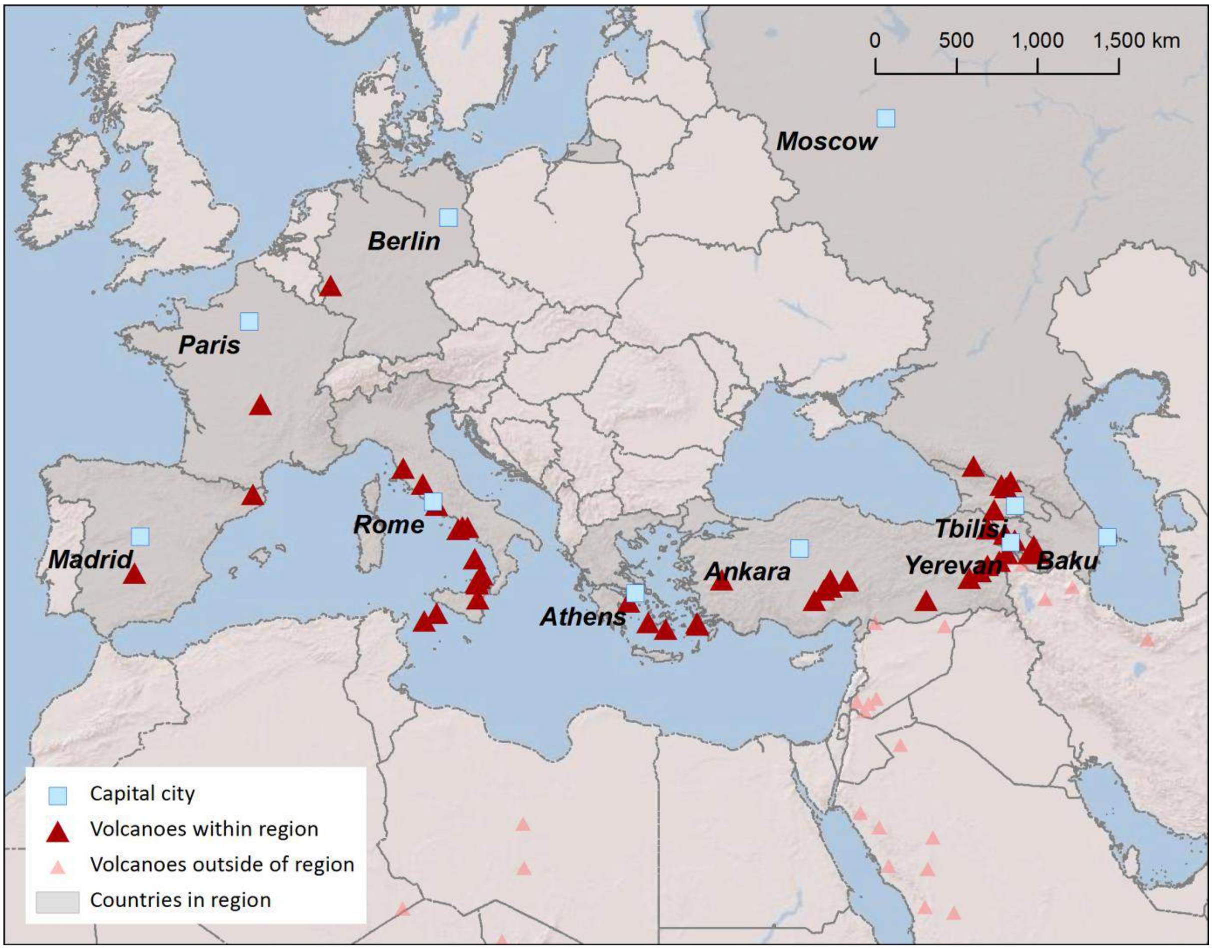

Figure 1.1 The distribution of Holocene volcanoes through the Mediterranean and West Asia region. The capital cities of the constituent countries are shown.

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 1.1 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.

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Region 1: The Mediterranean and West Asia comprises volcanoes in ten countries (Table 1.1) 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 1.2 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 1.3 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 1.2). 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.

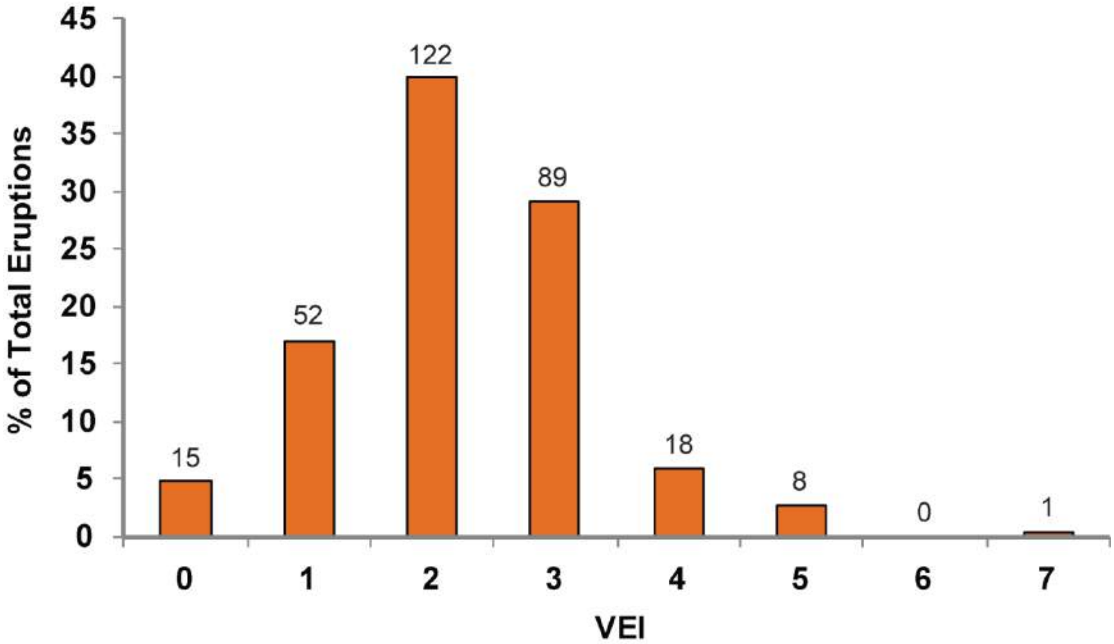

Figure 1.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 141 eruptions were recorded with unknown VEI.

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		Ferdinandea	Stromboli				
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 1.4 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 1900 AD, 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
3	6
9	5
15	4
9	3
4	2
0	1

Table 1.5 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
1	II
3	I
38	Unclassified

Table 1.6 The number of volcanoes in the Mediterranean and West Asia region classified at each risk level.

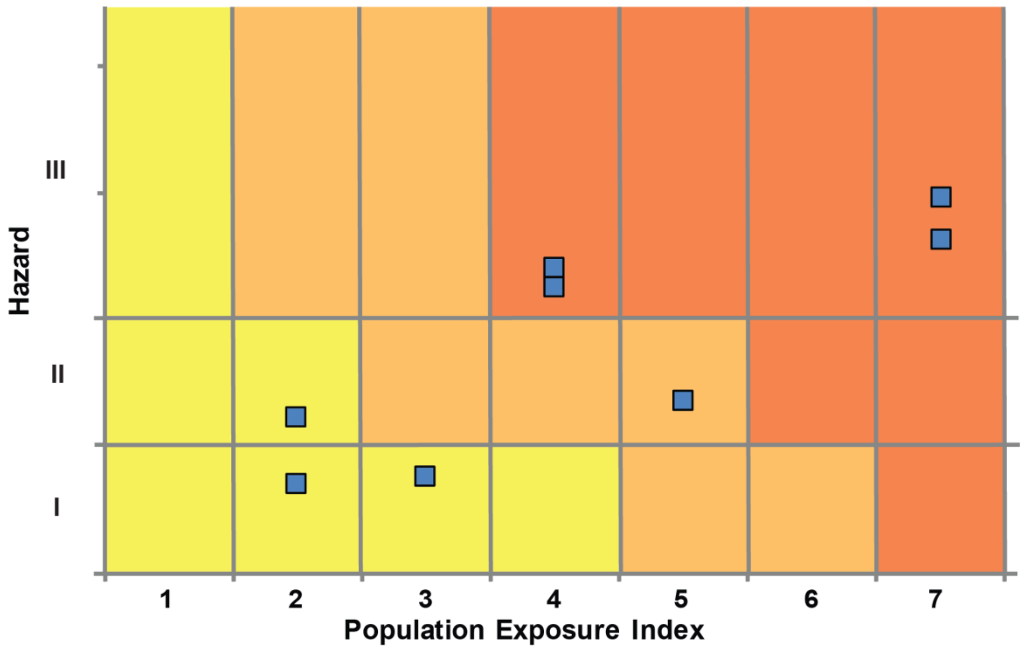

Figure 1.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing risk levels from Risk Level I - III.

Regional Monitoring Capacity

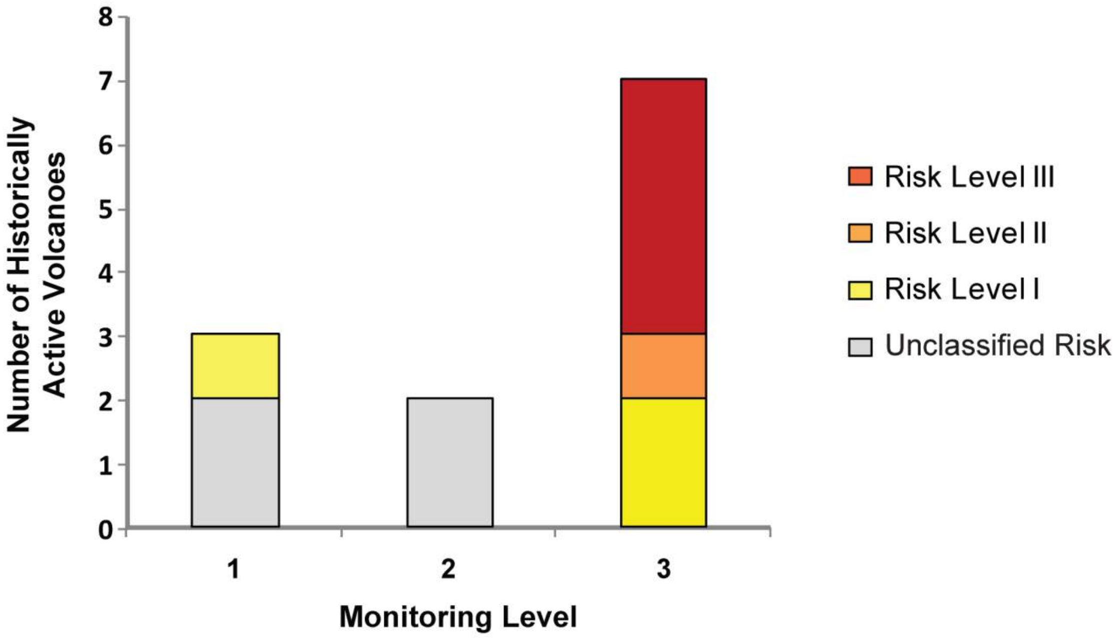

Figure 1.4 The monitoring and risk levels of the historically active volcanoes in the Mediterranean and West Asia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Armenia

Description

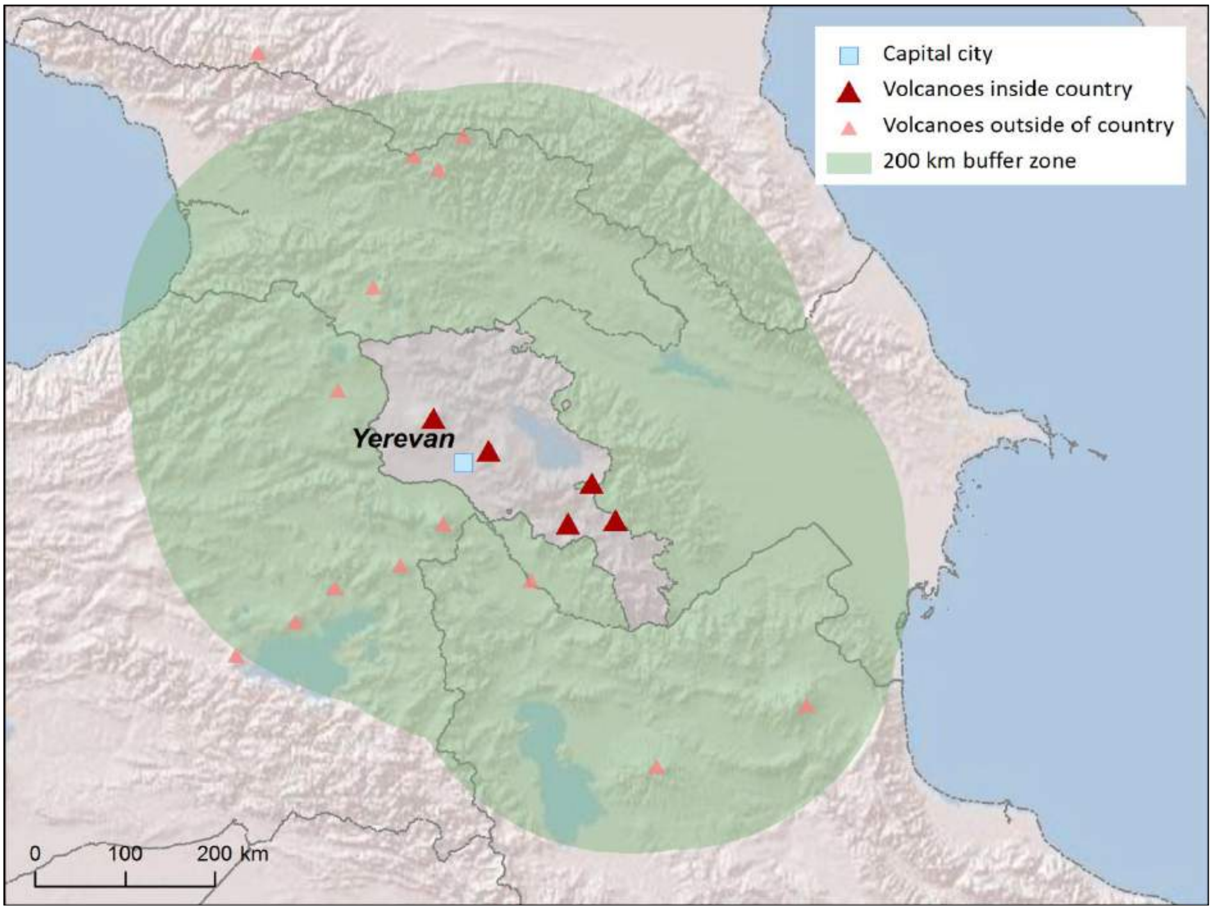

Figure 1.5 Location of Armenia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Armenia.

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).

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 trachyandesite to basaltic trachyandesitic 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 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.

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: www.nssp-gov.am/index_eng.htm

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

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

Connor, L.J., Connor, C.B., Meliksetian, K.H. and Savov, I. (2012) A probabilistic approach to modelling lava flow inundation. Lava flow hazard assessment for a nuclear facility in Armenia. Journal of Applied Volcanology, 1:3.

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 1.7 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 their population size:

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 , Savov and Halama 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, giving an annual probability of 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.

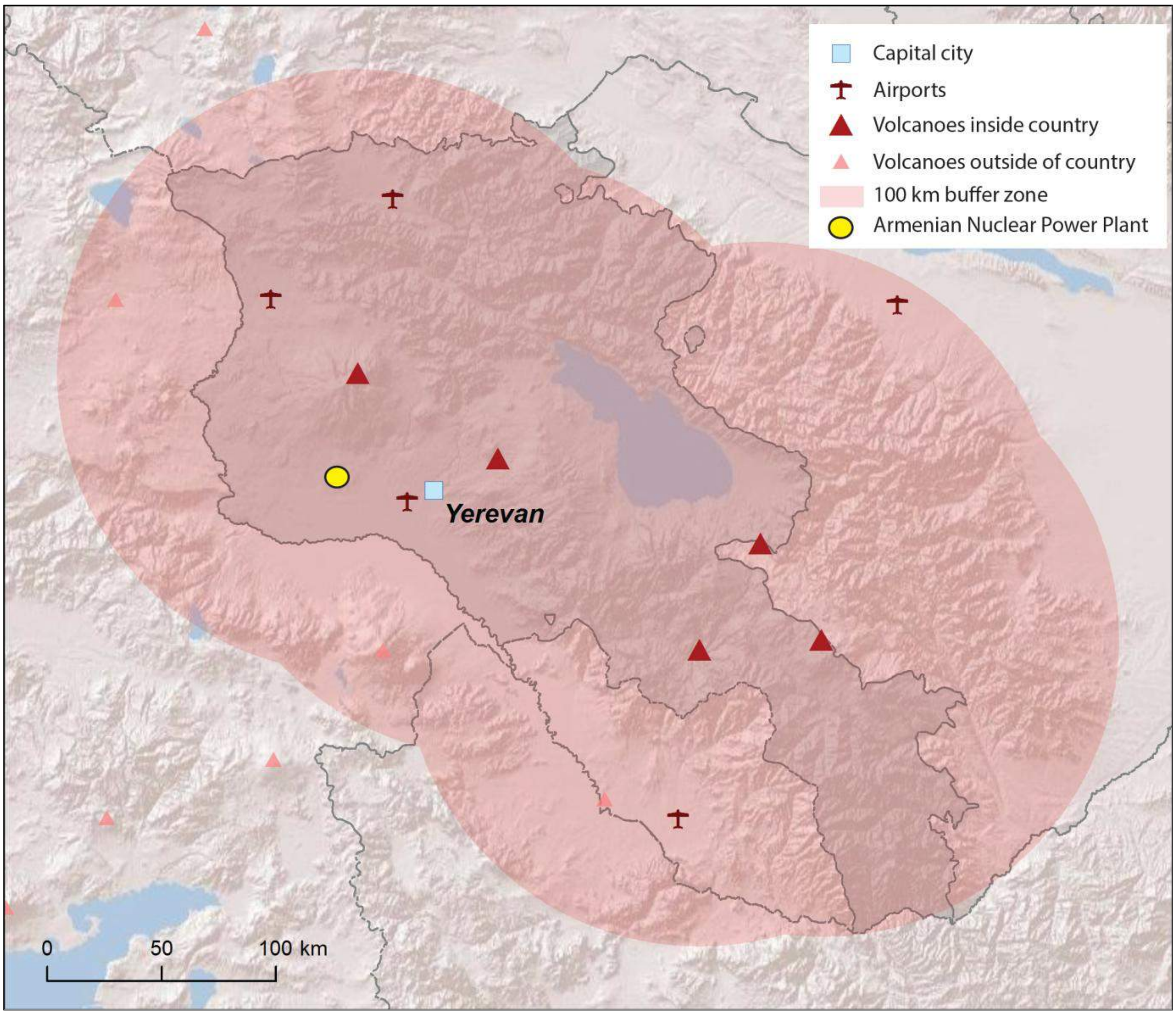

Figure 1.6 The location of Armenia's volcanoes and the extent of the 100 km zone surrounding them. Airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 1.8 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 1900 AD, 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

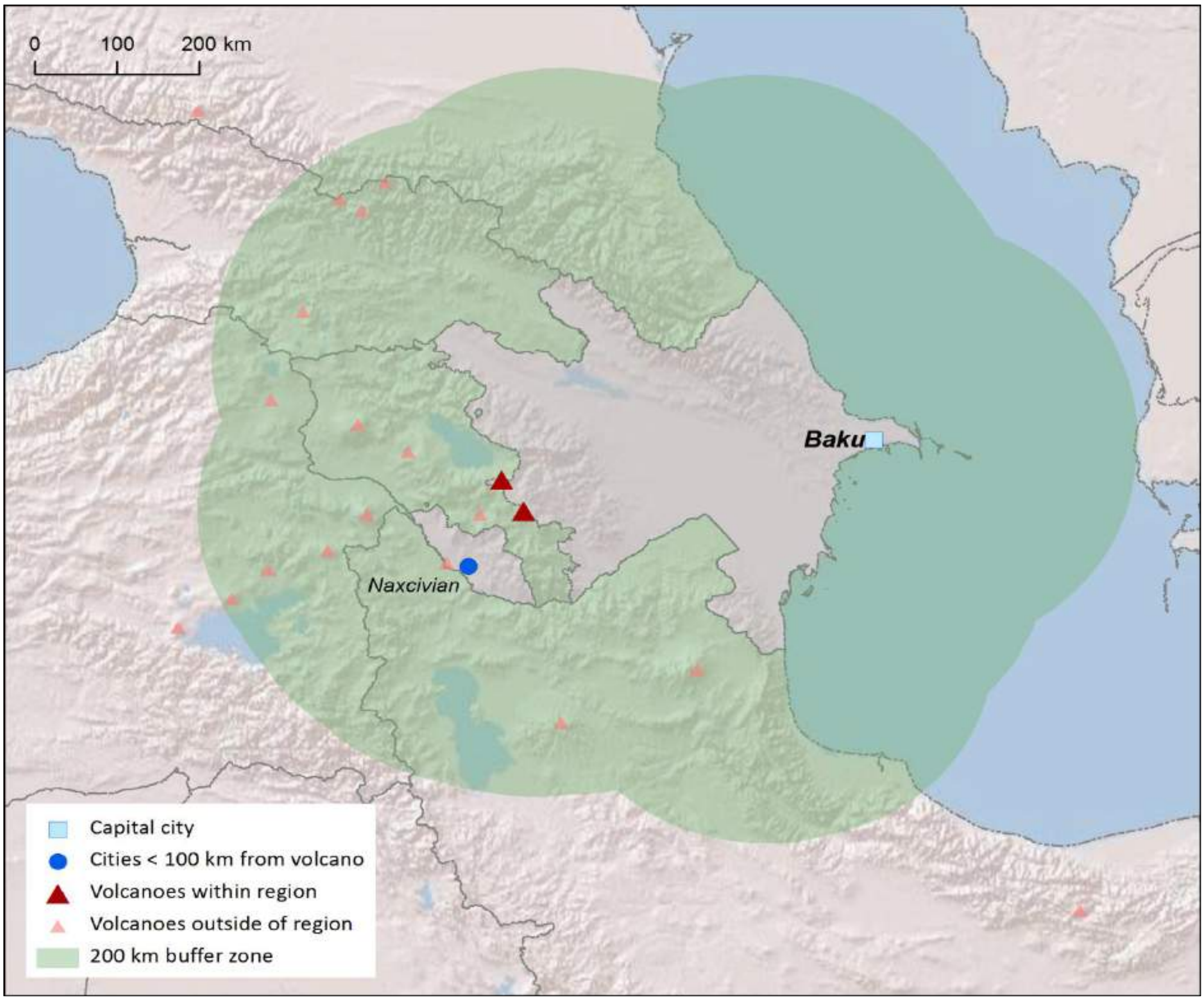

Figure 1.7 Location of Azerbaijan's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Azerbaijan.

There are two Holocene volcanoes partly located in Azerbaijan: Porak and Tskhouk-Karckar, which are also on the border with Armenia (Figure 1.7). 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.

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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:
www.adrc.asia/nationinformation.php?NationCode=31&Lang=en&NationNum=35

Ministry for Emergency Situations: 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 1.9 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 their population size:

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.

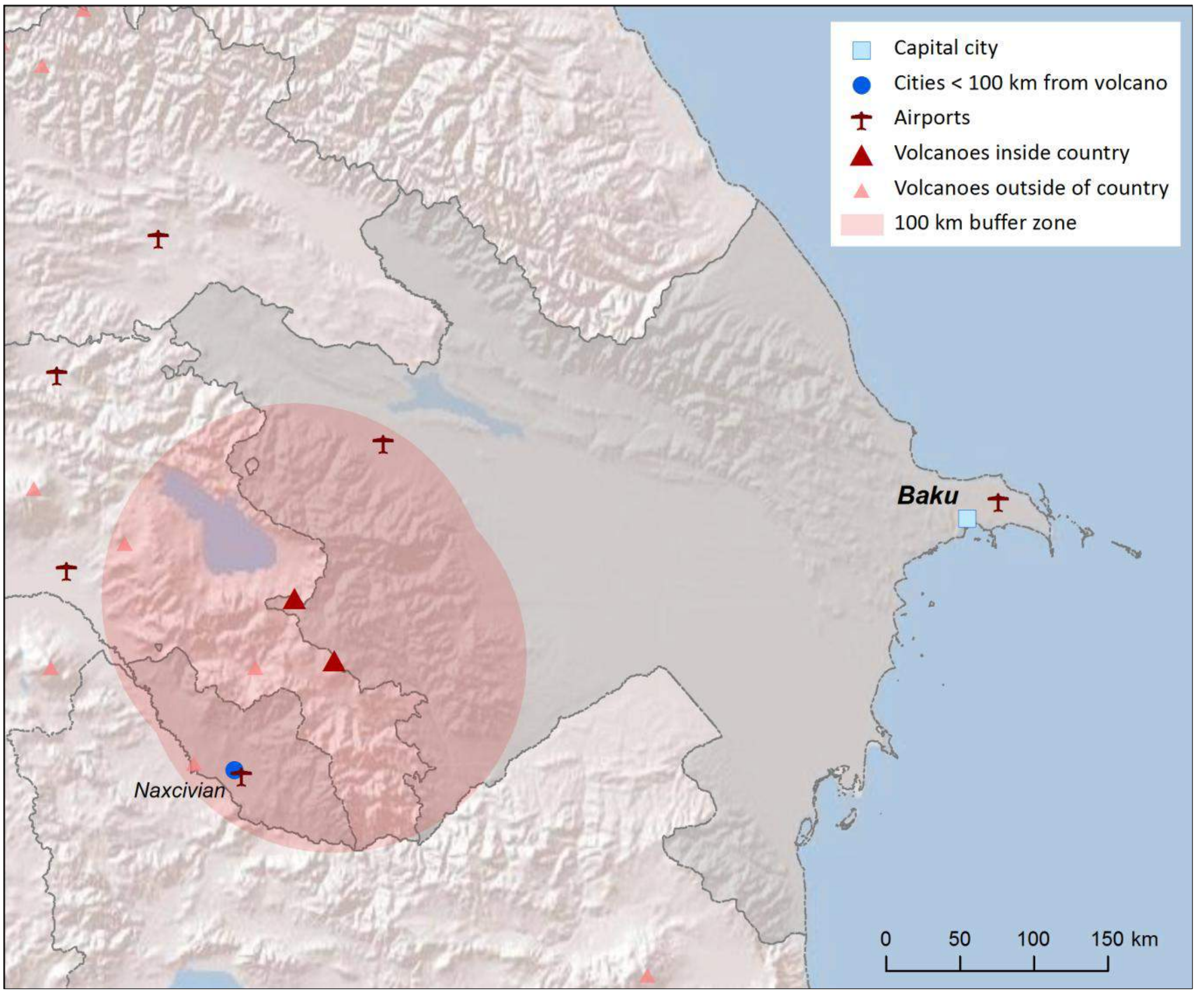

Figure 1.8 The location of Azerbaijan's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 1.10 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 1900 AD, 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

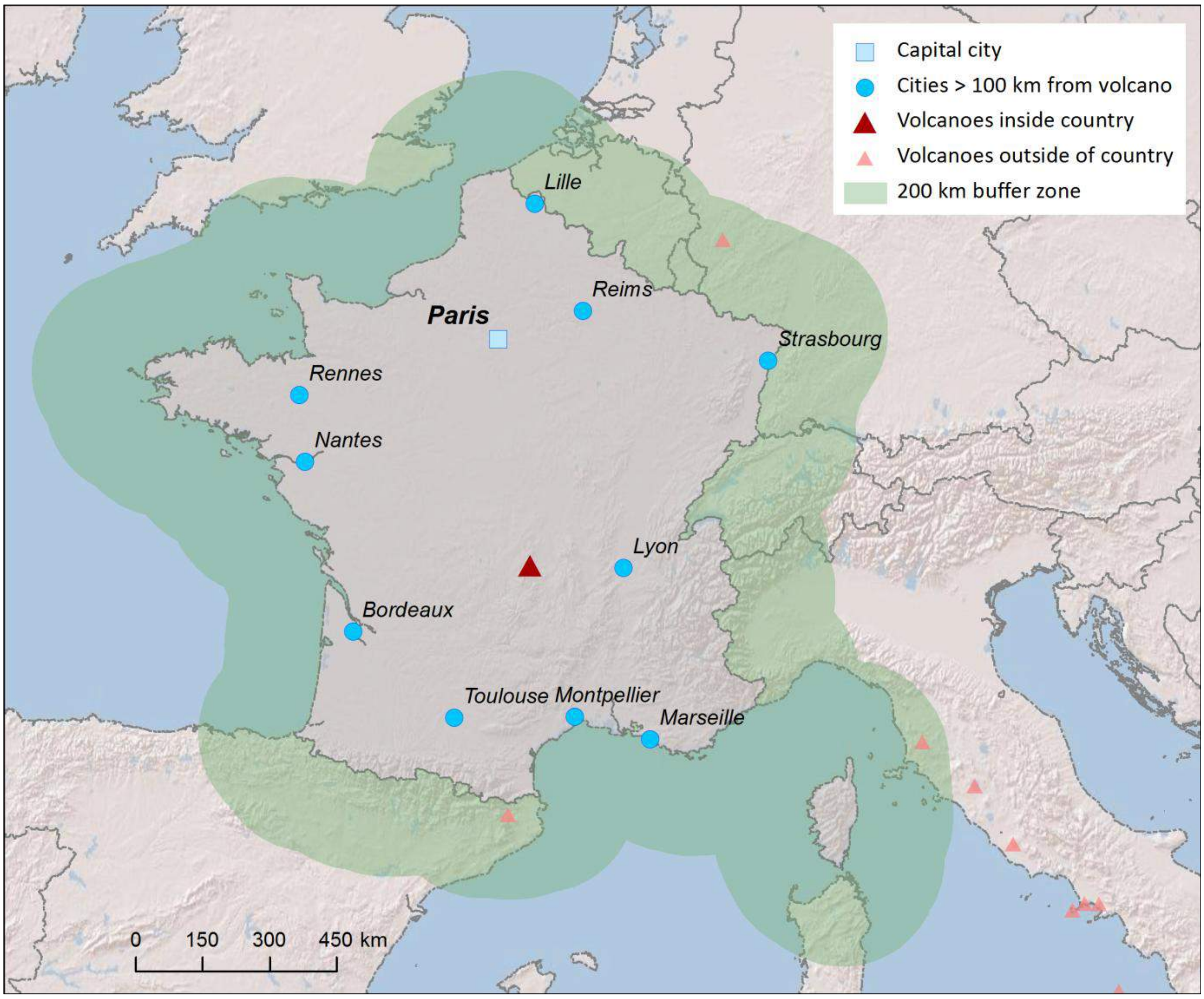

Figure 1.9 Location of Mainland France's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect France.

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 1.11 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 population size (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.

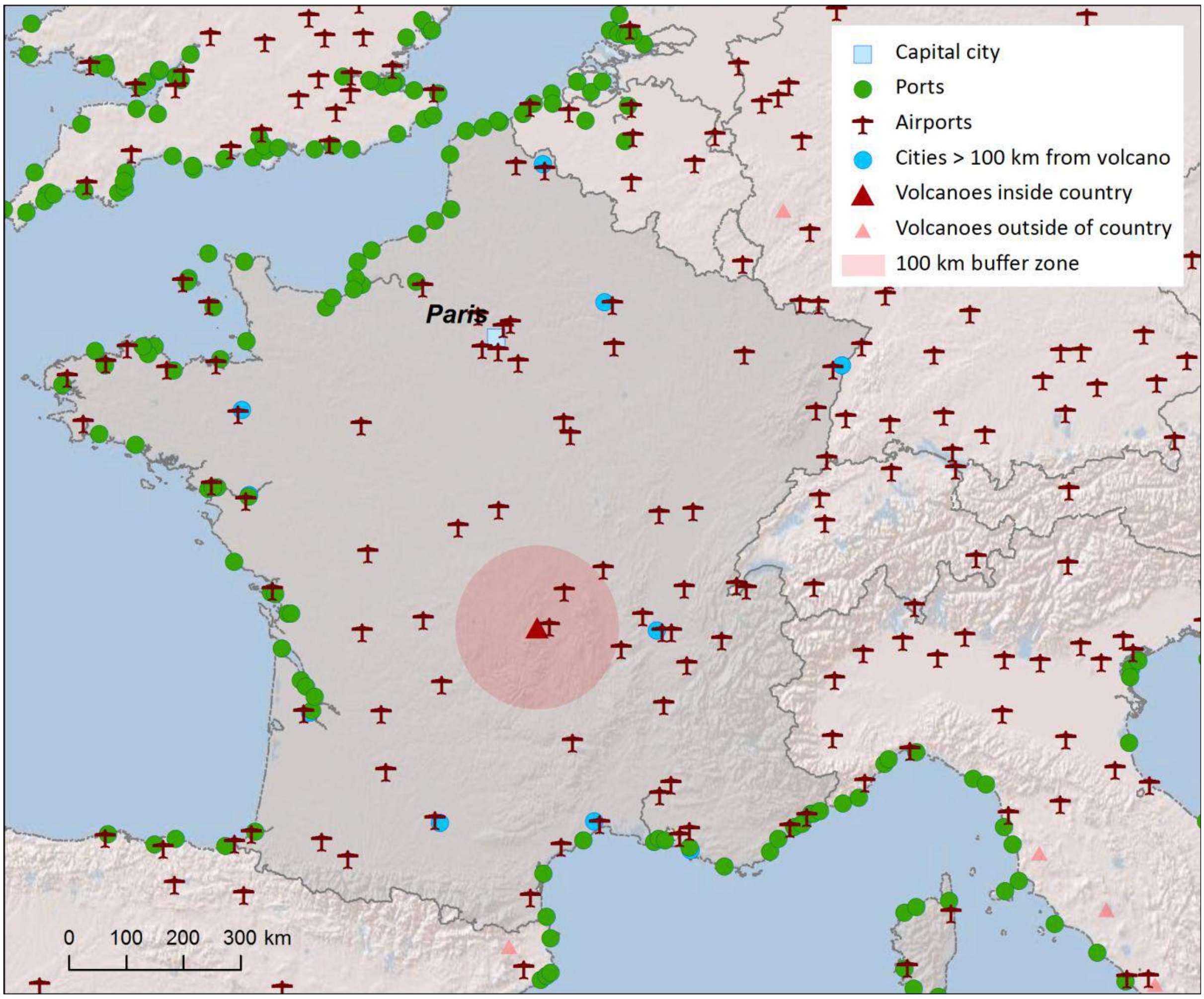

Figure 1.10 The location of Mainland France's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 1.12 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 1900 AD, 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

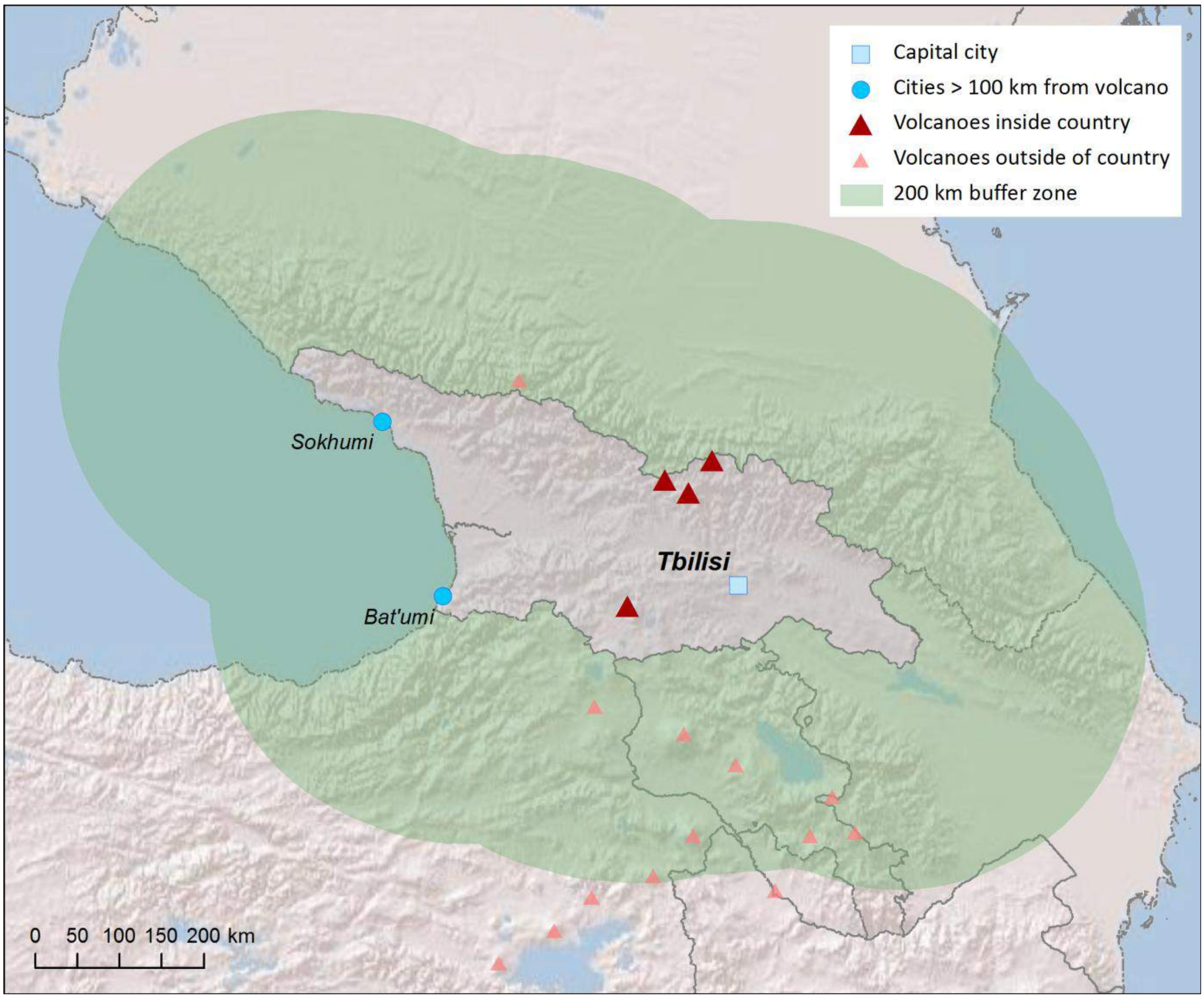

Figure 1.11 Location of Georgia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Georgia.

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 1.13 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 their population size:

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.

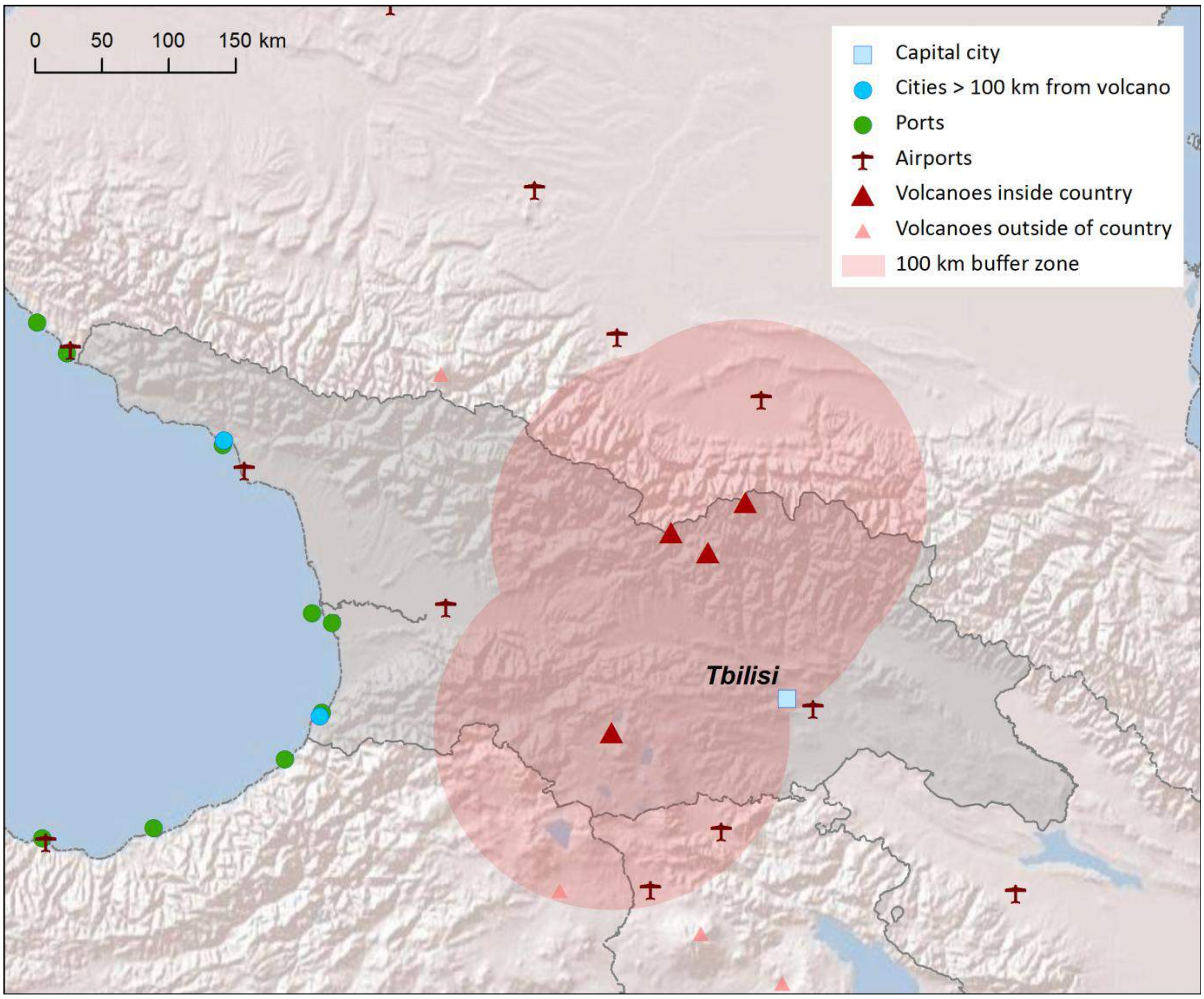

Figure 1.12 The location of Georgia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 1.14 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 1900 AD, 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

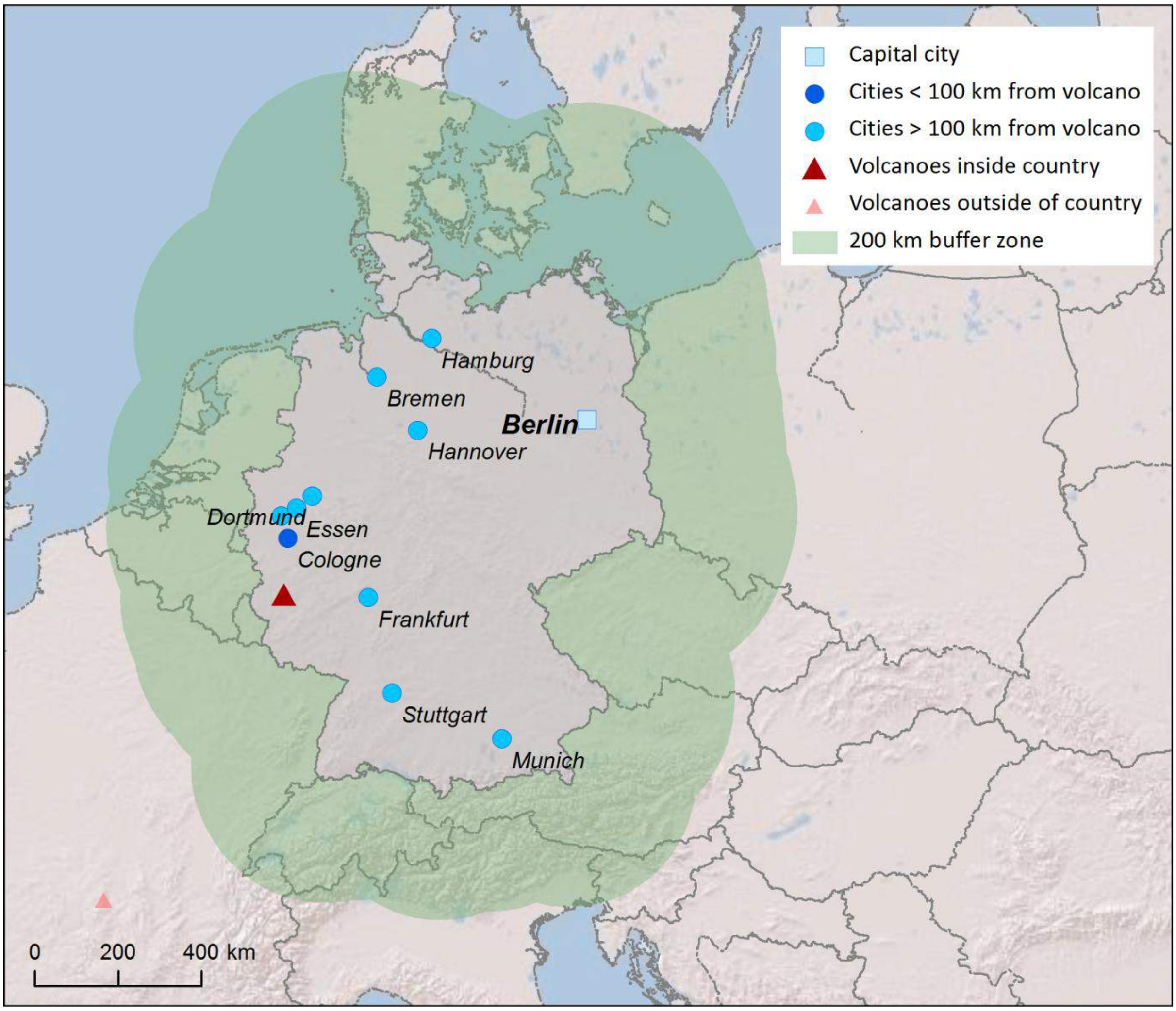

Figure 1.13 Location of Germany's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Germany.

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 1.15 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 their population size:

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.

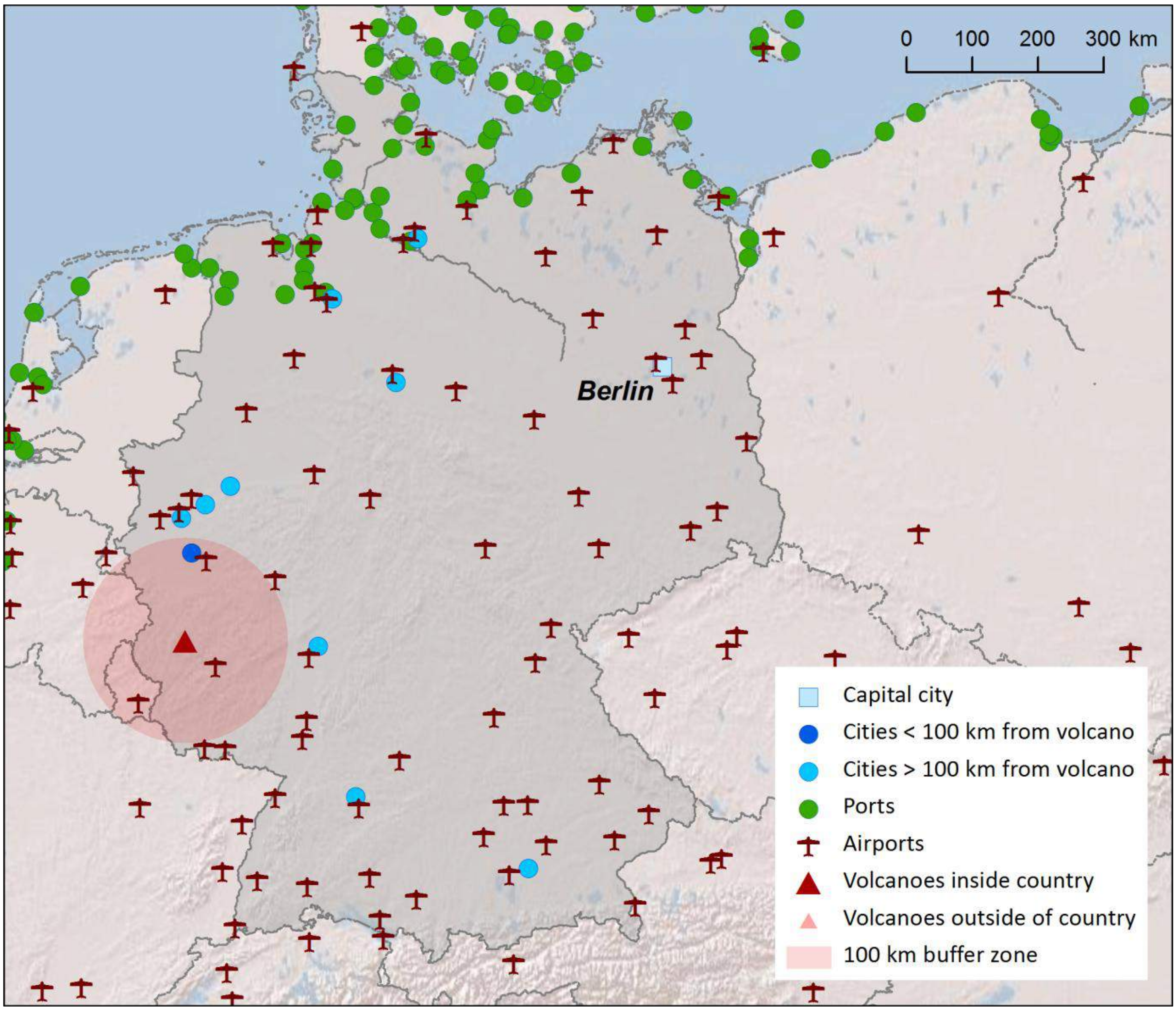

Figure 1.14 The location of Germany's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 1.16 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 1900 AD, 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

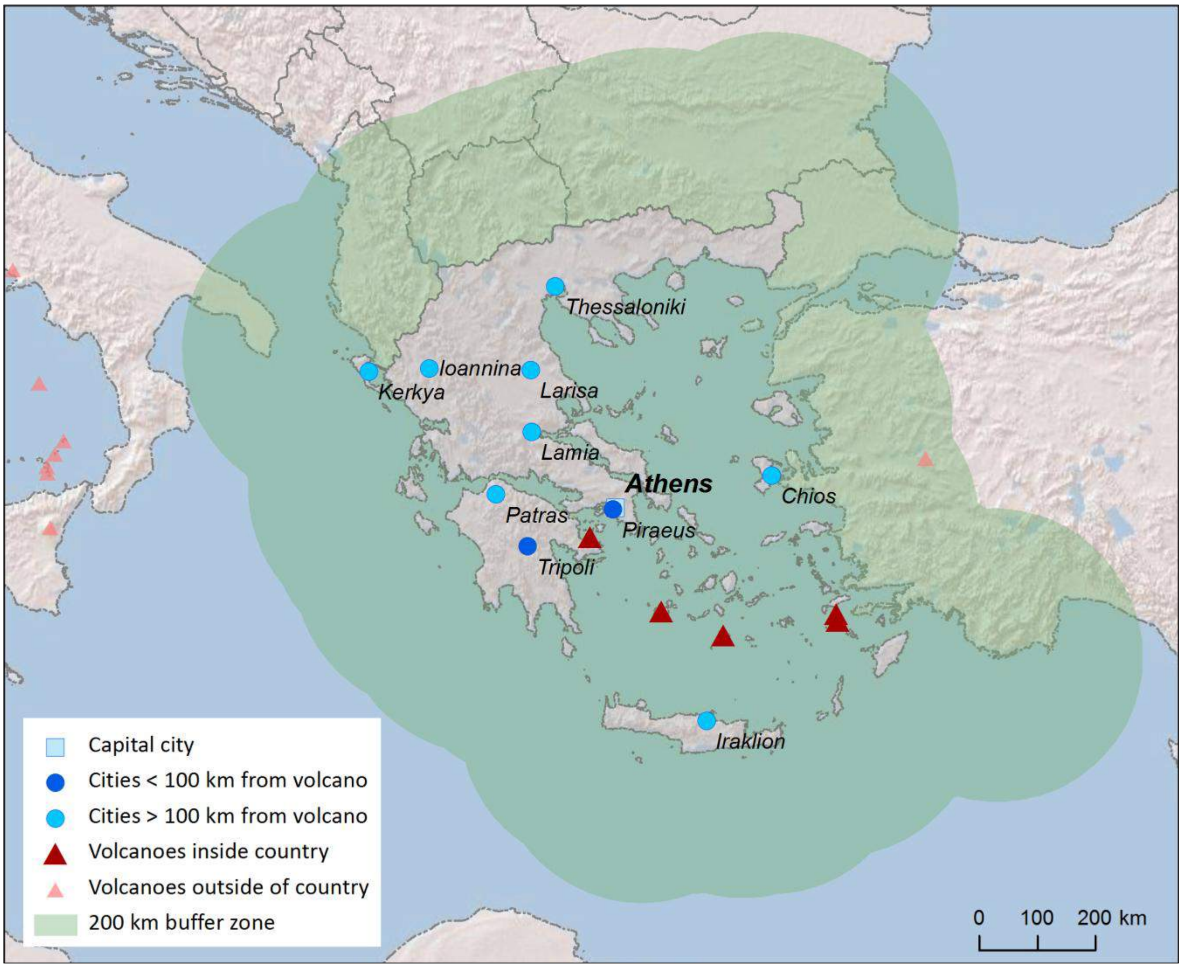

Figure 1.15 Location of Greece's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Greece.

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 programme. 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, santorini.earth.ox.ac.uk/home for discussion of the 2011-12 unrest and monitoring.

Nisyros Volcano Observatory, 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 1.17 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 their population size:

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.

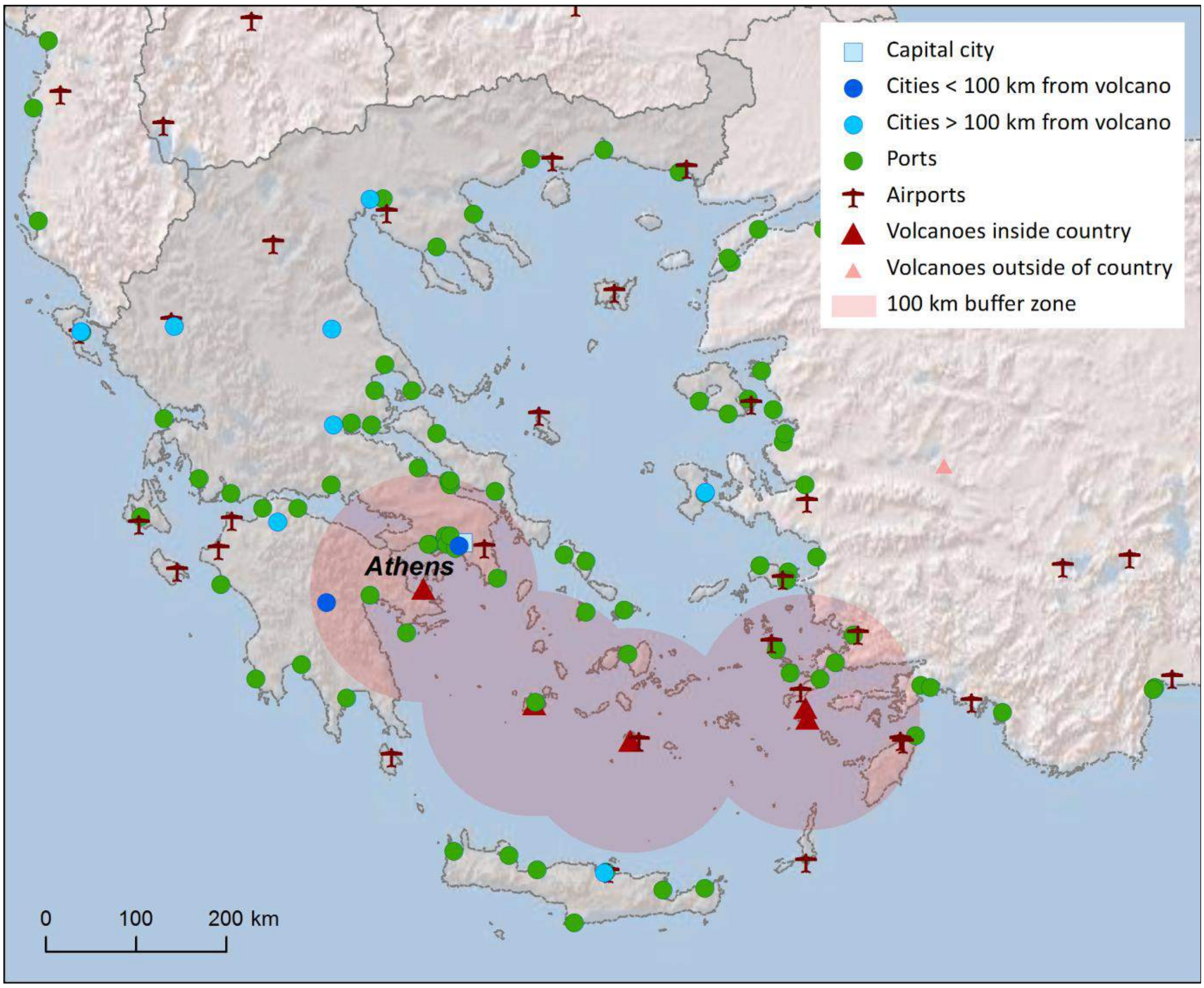

Figure 1.16 The location of Greece's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 1.18 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 1900 AD, 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 1.19 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.

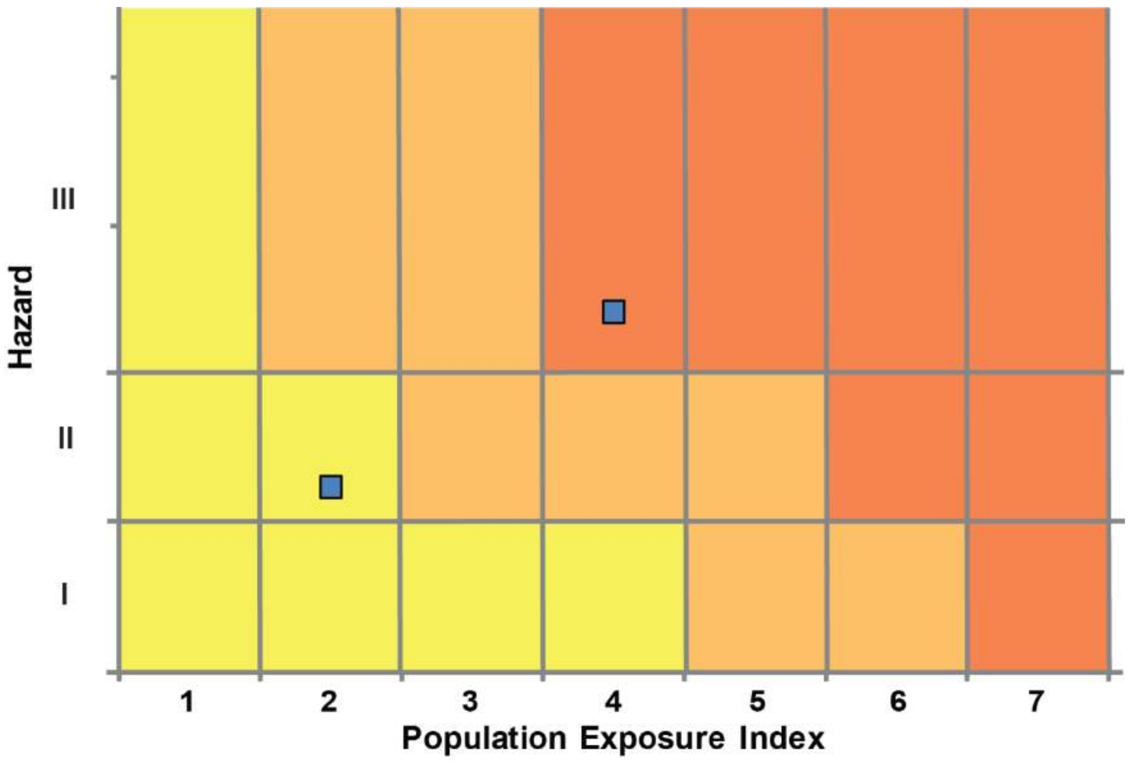

Figure 1.17 Distribution of Greece's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

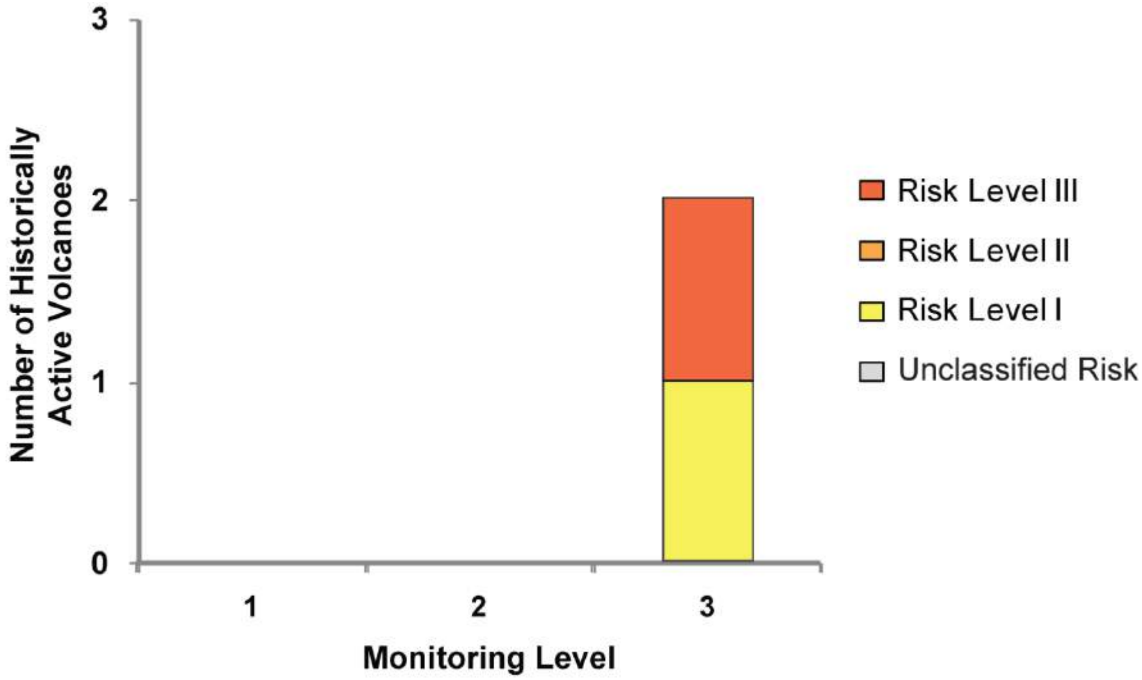

Figure 1.18 The monitoring and risk levels of the historically active volcanoes in Greece. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates 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 the submarine Ferdinandea[1] and other submerged volcanoes of the Sicily Channel, 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, there are 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,

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[1] The submarine Ferdinandea volcano is called Campi Flegrei Mar Sicilia in VOTW4.0, but is known locally as Ferdinandea. Here we use the name Ferdinandea to describe the submerged volcanoes of the Sicily Channel.
[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.

Ischia and Etna. 26 eruptions at Campi Flegrei, Vesuvius, Ischia, Strombolia and Etna have resulted in 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.

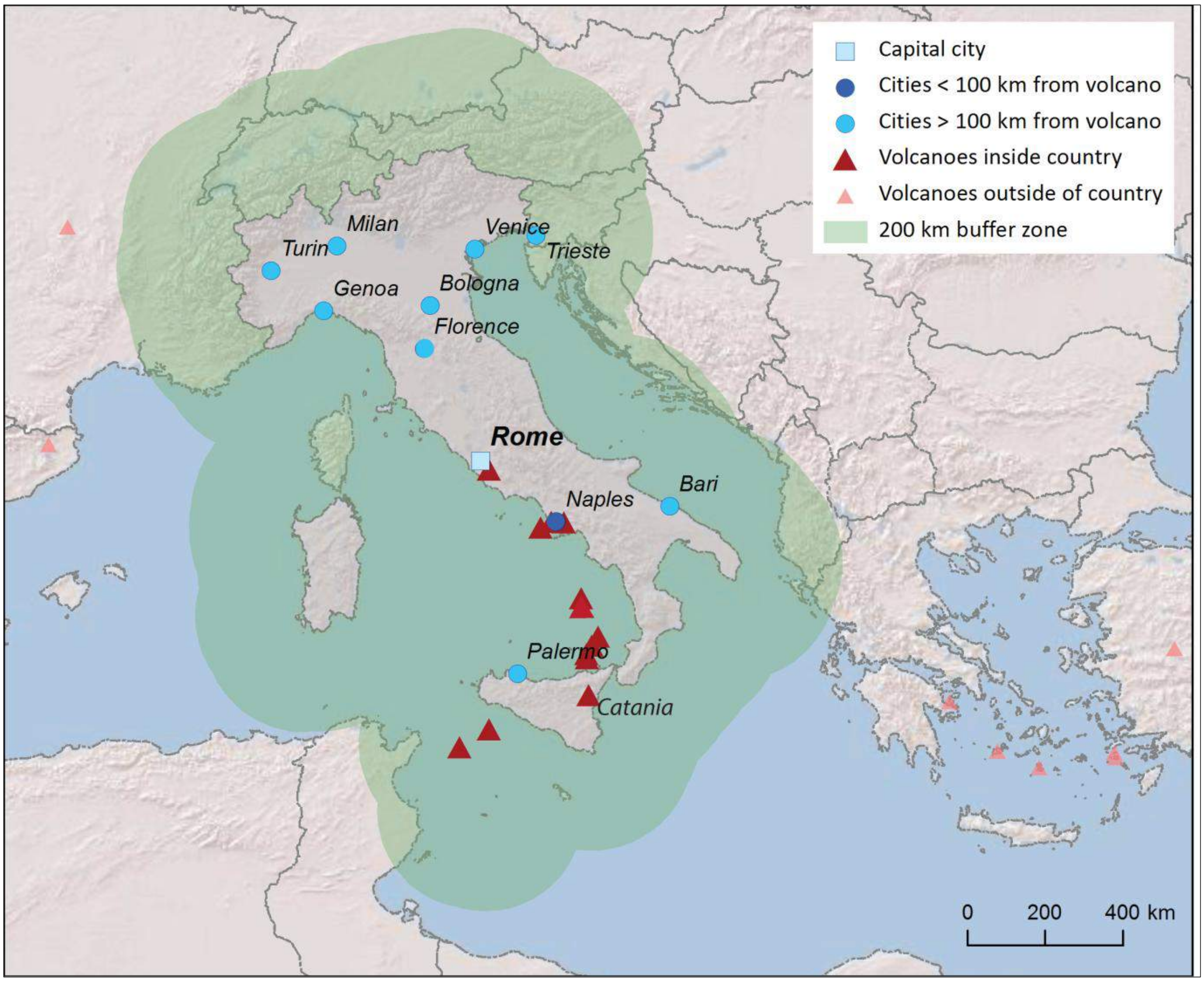

Figure 1.19 Location of Italy’s volcanoes, the capital and largest cities. Note that Vulsini and Larderello are not included in this map as they are no longer considered Holocene volcanoes. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect 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 1.20 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 their population size:

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.

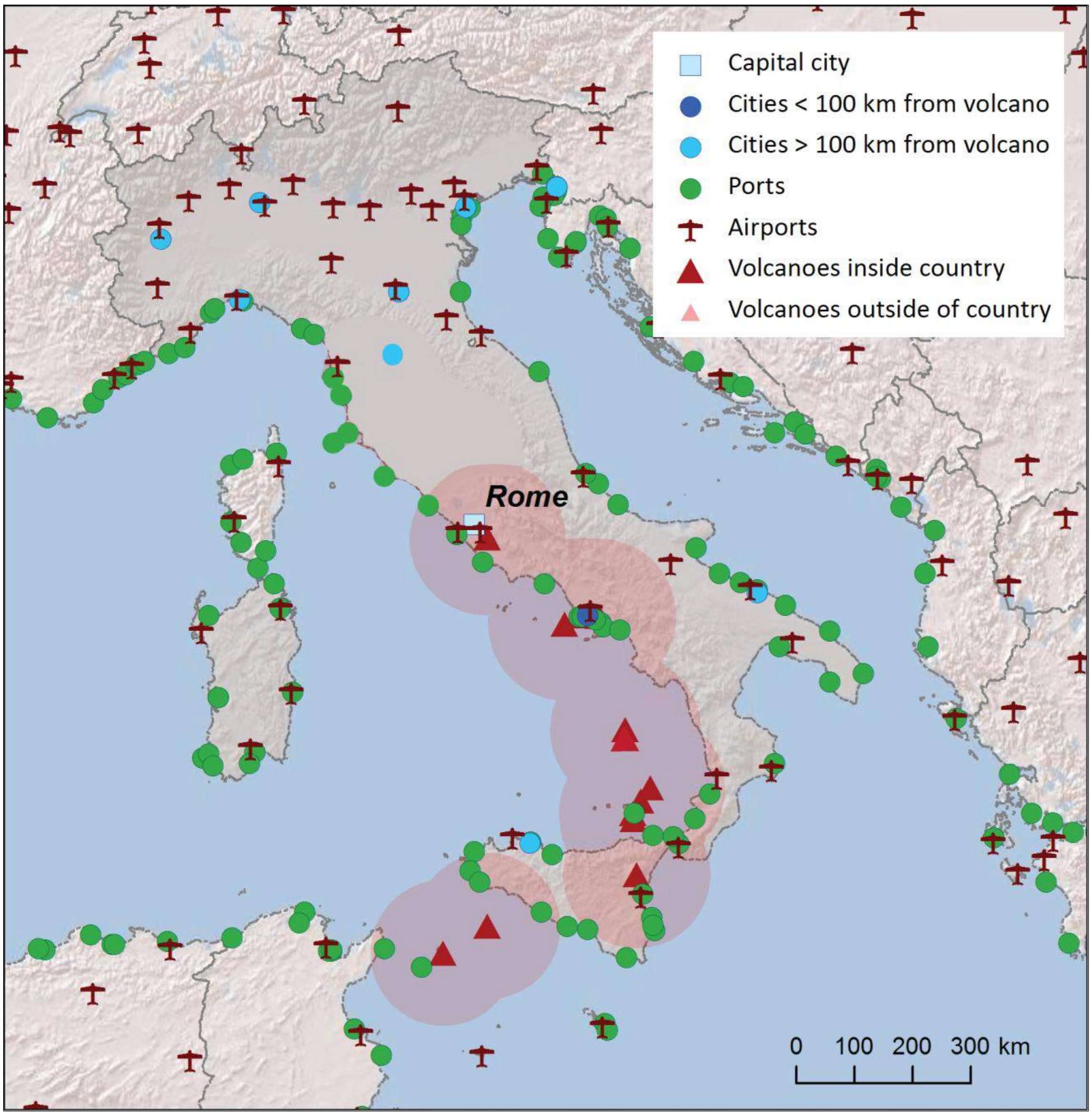

Figure 1.20 The location of Italy's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Six of the Italian volcanoes have sufficient information available in their records to allow the classification of a Hazard Level. These plot across all three hazard levels: Ferdinandea (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.

Throughout this work, we use the term 'historical' to mean events since 1500 AD. This is the time at which records around much of the world improved significantly, with many causes including the expansion of the population, global trade and colonisation and improvements in record keeping. Prior to this time, most of our eruption knowledge comes from geological study, rather than contemporary eruption records. Of course, in Italy, written records stretch back much further in time than in much of the world, and indeed the historical record for Etna goes back to about 1500 BC. The term 'historical' could therefore be extended beyond our definition of 1500 AD, however for consistency we maintain the definition here. This does mean that volcanoes such as Ischia are classified in the U-HR category, when strictly this does have a historical record. Ischia has erupted numerous times in the recent Holocene, with at least eight eruptions since 1 AD including at least one VEI 3 eruption and most recently the production of the Arso lava flow, through what is now a highly populated area. Ischia is the site of significant degassing and presents potential flank instability hazards including tsunamigenic potential.

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

*Table 1 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 1900 AD, 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
Etna	5	II
Vulcano	4	III
Stromboli	3	I
Ferdinandea	2	I

Table 1.21 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 – 2 volcanoes; Risk Level II –1 volcano; Risk Level III – 3 volcanoes.

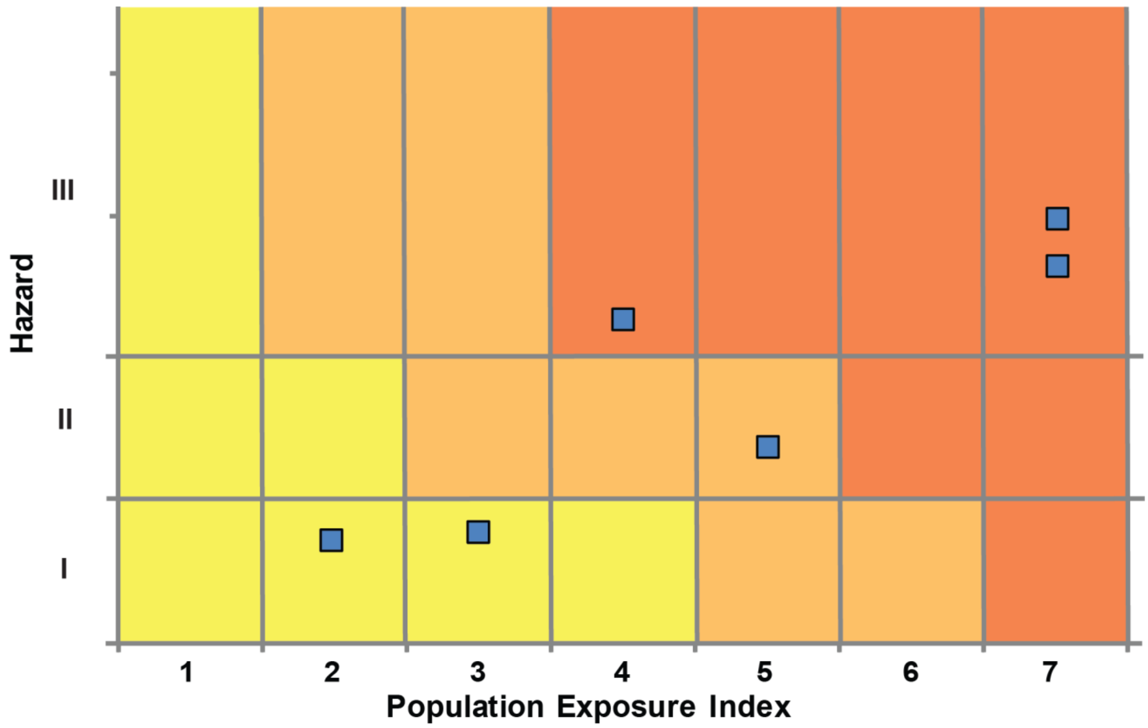

Figure 1.21 Distribution of Italy's volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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 Aeolian 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.

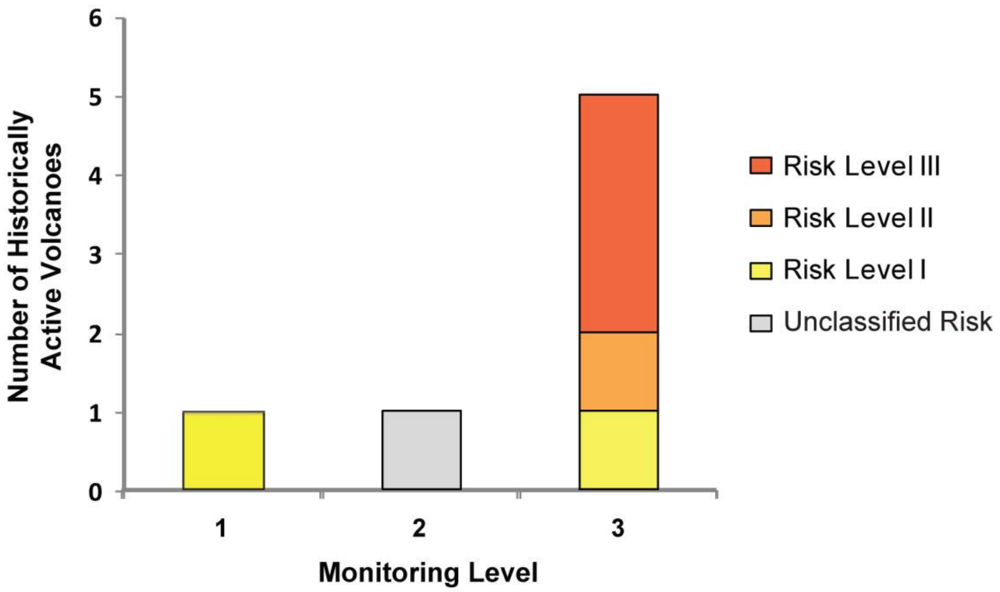

Figure 1.22 The monitoring and risk levels of the historically active volcanoes in Italy. Monitoring Level 1 indicates no known dedicated ground-based monitoring (the submarine Ferdinandea volcano); Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

References

Palladino, D, Simei, S., Sottili, G., and Trigila, R., 2010, Integrated approach for the reconstruction of stratigraphy and geology of Quaternary volcanic terrains: An application to the Vulsini Volcanoes (central Italy), in Stratigraphy and Geology of Volcanic Areas (eds. G. Groppelli, and L. Viereck-Goette), The Geological Society of America Special Paper, 464, 63-84. doi: 10.1130/2010.2464(04)

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.

Gail A.M., Wes H., 1986, Geology of the peralkaline volcano at Pantelleria, Strait of Sicily. Bull Volcanol, 48:143-172

Spain – Mainland

Description

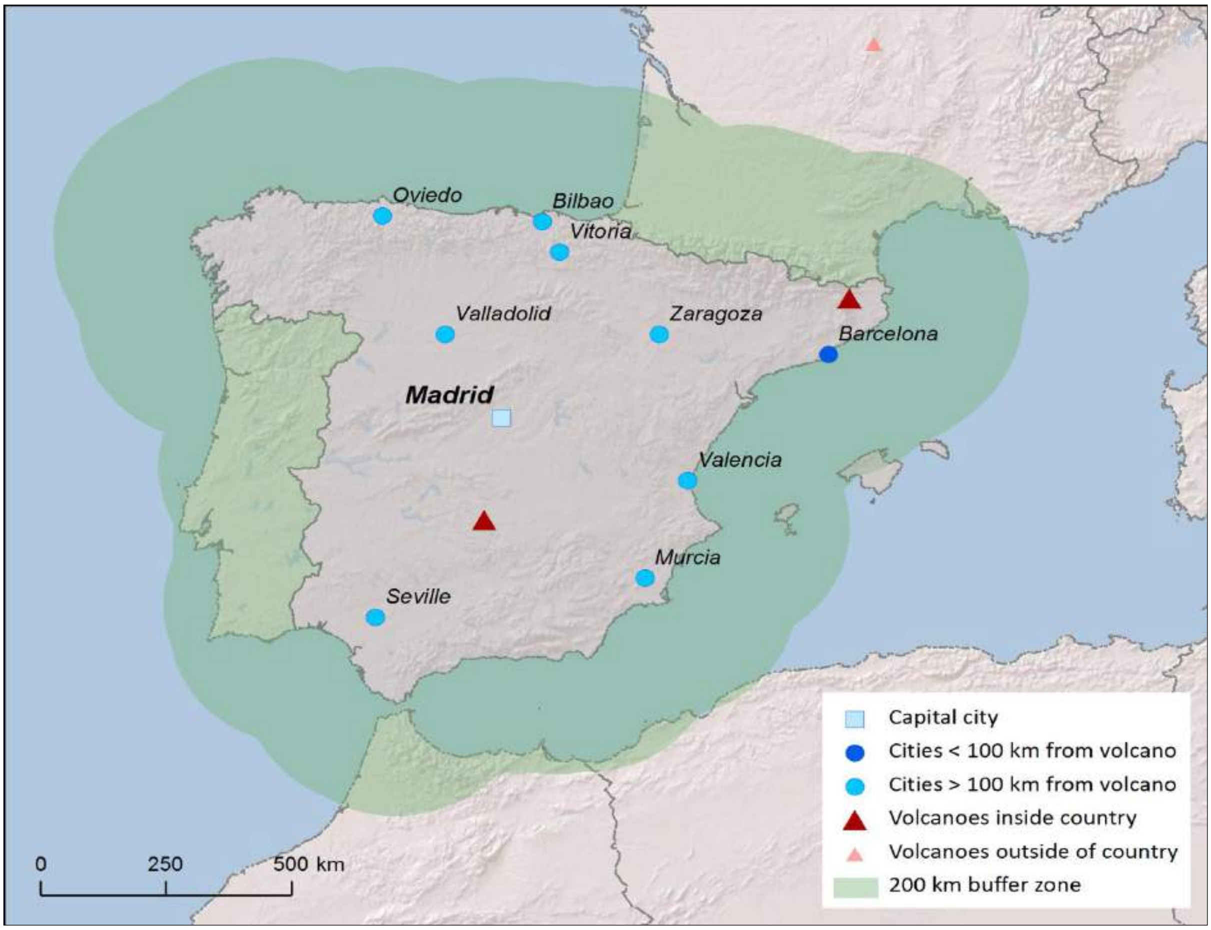

Figure 1.23 Location of Spain's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Spain.

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 1.22 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 their population size:

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

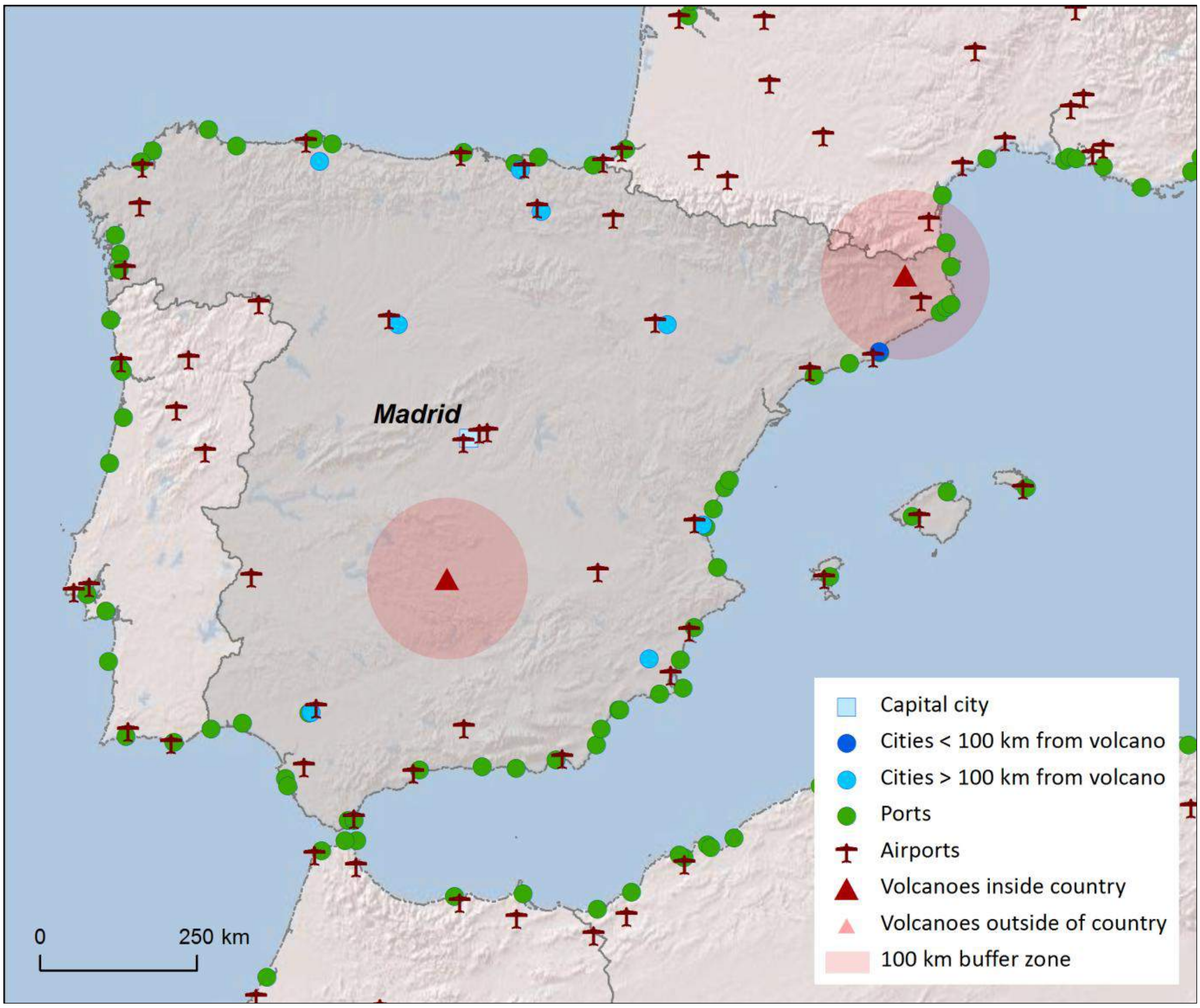

Figure 1.24 The location of Spain's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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.

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 1.23 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 1900 AD, 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

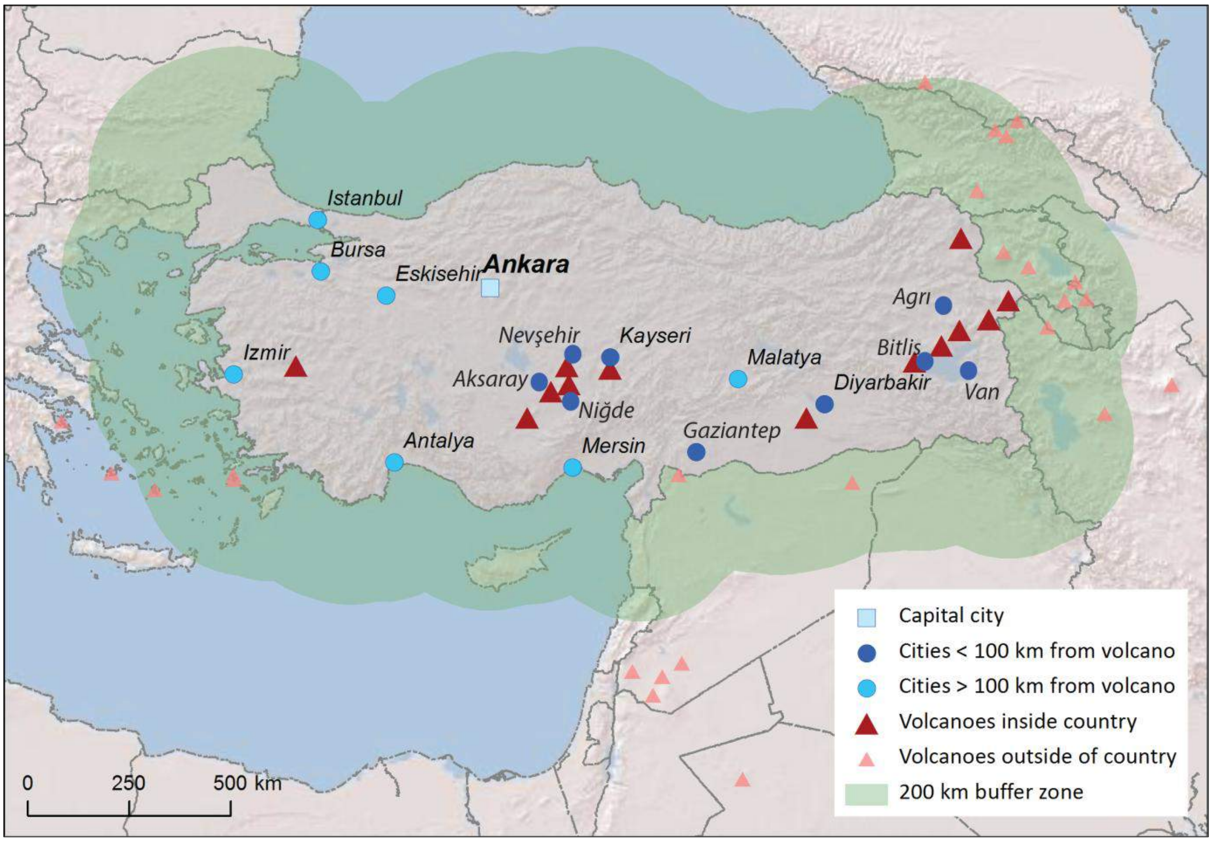

Figure 1.25 Location of Turkey's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Turkey.

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.

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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: 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 1.24 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 their population size (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.

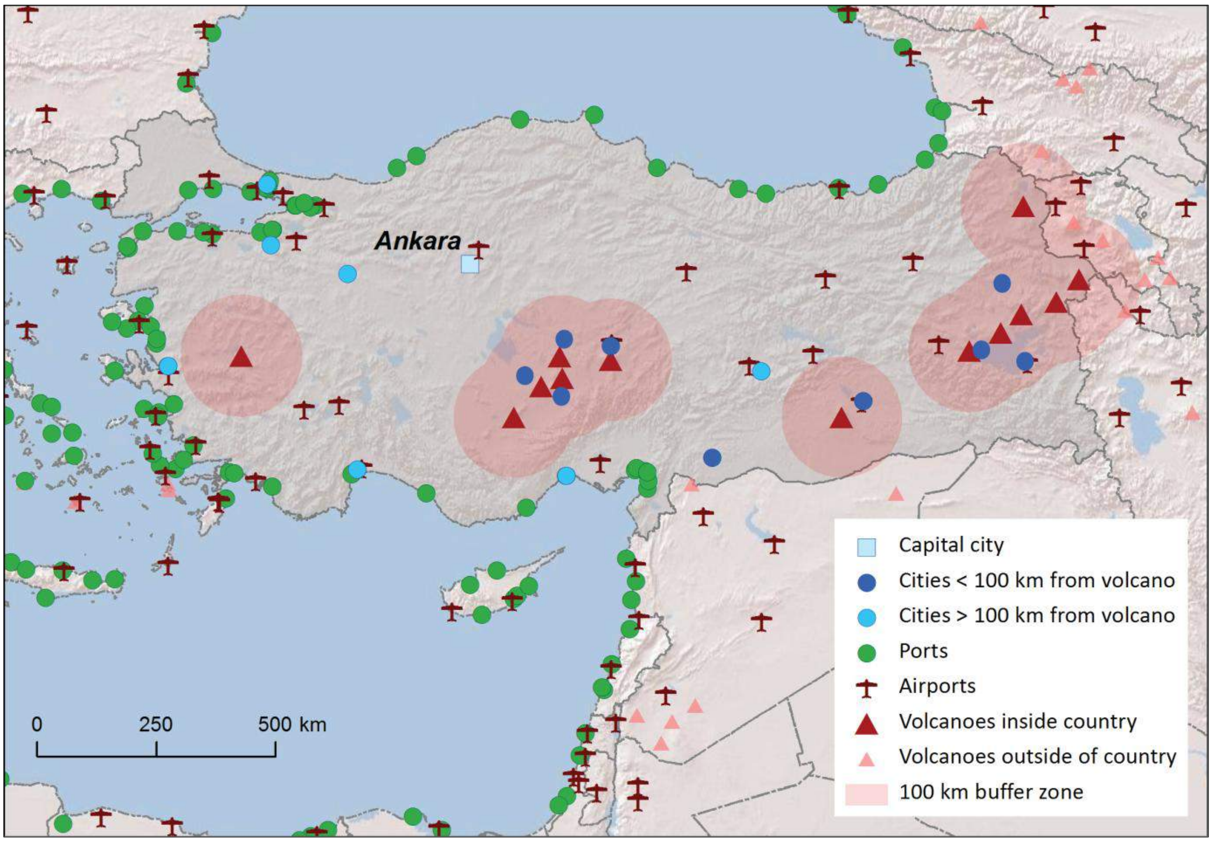

Figure 1.26 The location of Turkey's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 1.25 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.

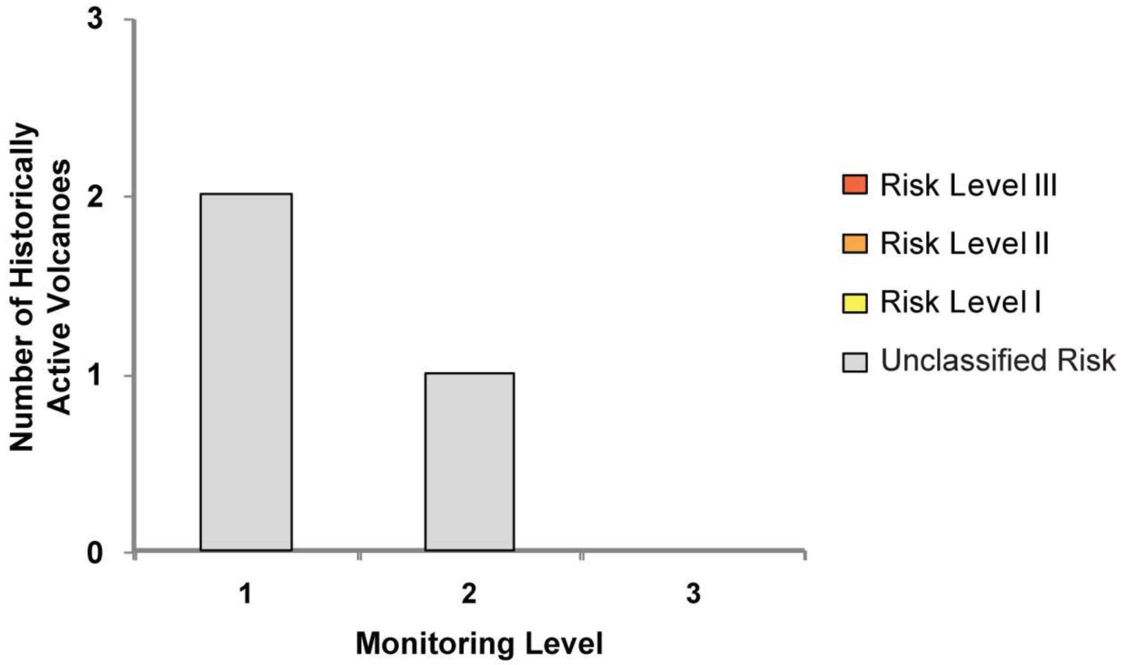

Figure 1.27 The monitoring and risk levels of the historically active volcanoes in Turkey. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 2: Africa and Red Sea

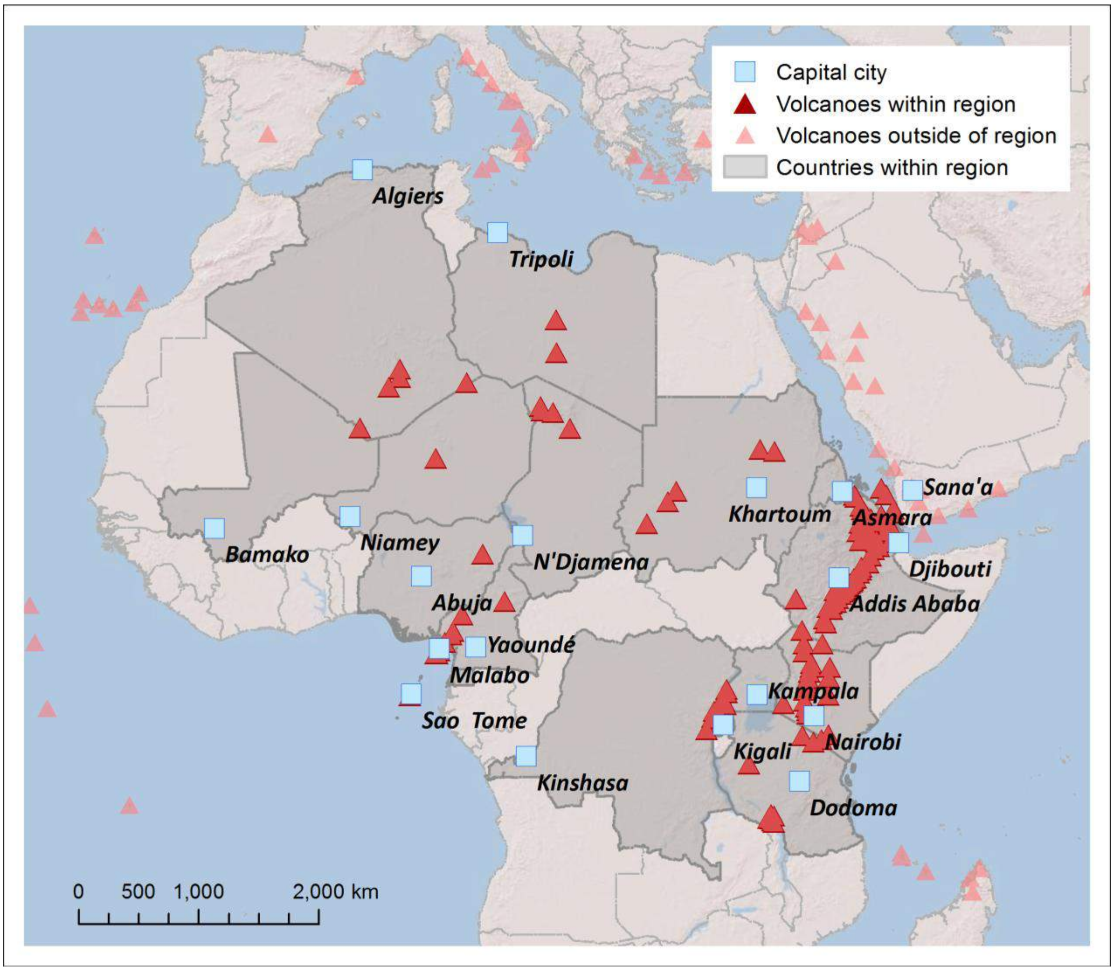

Figure 2.1 The distribution of Holocene volcanoes through the Africa and Red Sea region. The capital cities of the constituent countries are shown.

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 2.1 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 2.2 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 2.3 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 occurs 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 2.2). VEI 0 to 2 eruptions dominate the record, making up about 80% of eruptions. Nearly 8% of eruptions in this region are VEI ≥4.

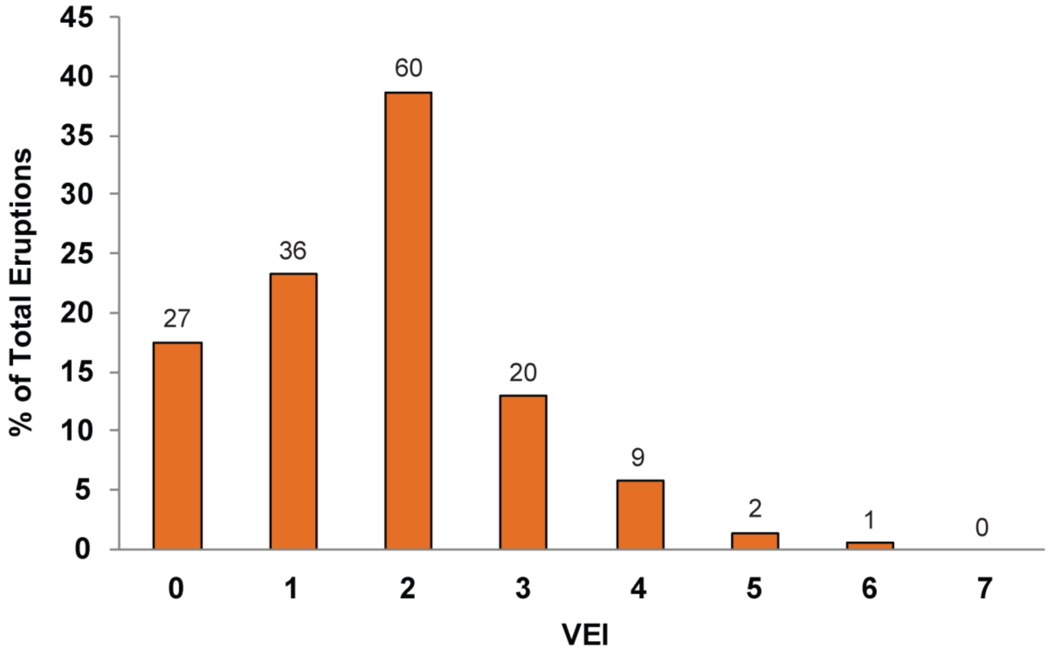

Figure 2.2 Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 41 eruptions were recorded with unknown VEI.

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 2.4 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 1900 AD, 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 2.5 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 2.6 The number of volcanoes in the Africa and Red Sea region classified at each Risk Level.

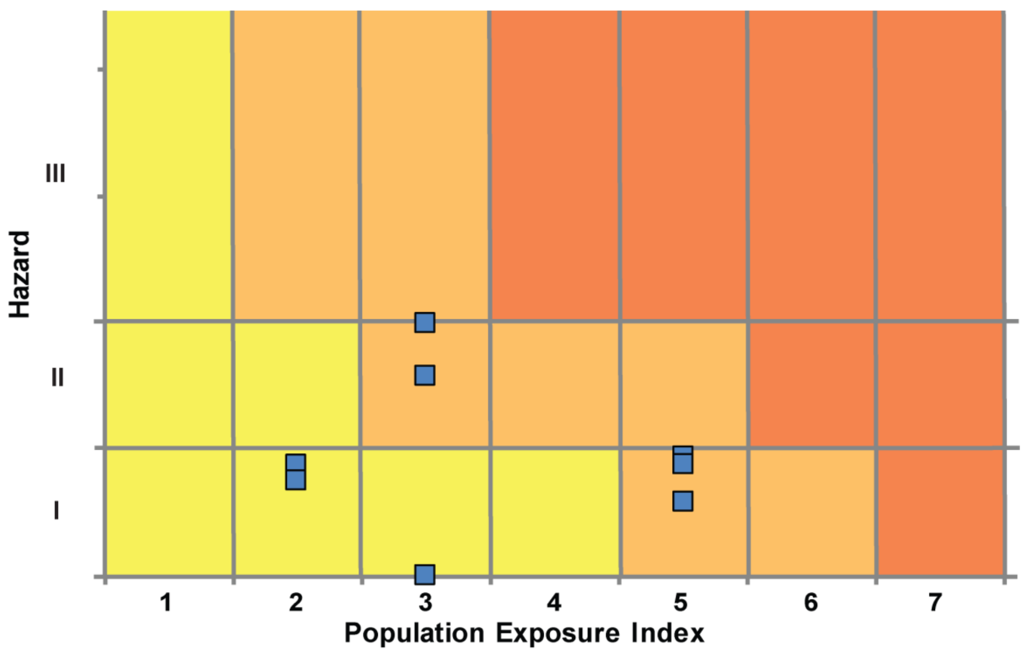

Figure 2.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional Monitoring Capacity

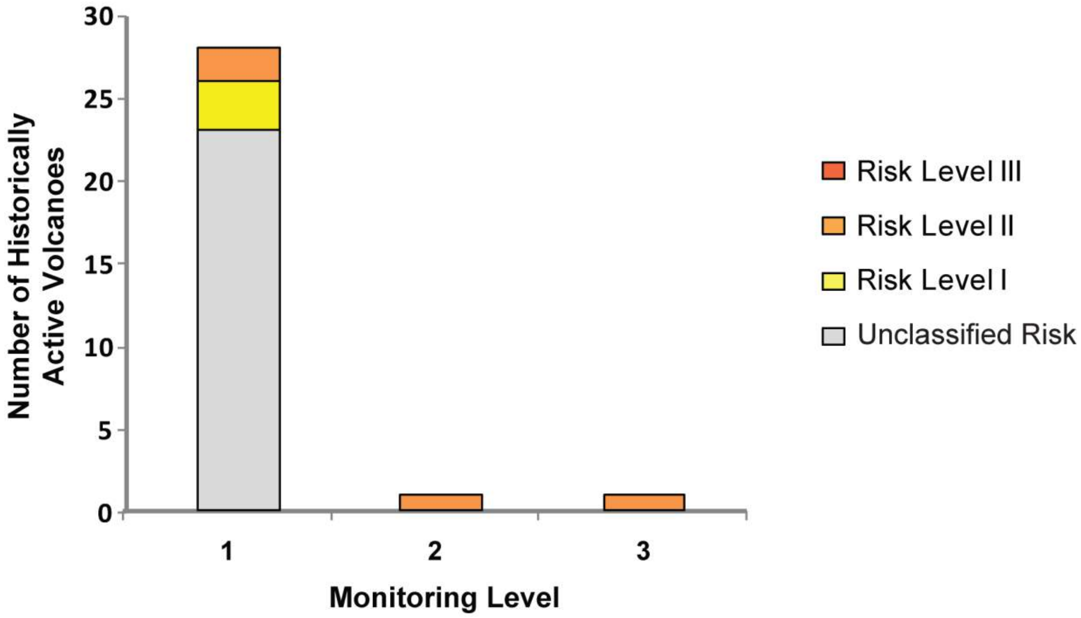

Figure 2.4 The monitoring and risk levels of the historically active volcanoes in Africa and the Red Sea. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring 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.

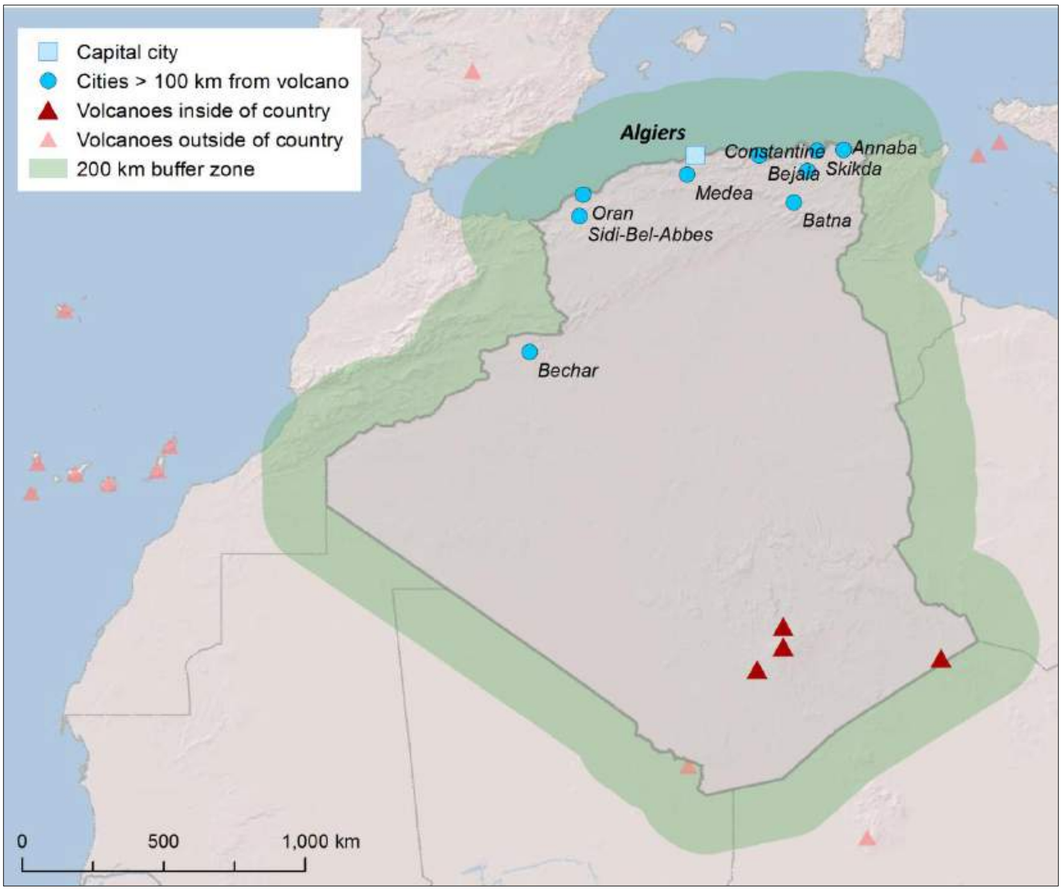

Figure 2.5 Location of Algeria's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Algeria.

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 2.7 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 their population size:

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. One airport is located within 100 km: the Aguenar-Hadj Bey Akhamok international airport, between the Tahalra and Atakor Volcanic Fields.

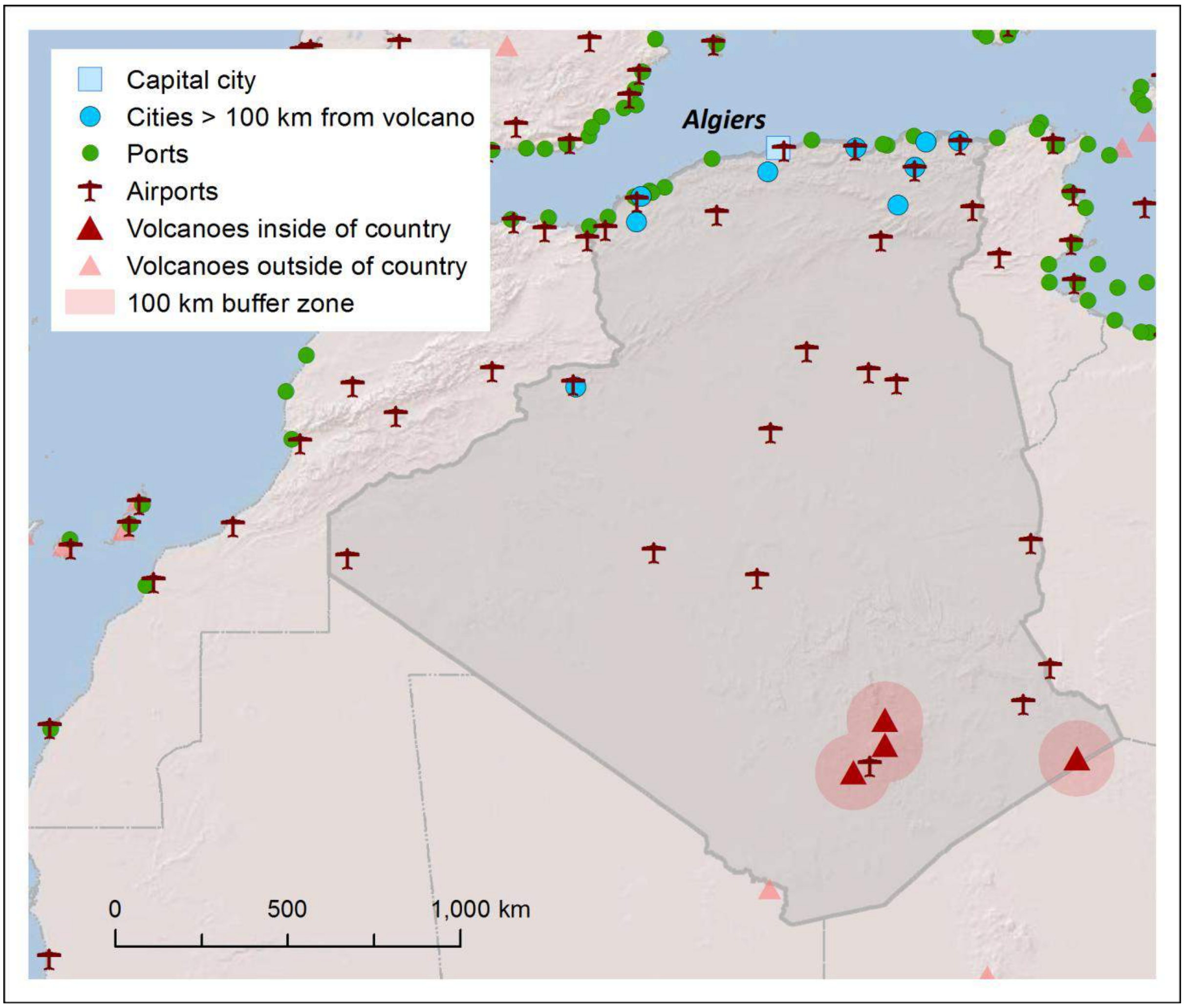

Figure 2.6 The location of Algeria's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.8 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 1900 AD, 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

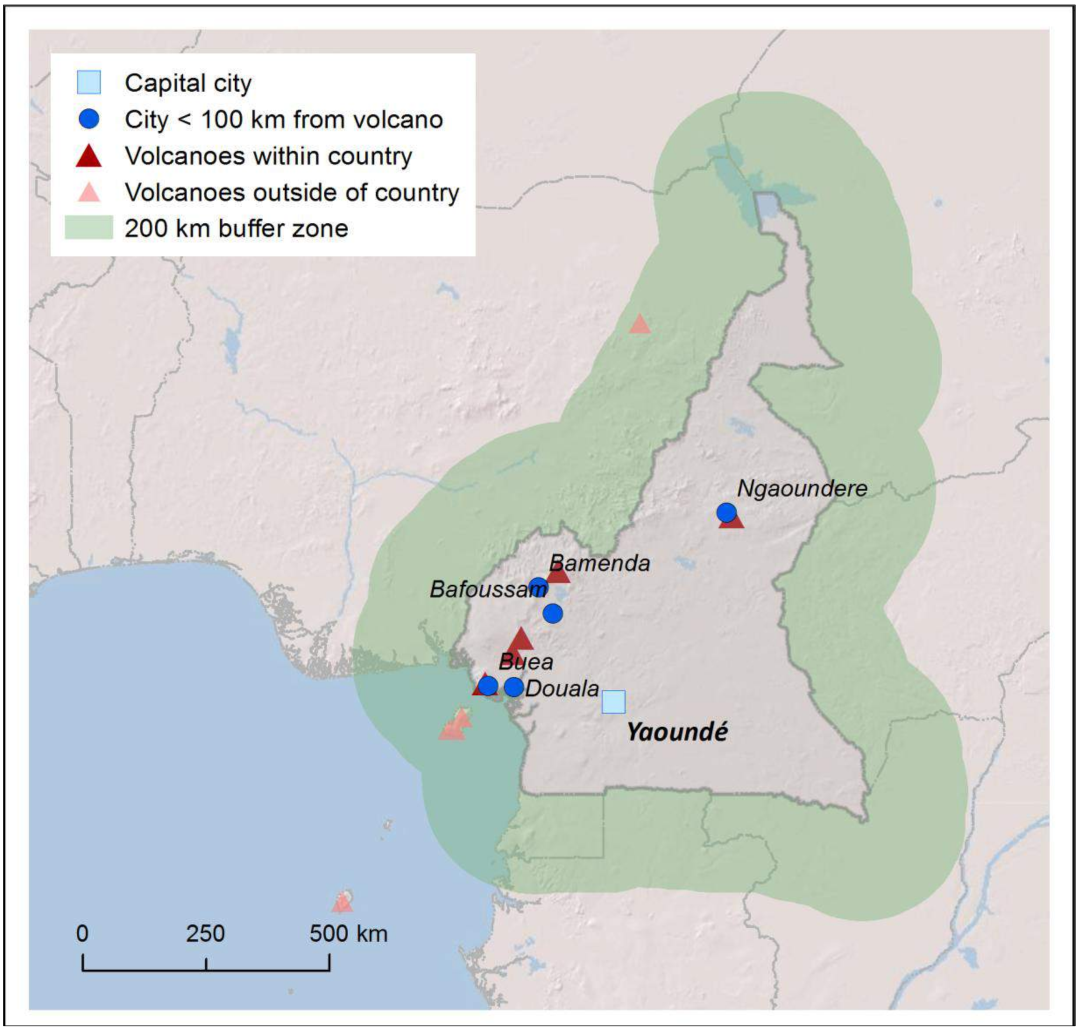

Figure 2.7 Location of Cameroon's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Cameroon.

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 2.9 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 their population size:

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 six airports and nearly 2,500 km of roads. With Mt Cameroon and Tobel Graben located near the coast, five ports are situated within 100 km distance.

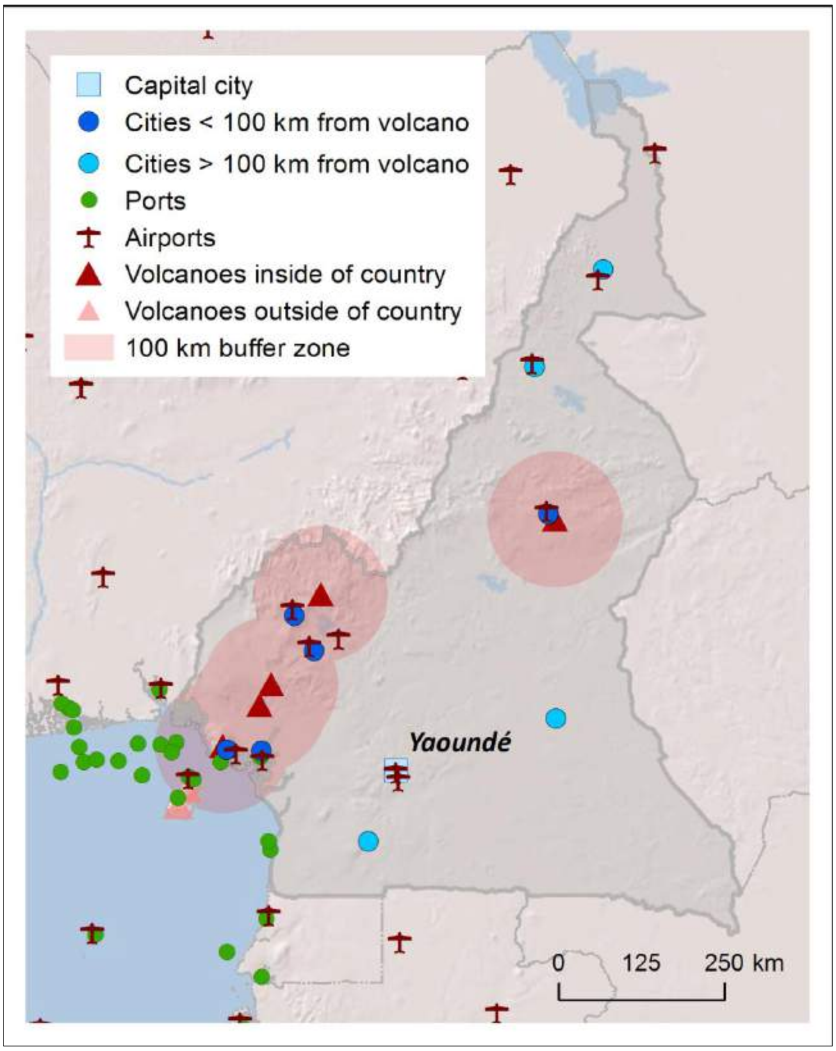

Figure 2.8 The location of Cameroon's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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.

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

*Table 2.10 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 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Cameroon	5	II

Table 2.11 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.

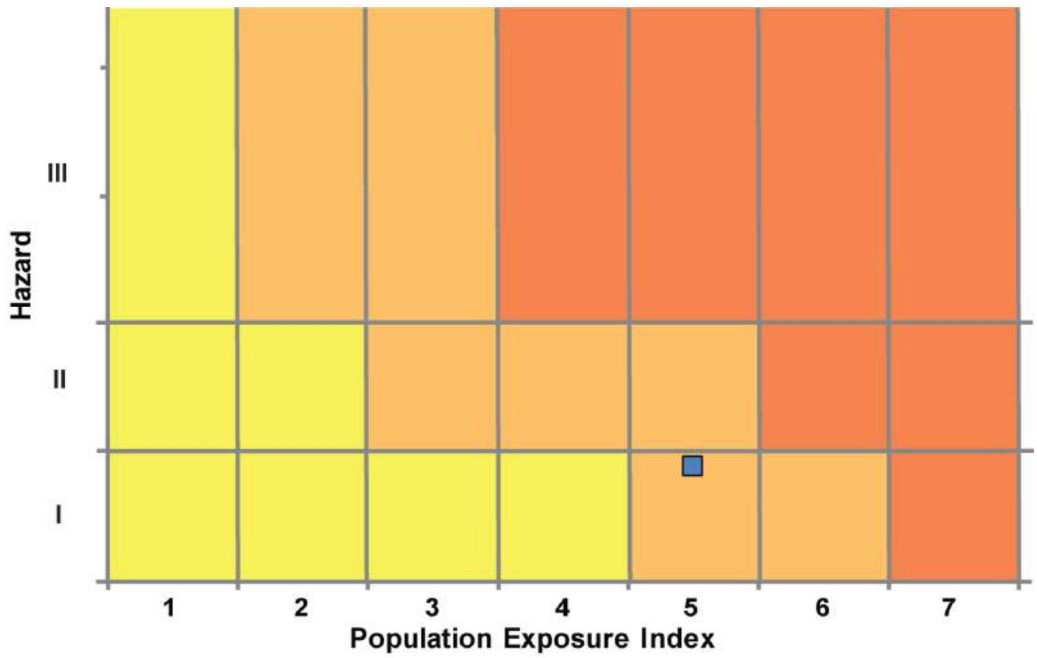

Figure 2.9 Distribution of Cameroon's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Just one volcano, the Risk Level II 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.

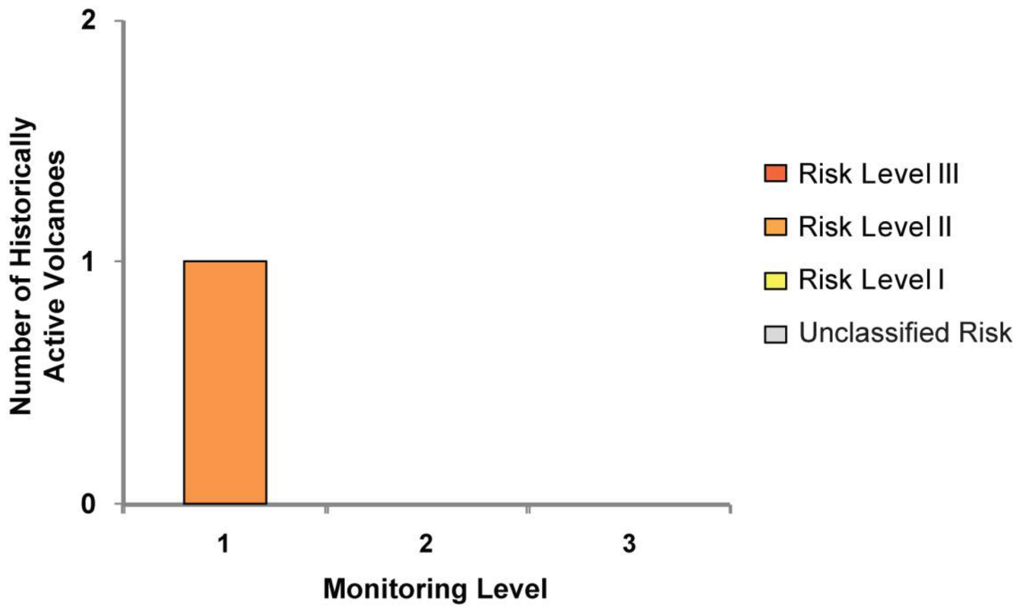

Figure 2.10 The monitoring and risk levels of the historically active volcanoes in Cameroon. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Chad

Description

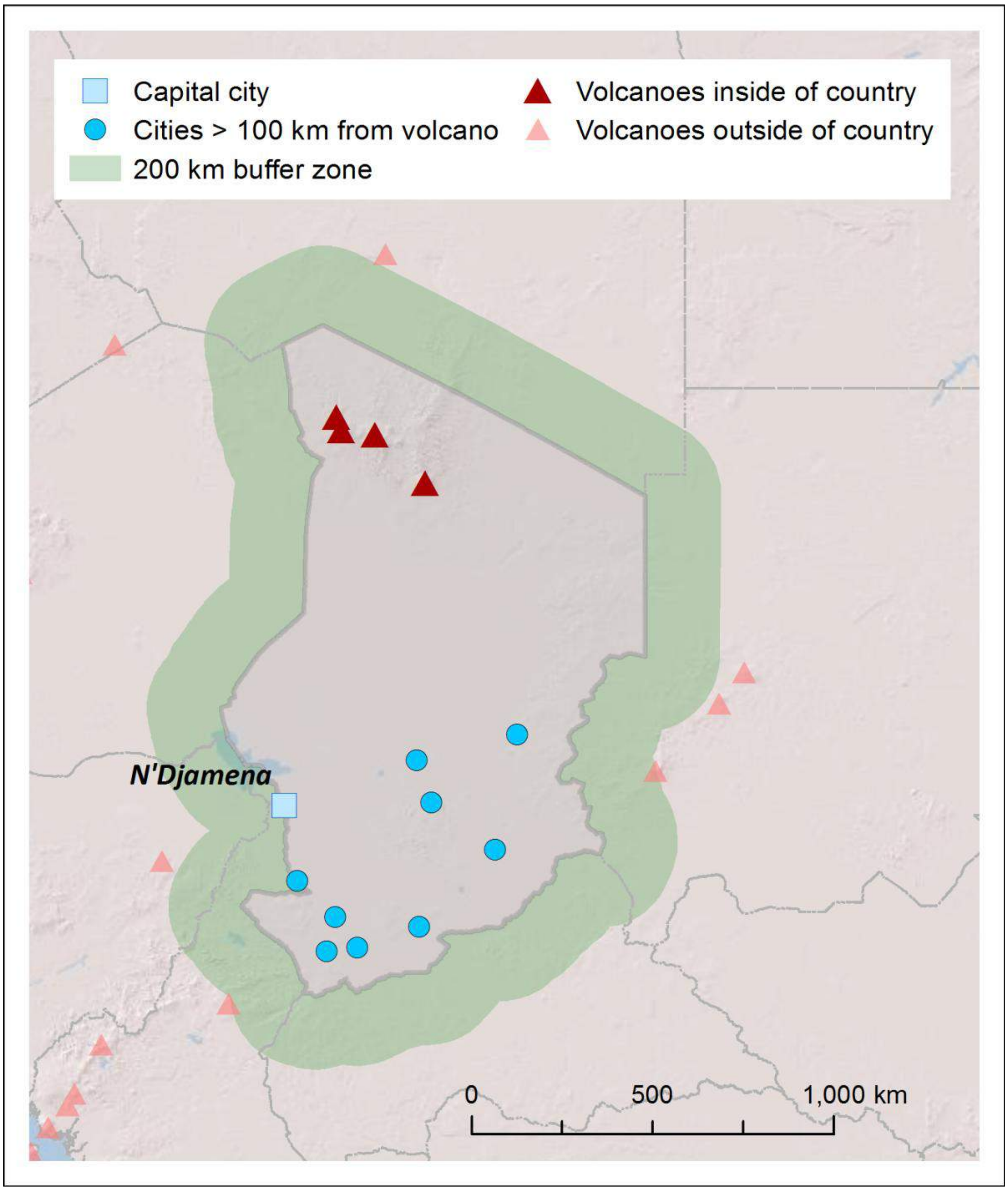

Figure 2.11 Location of Chad's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Chad.

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 2.12 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 their population size:

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.

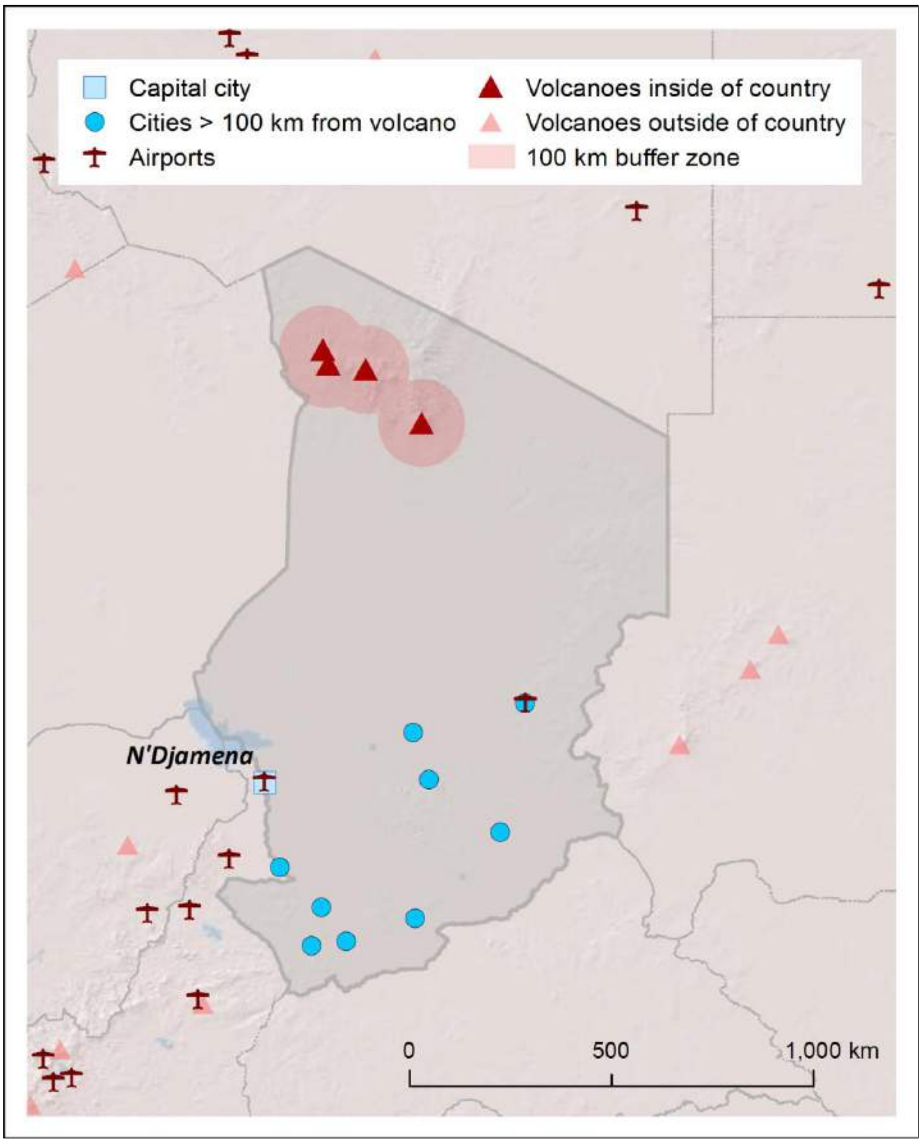

Figure 2.12 The location of Chad's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.13 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 1900 AD, 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.

Democratic Republic of Congo

Description

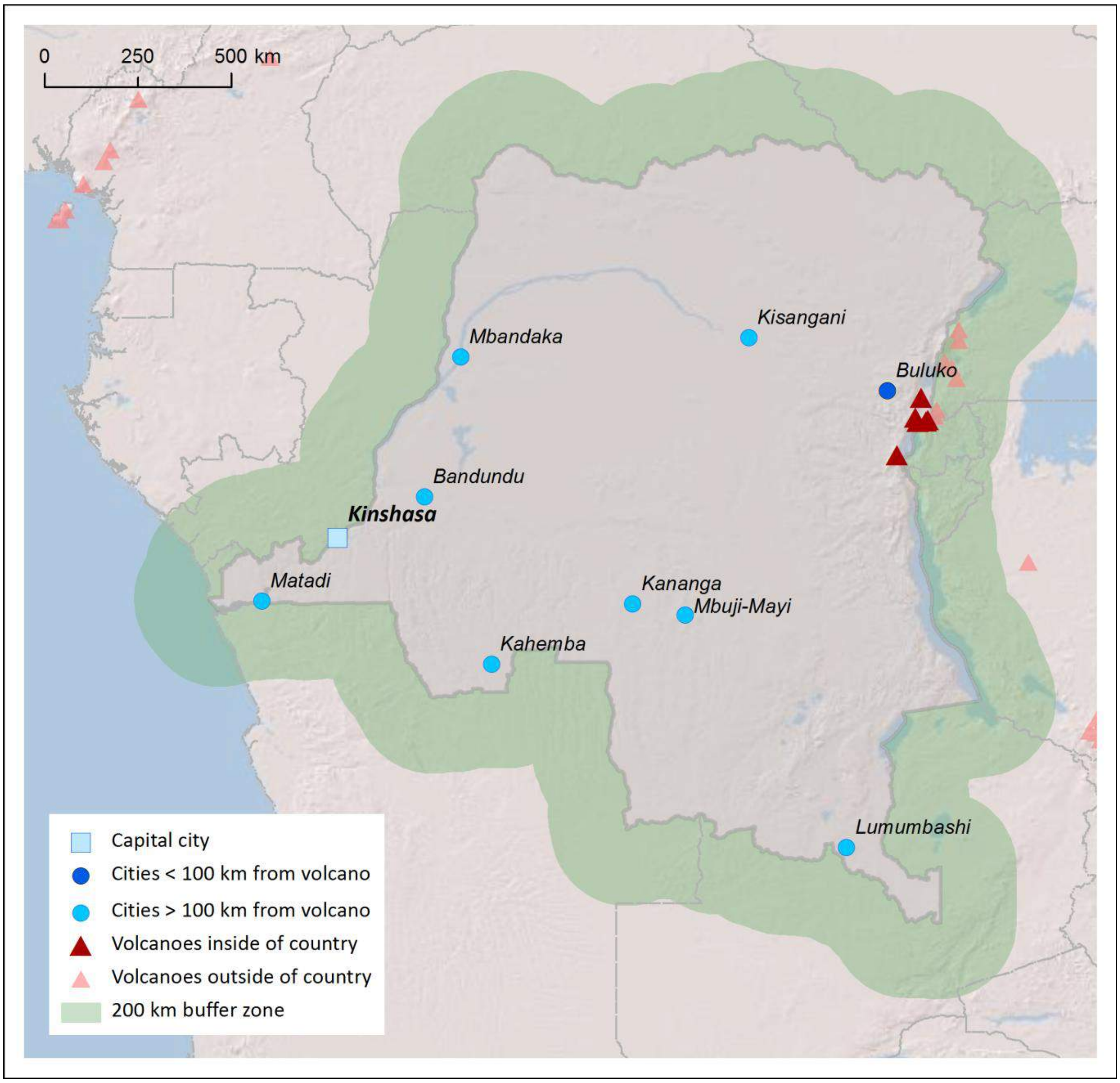

Figure 2.13 Location of the volcanoes of the Democratic Republic of Congo, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the DRC.

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 2.14 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 their population size:

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.

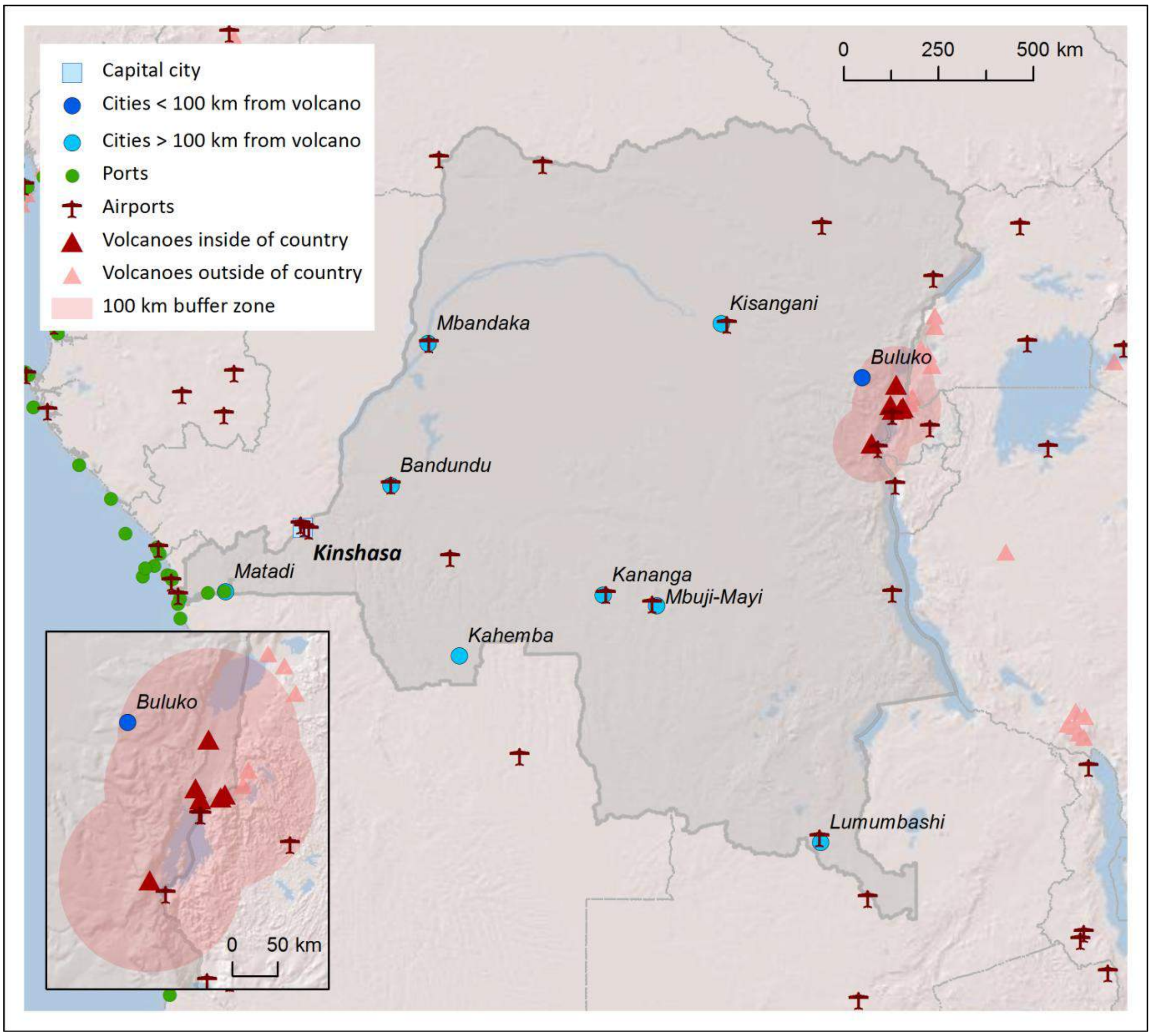

Figure 2.14 The location of the volcanoes of the Democratic Republic of Congo and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.15 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 1900 AD, 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 2.16 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.

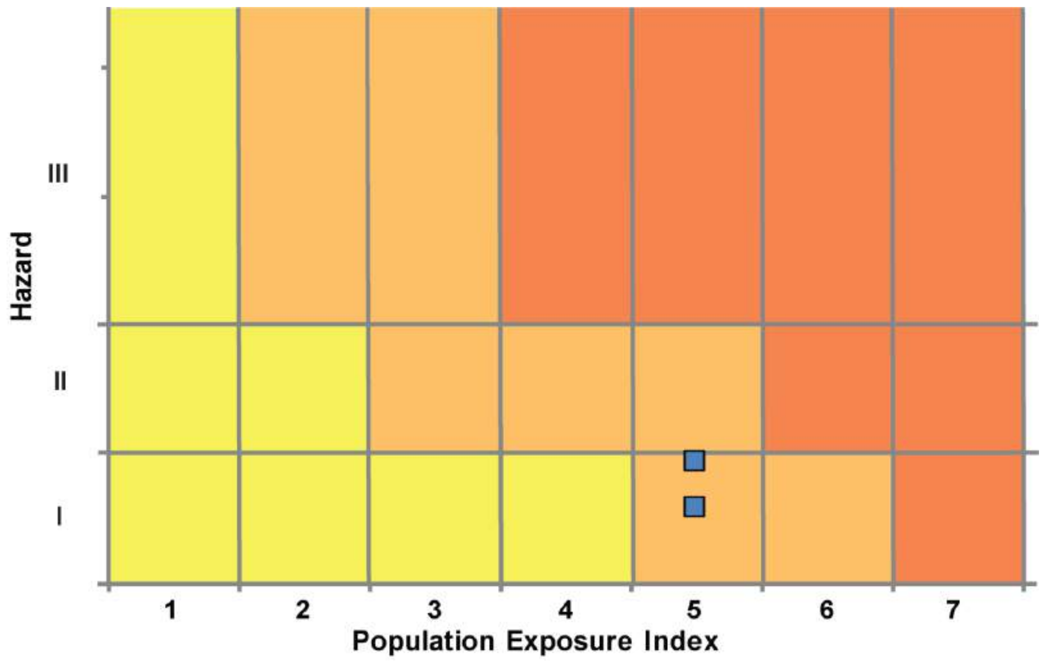

Figure 2.15 Distribution of the DRC's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

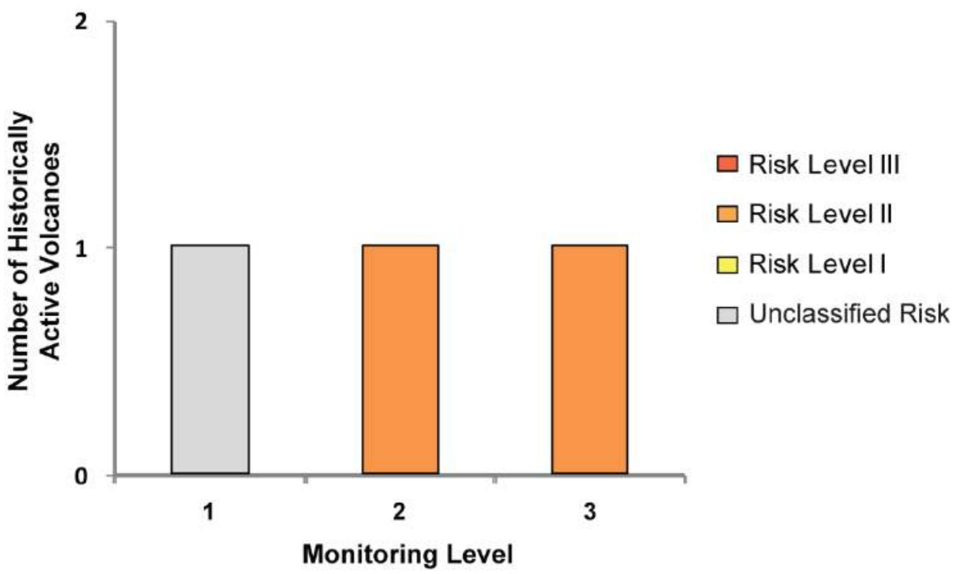

Figure 2.16 The monitoring and risk levels of the historically active volcanoes in the DRC. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Djibouti

Description

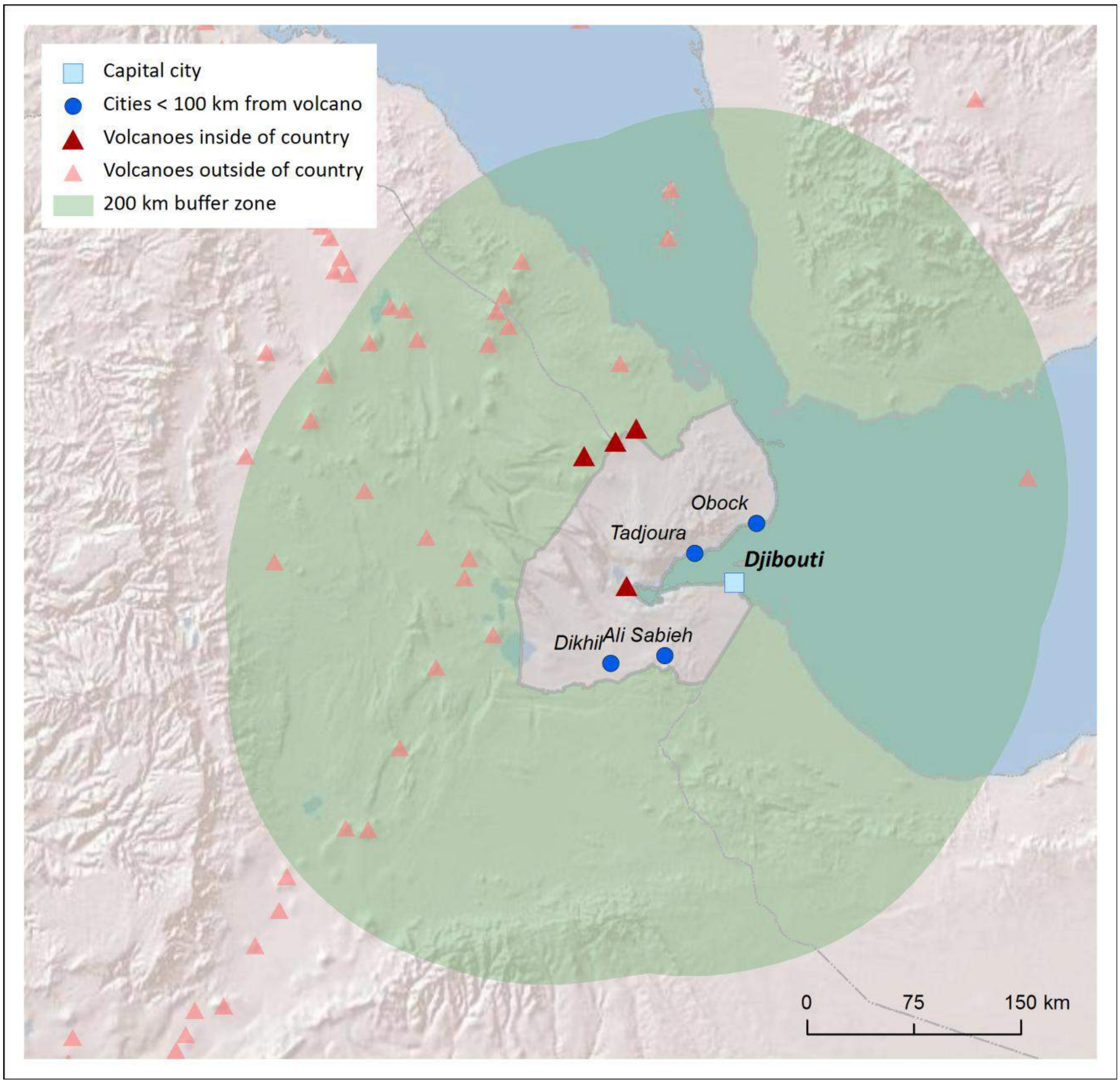

Figure 2.17 Location of Djibouti's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Djibouti.

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 2.17 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 their population size:

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

Infrastructure Exposure

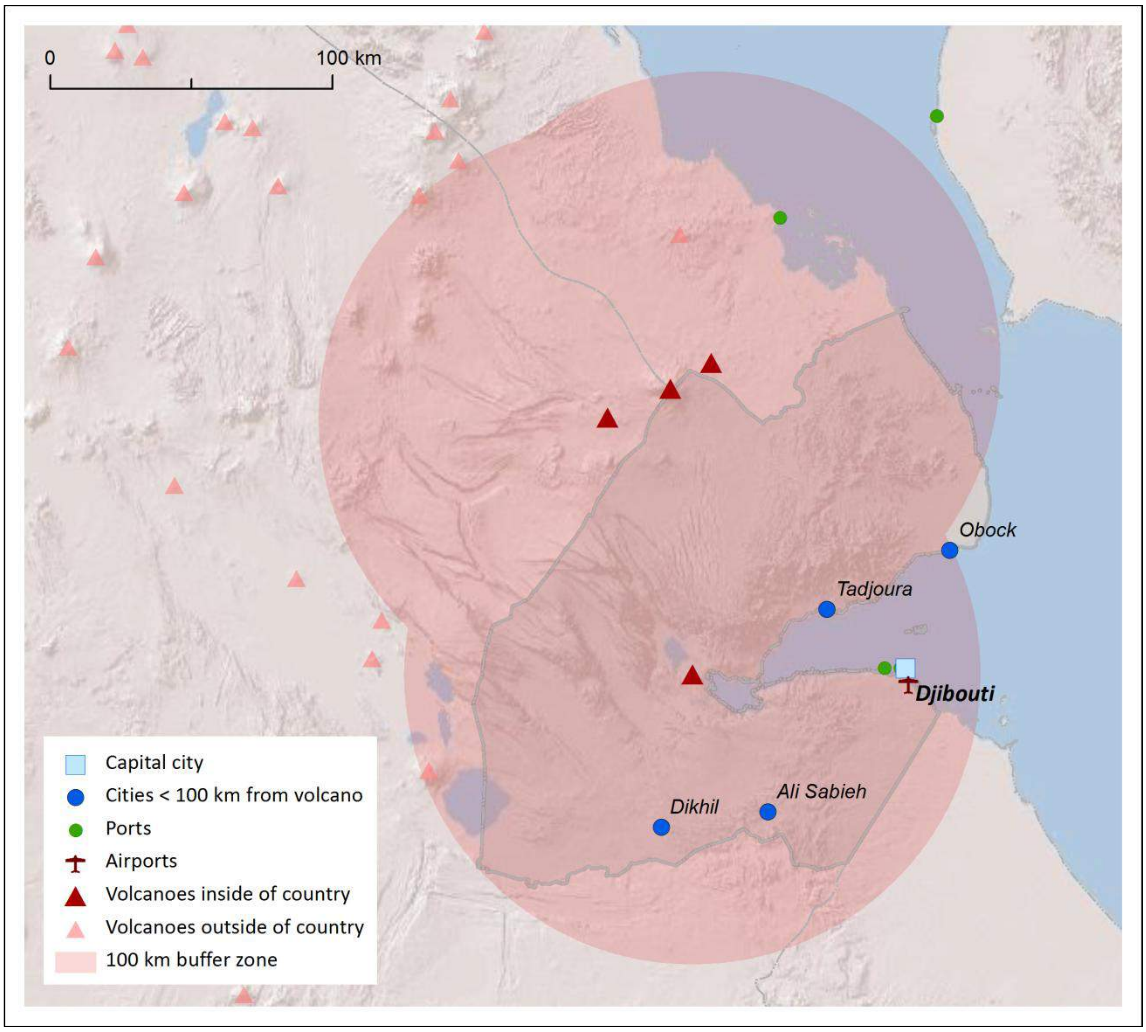

Figure 2.18 The location of Djibouti's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.18 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 1900 AD, 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.

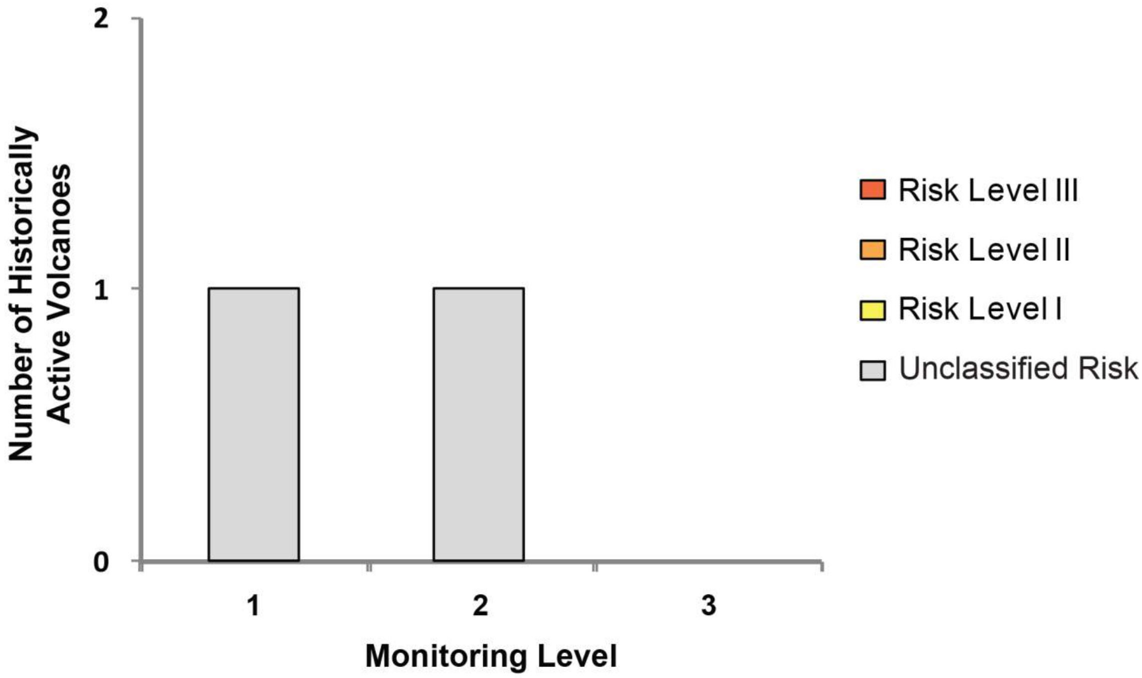

Figure 2.19 The monitoring and risk levels of the historically active volcanoes in Djibouti. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Equatorial Guinea

Description

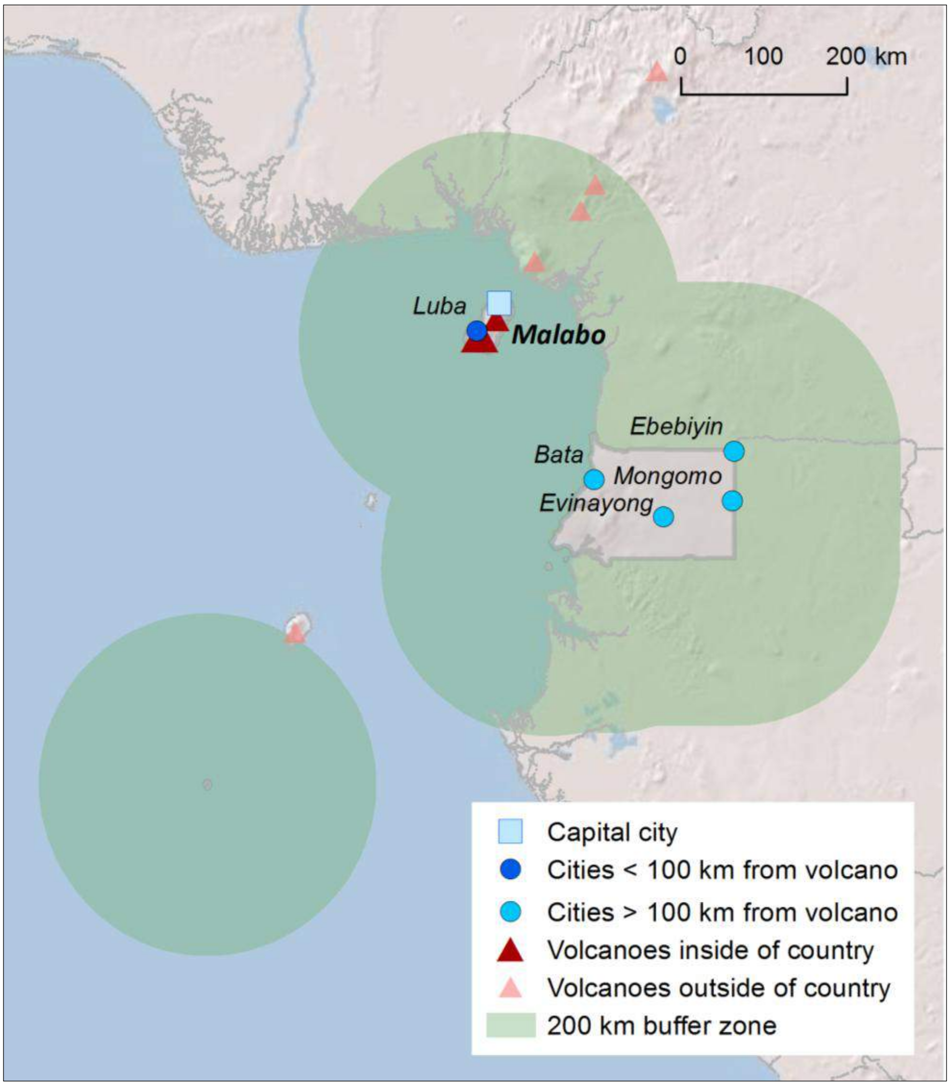

Figure 2.20 Location of Equatorial Guinea's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Equatorial Guinea.

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 2.19 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 their population size:

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

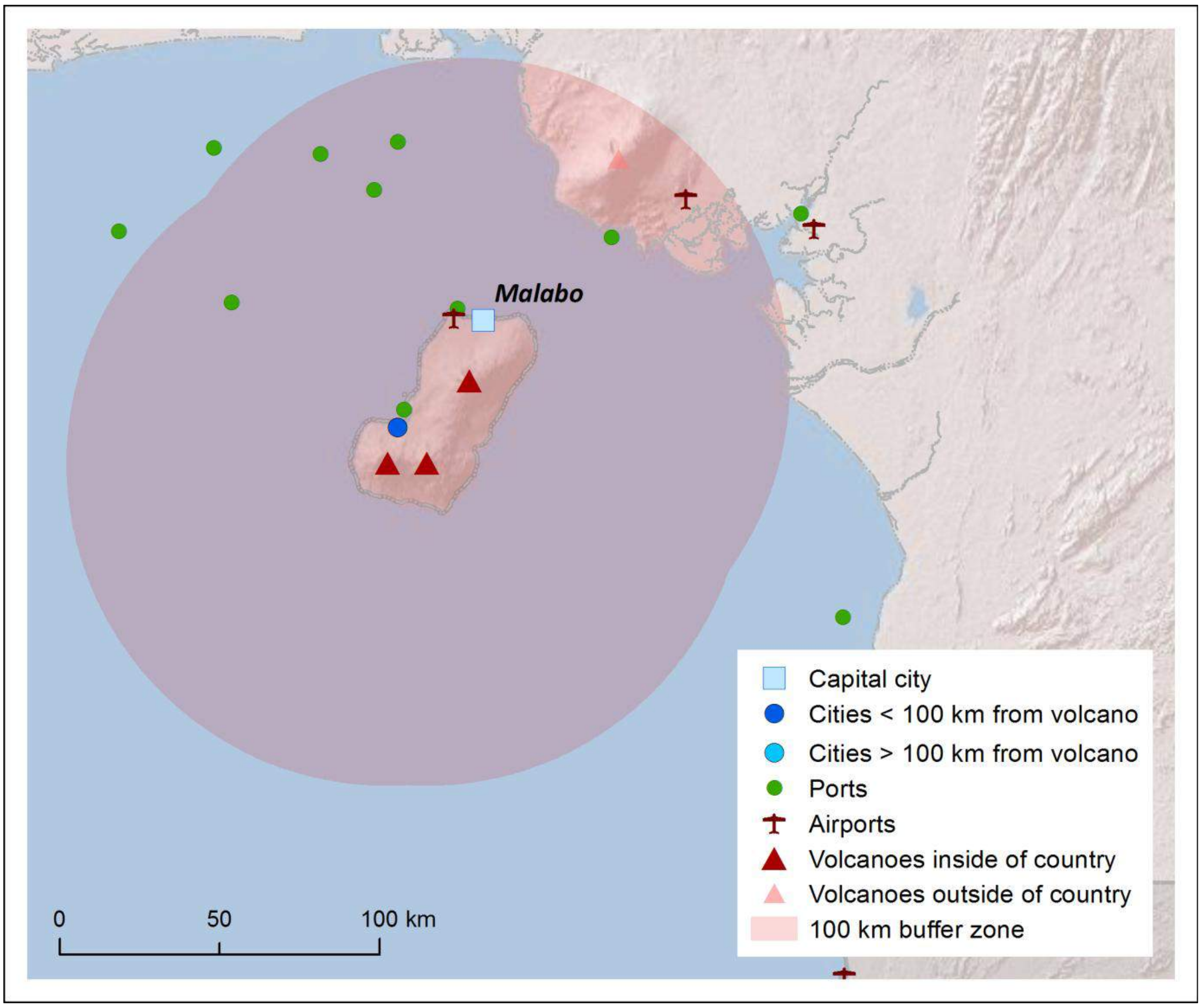

Figure 2.21 The location of Equatorial Guinea's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.20 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 1900 AD, 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.

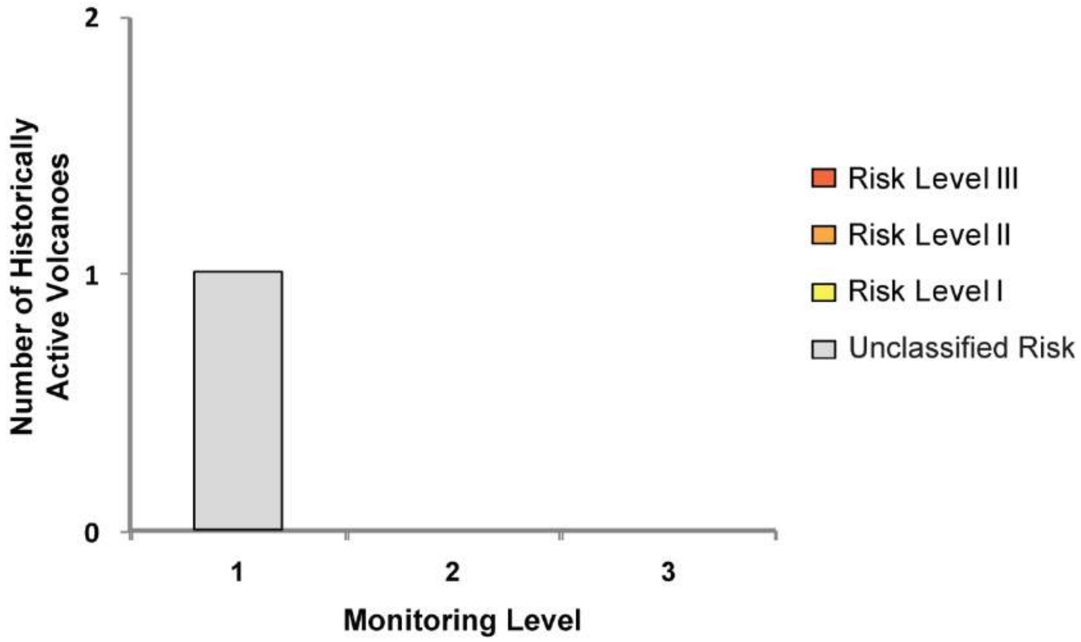

Figure 2.22 The monitoring and risk levels of the historically active volcanoes in Equatorial Guinea. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Eritrea

Description

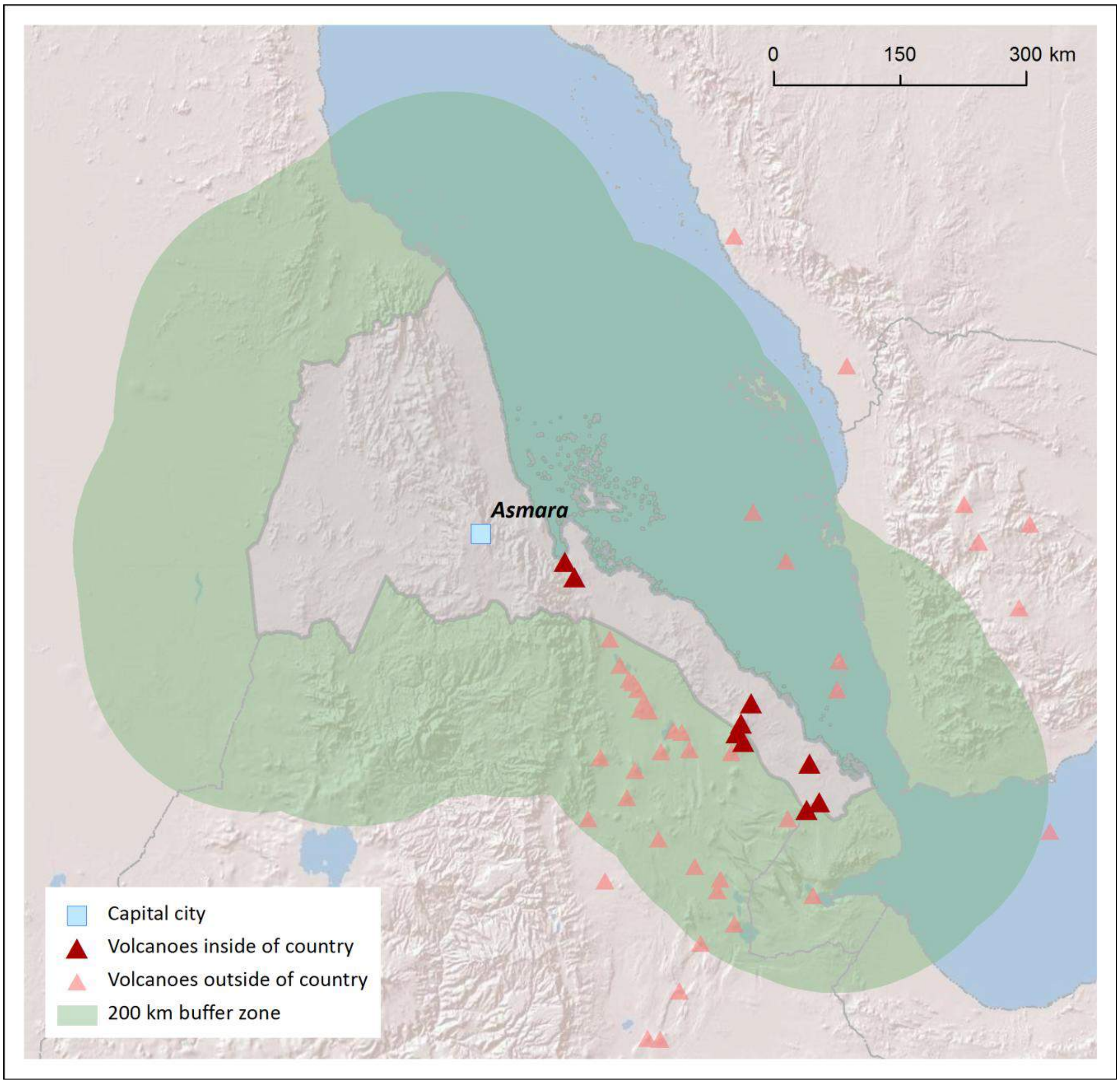

Figure 2.23 Location of Eritrea's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Eritrea.

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 2.22 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 their population size:

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

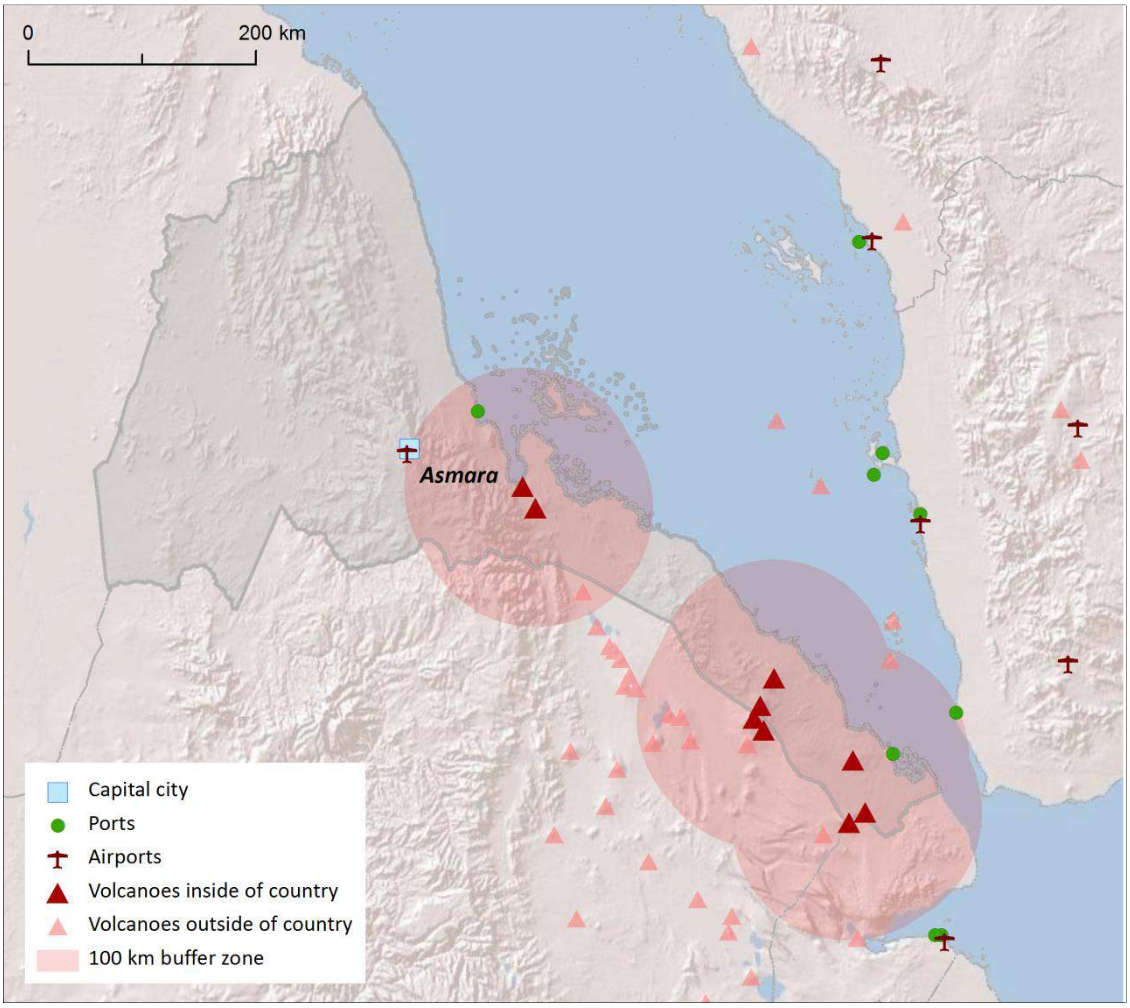

Figure 2.24 The location of Eritrea's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.23 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 1900 AD, 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.

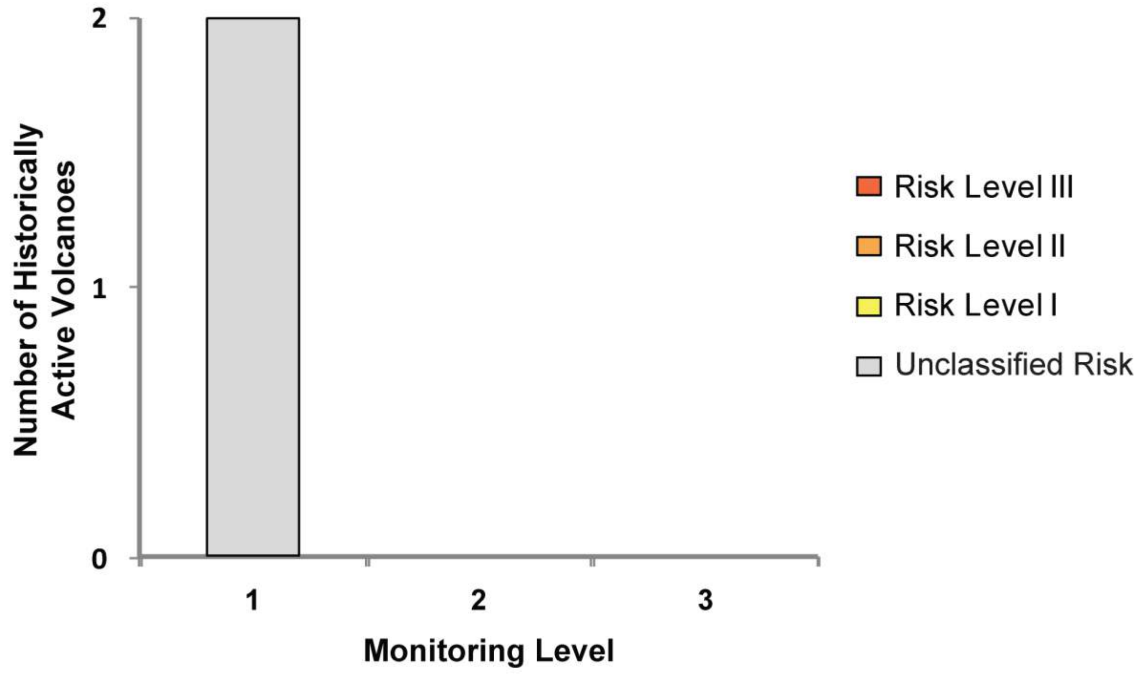

Figure 2.25 The monitoring and risk levels of the historically active volcanoes in Eritrea. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Ethiopia

Description

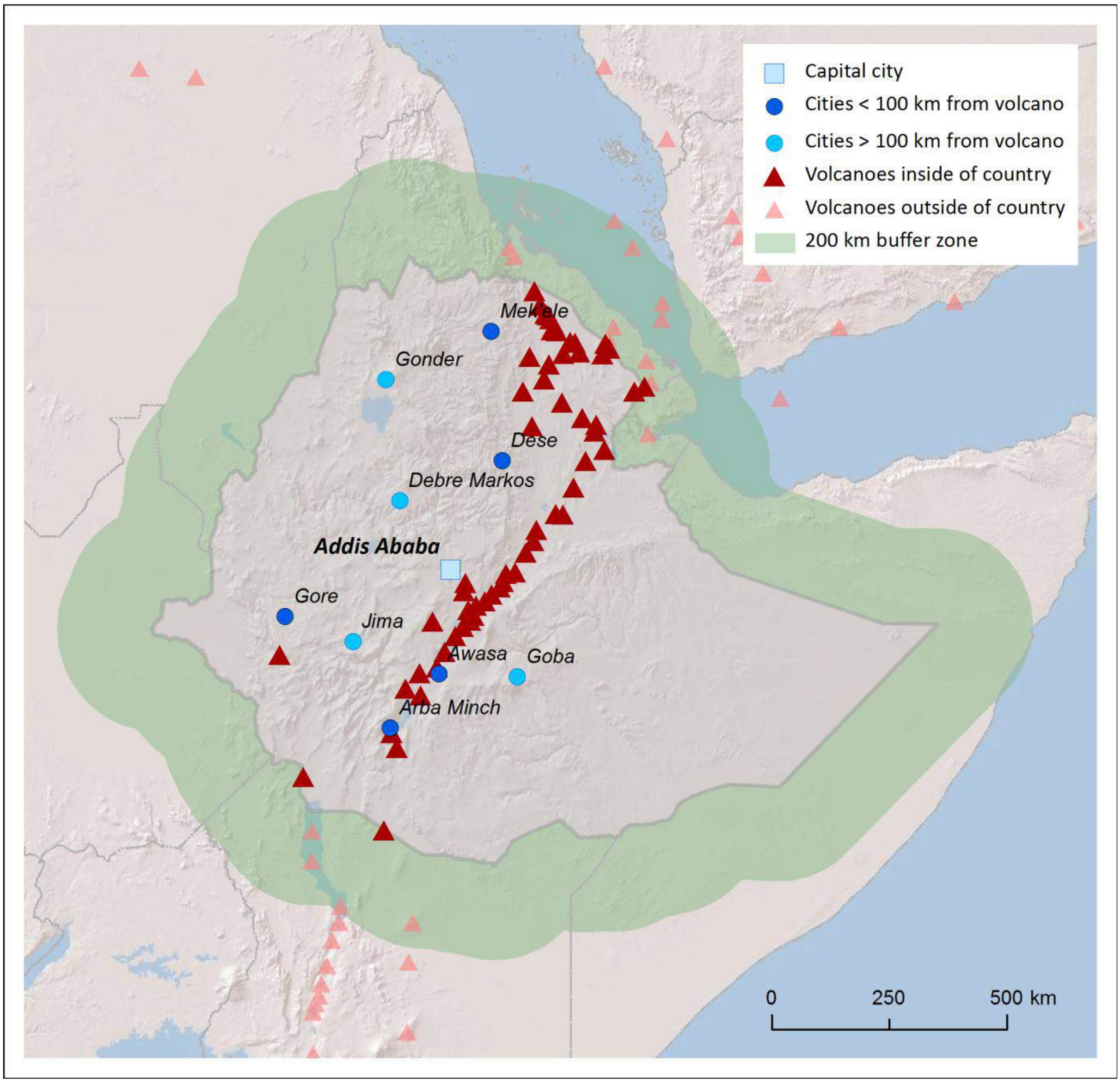

Figure 2.26 Location of Ethiopia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Ethiopia.

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 2.24 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 their population size (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.

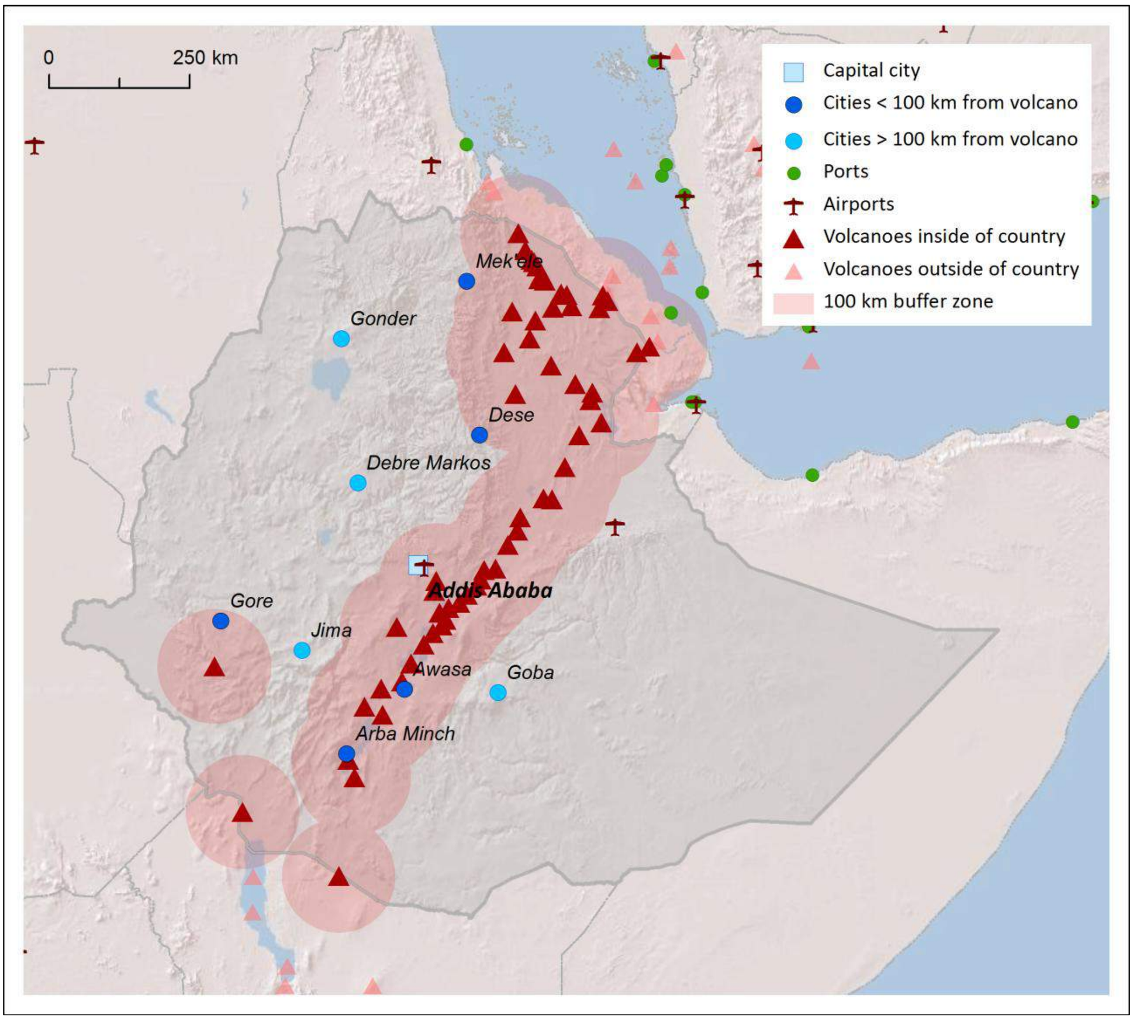

Figure 2.27 The location of Ethiopia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.25 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 1900 AD, 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 2.26 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.

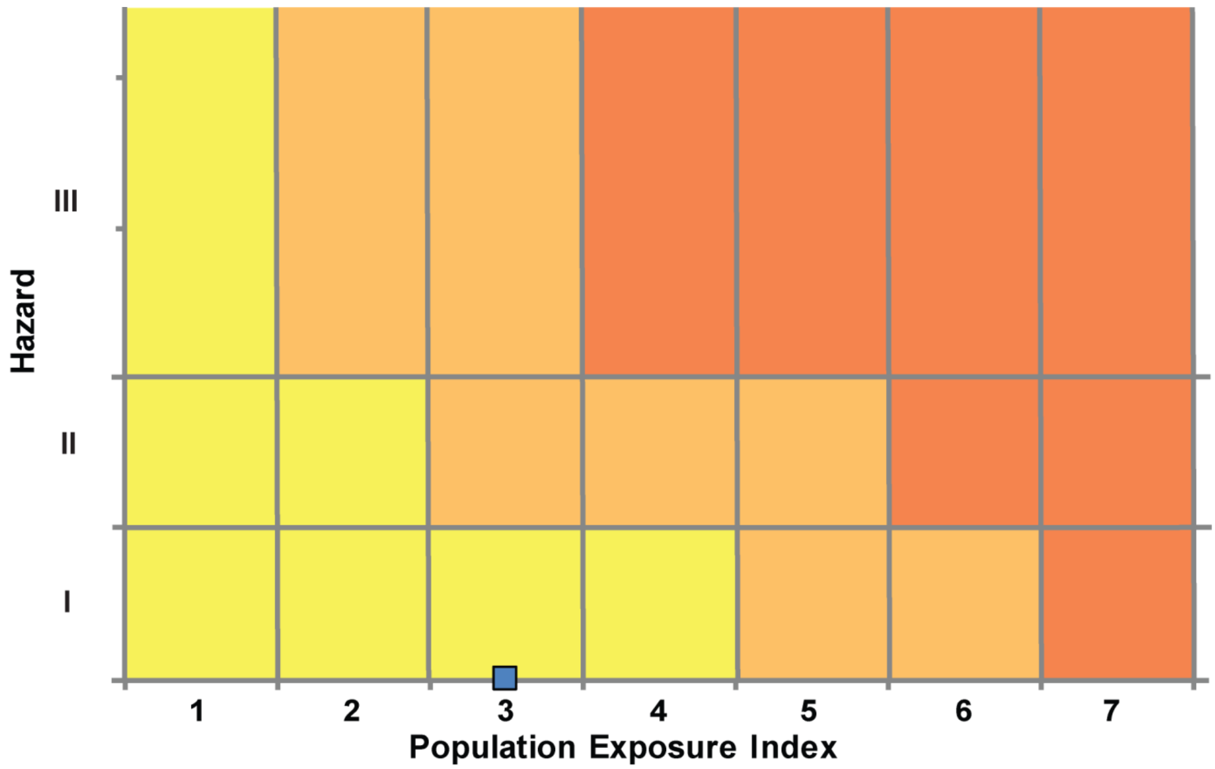

Figure 2.28 Distribution of Ethiopia's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

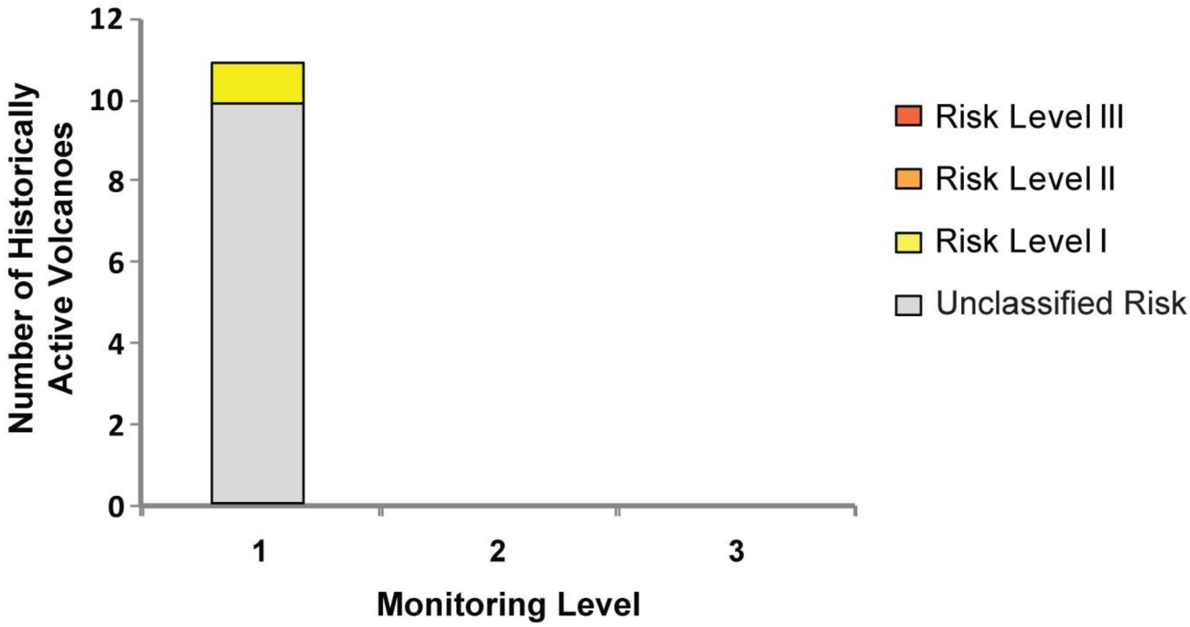

Figure 2.29 The monitoring and risk levels of the historically active volcanoes in Ethiopia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Kenya

Description

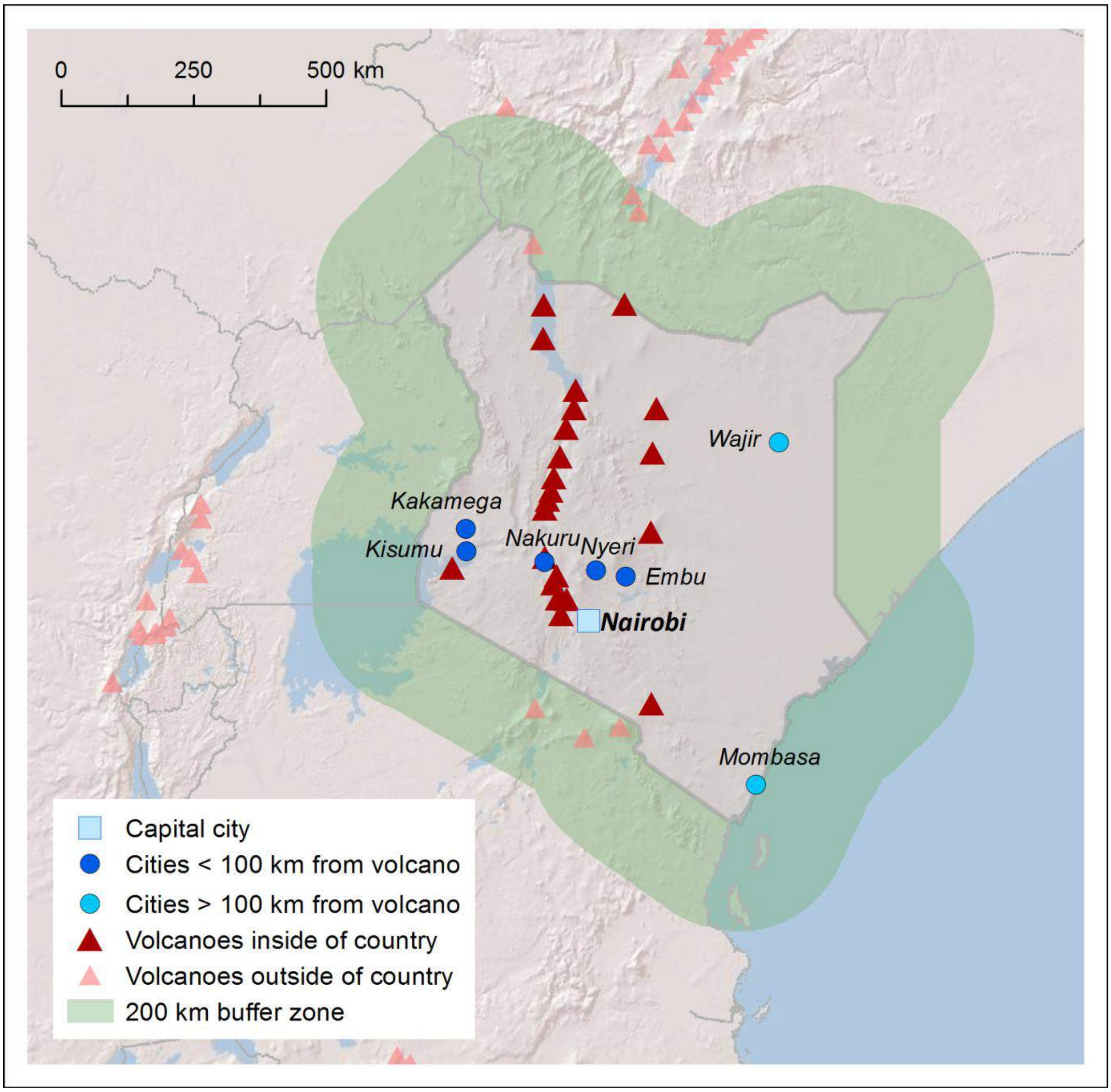

Figure 2.30 Location of Kenya's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Kenya.

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 known 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 2.27 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 their population size:

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.

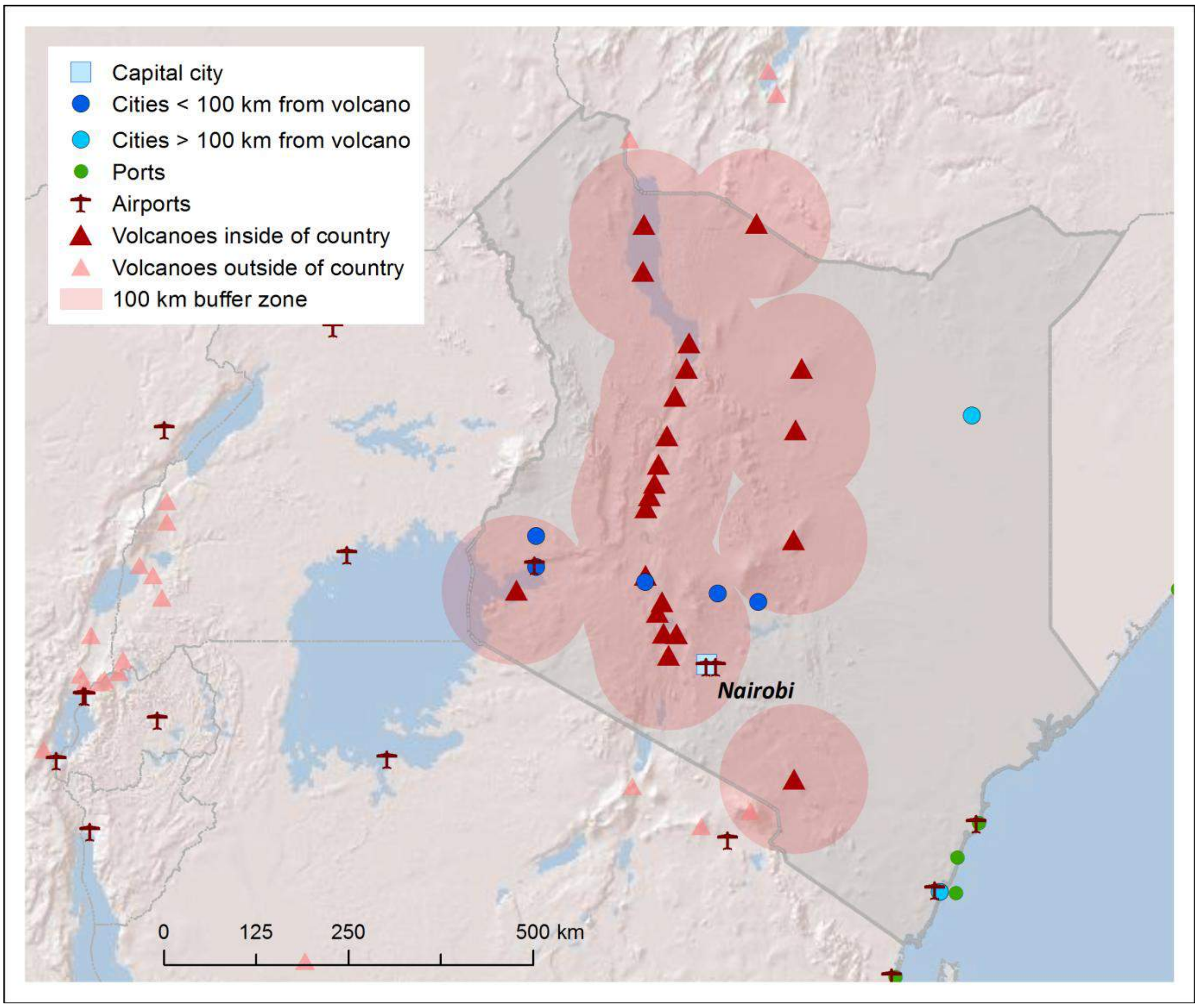

Figure 2.31 The location of Kenya's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.28 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 1900 AD, 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 2.29 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.

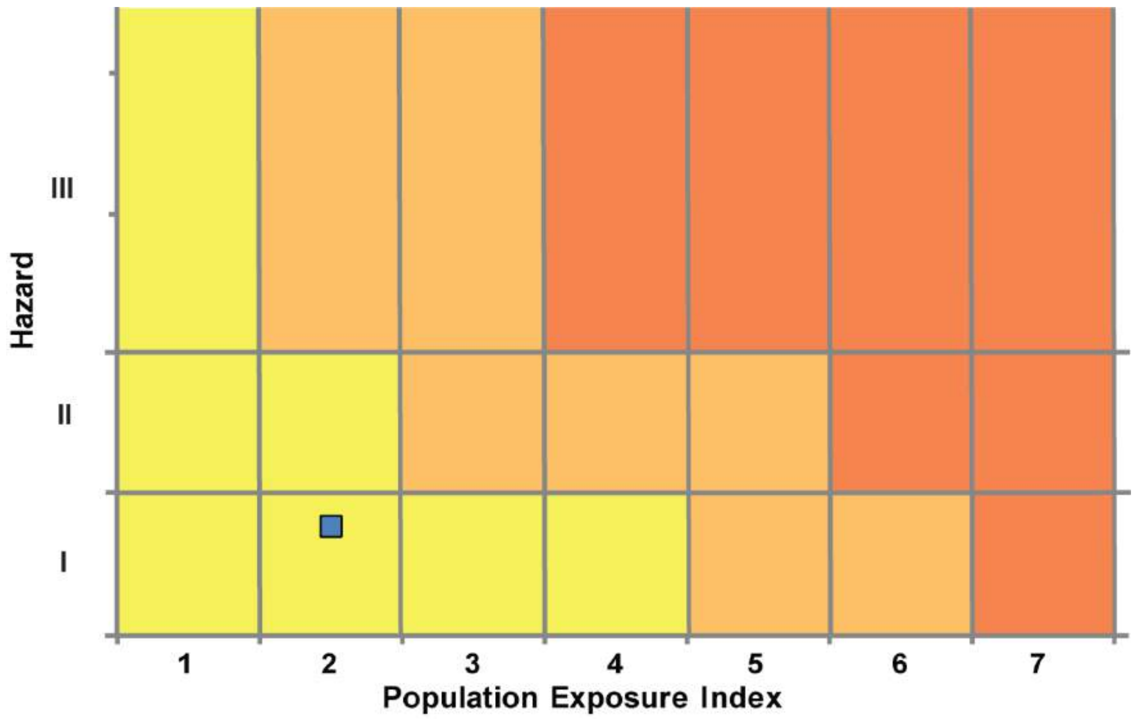

Figure 2.32 Distribution of Kenya's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

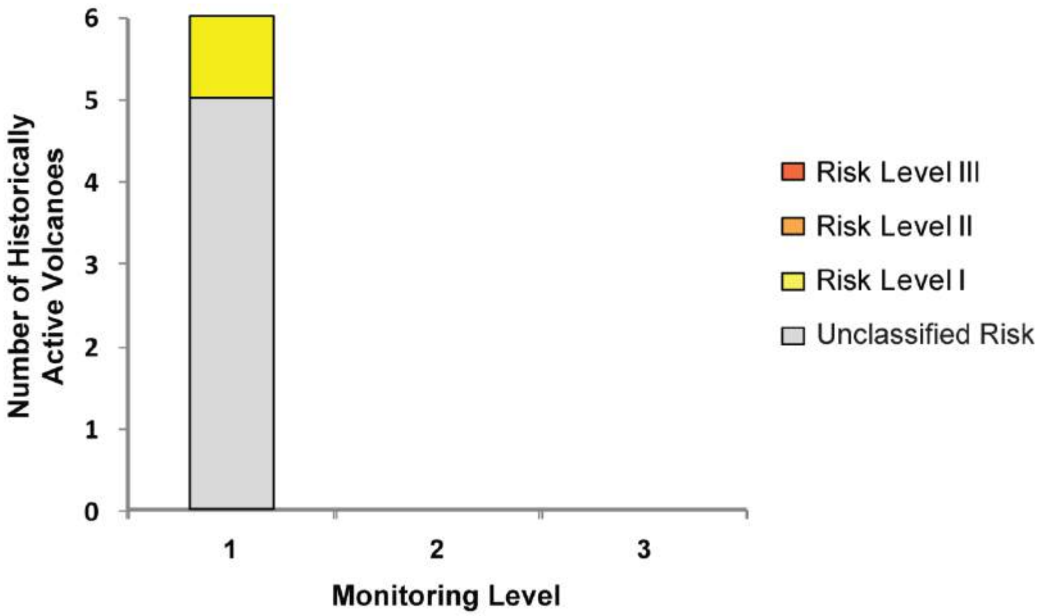

Figure 2.33 The monitoring and risk levels of the historically active volcanoes in Kenya. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Libya

Description

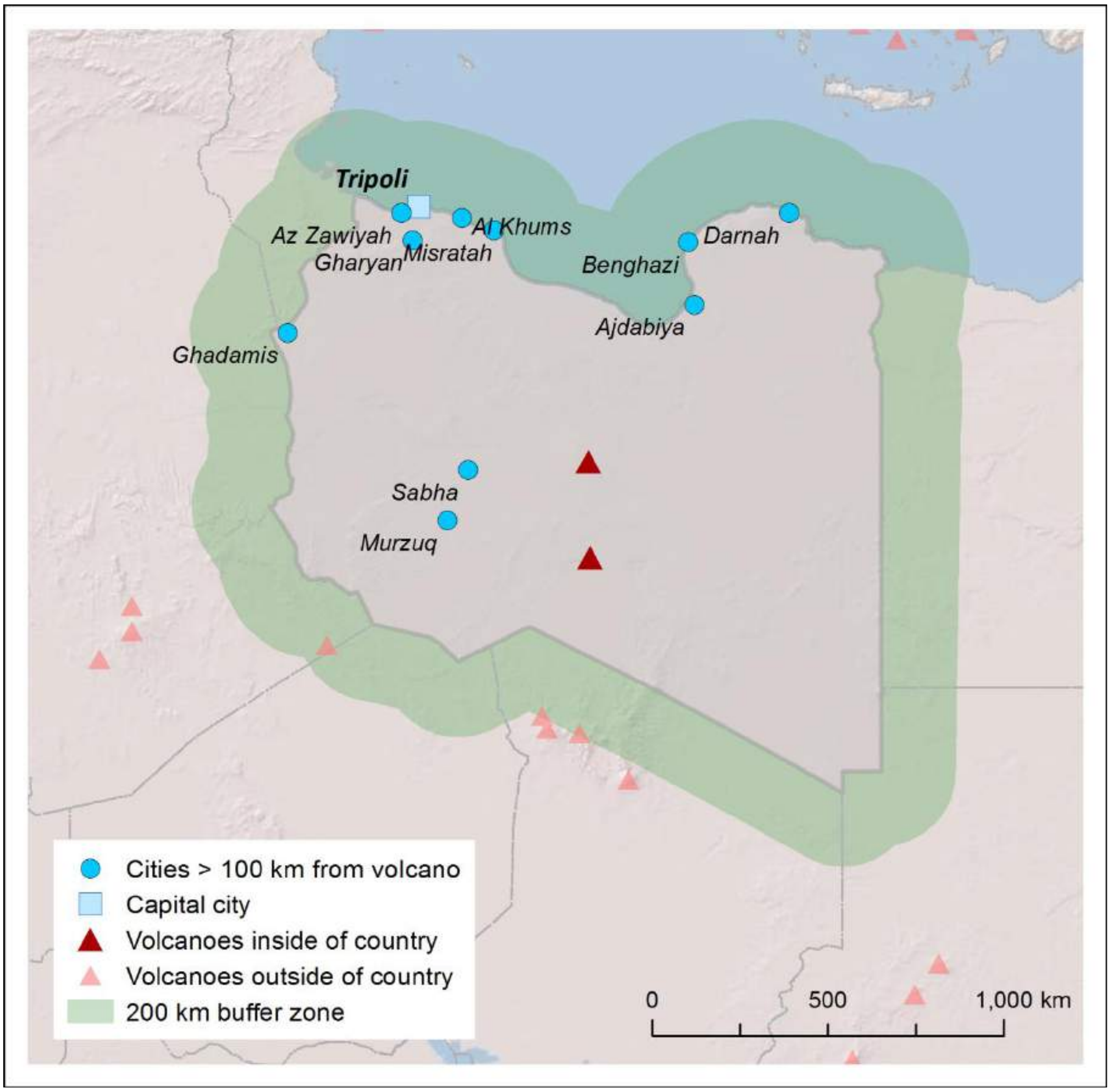

Figure 2.34 Location of Libya's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Libya.

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 2.30 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 their population size:

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.

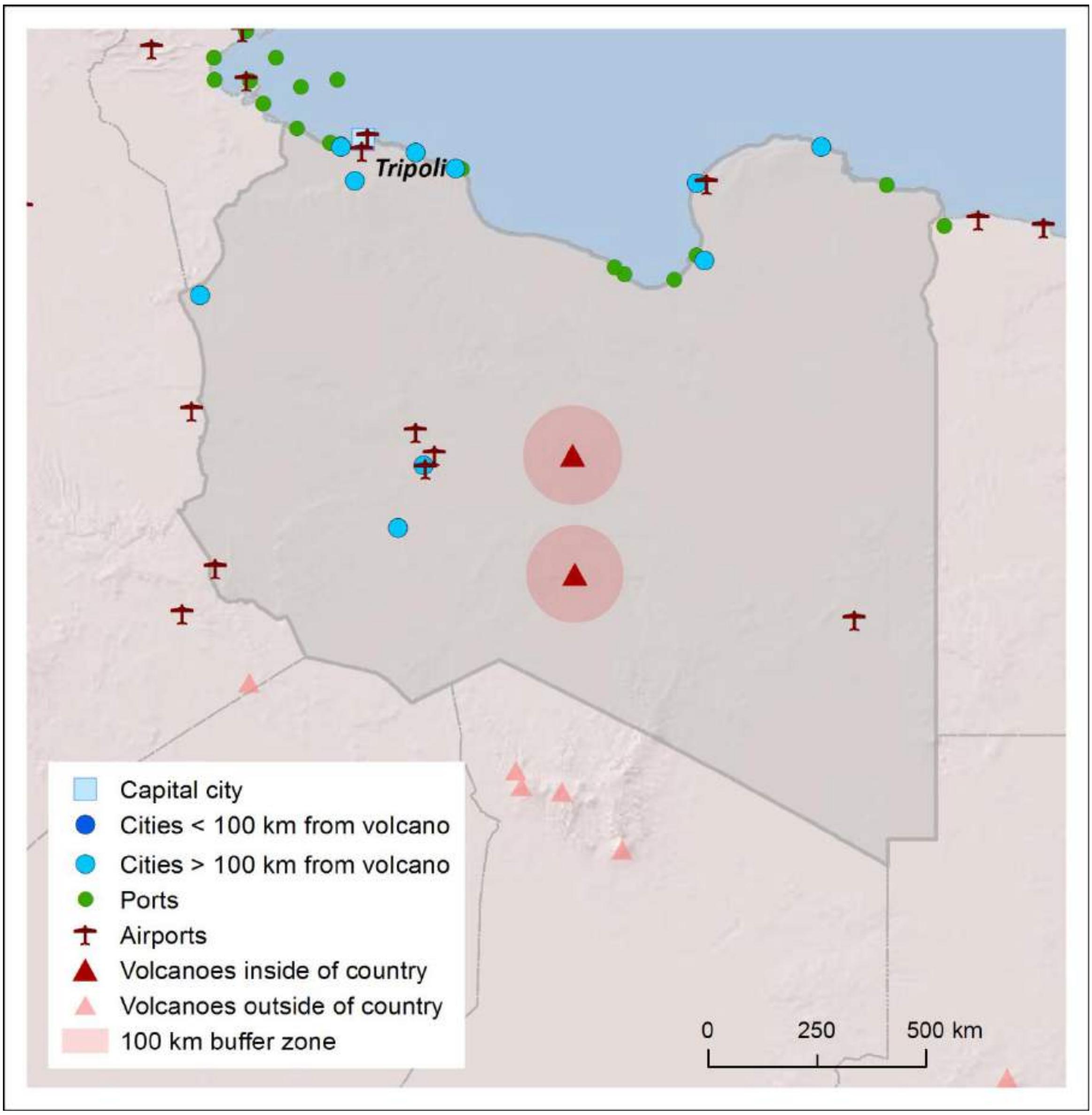

Figure 2.35 The location of Libya's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.31 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 1900 AD, 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 100 km radius of this volcano extends beyond the borders into Algeria.

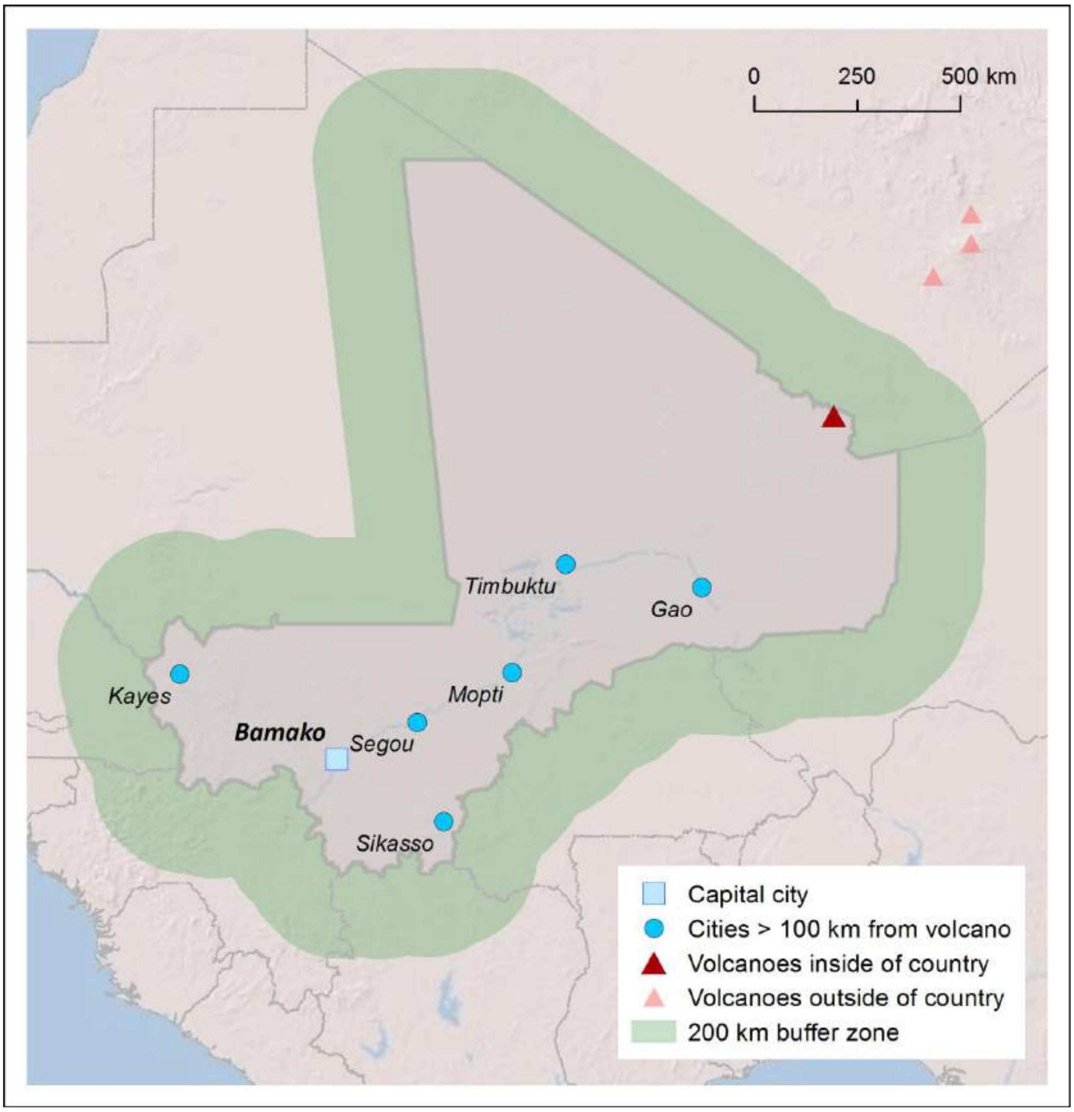

Figure 2.36 Location of Mali's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Mali.

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 2.322 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 their population size:

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

Infrastructure Exposure

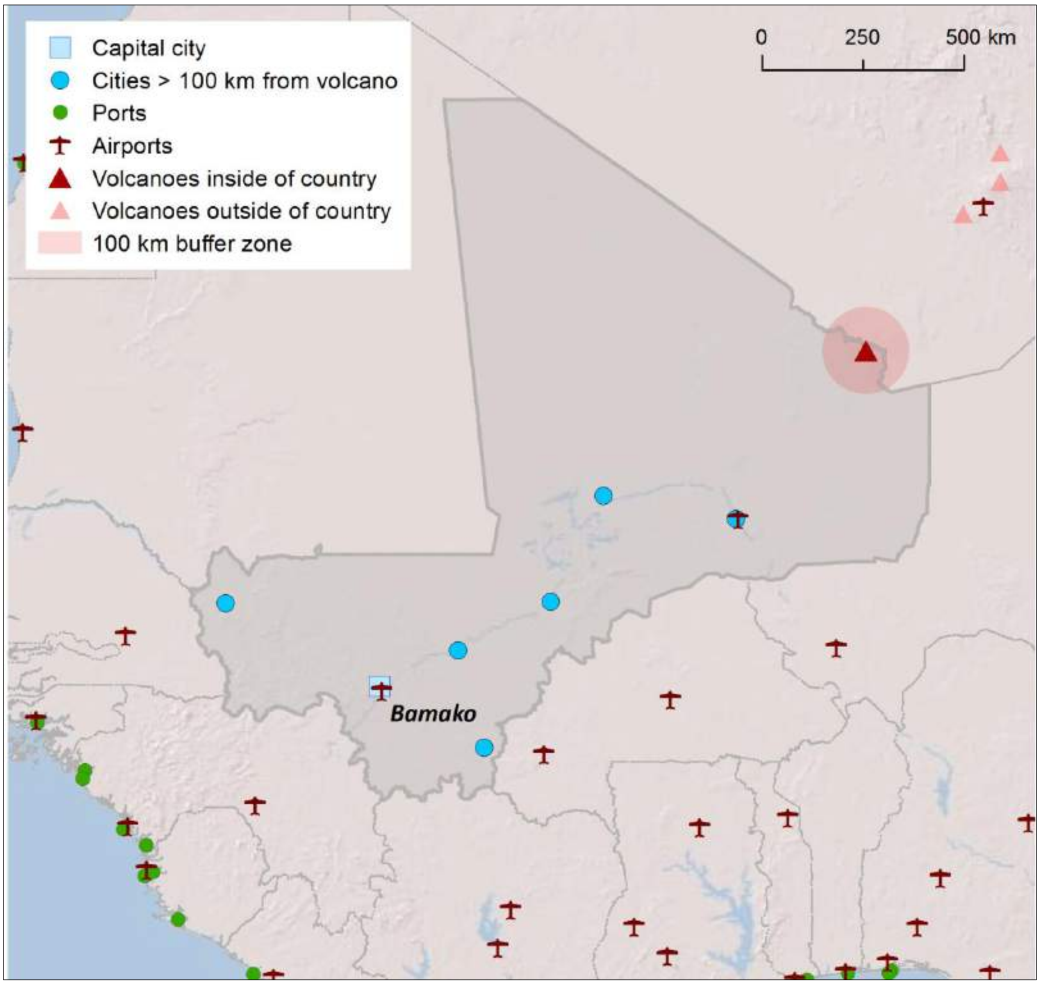

Figure 2.37 The location of Mali's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.33 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 1900 AD, 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.

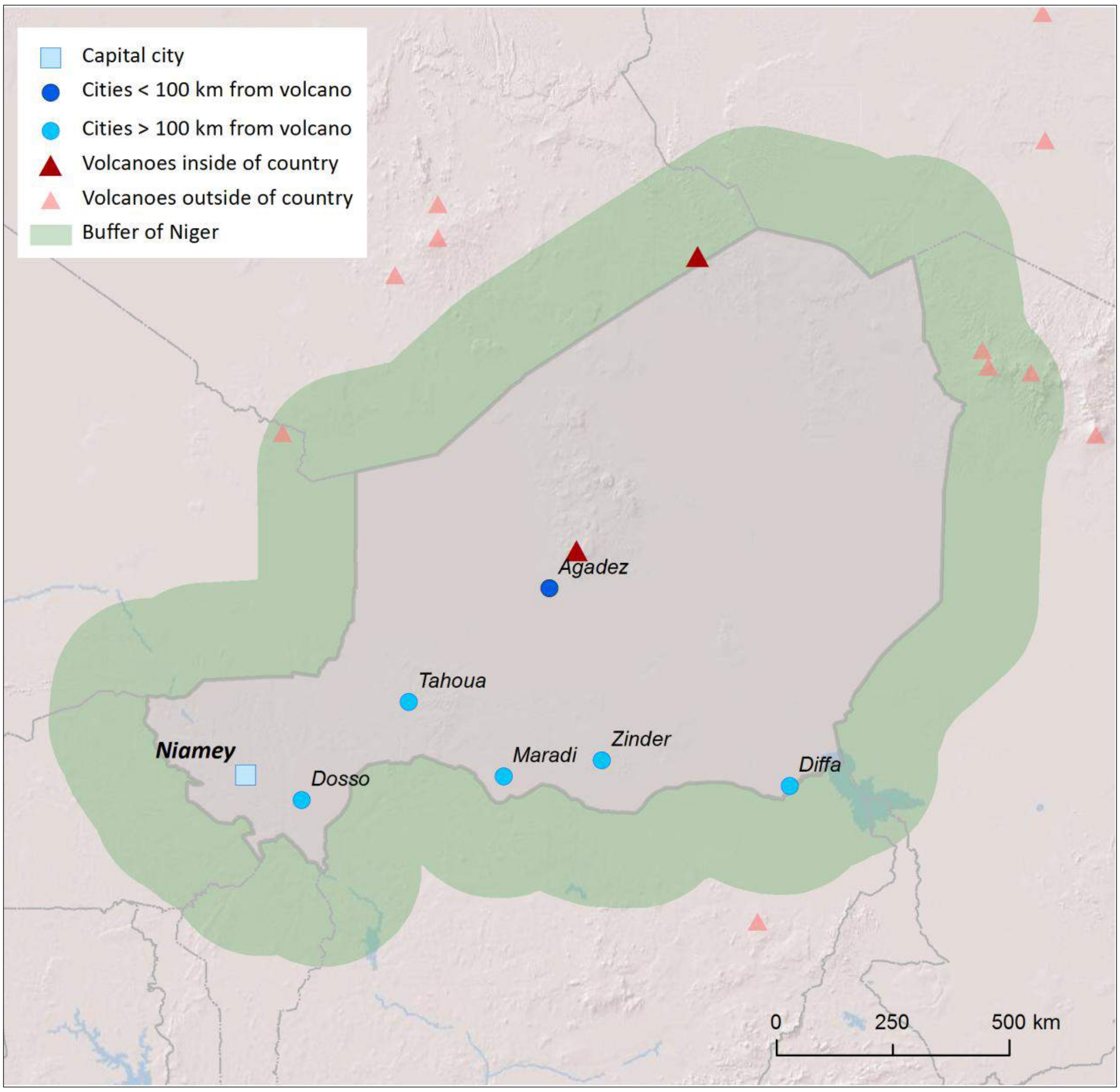

Figure 2.38 Location of Niger's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Niger.

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 2.34 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 their population size:

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.

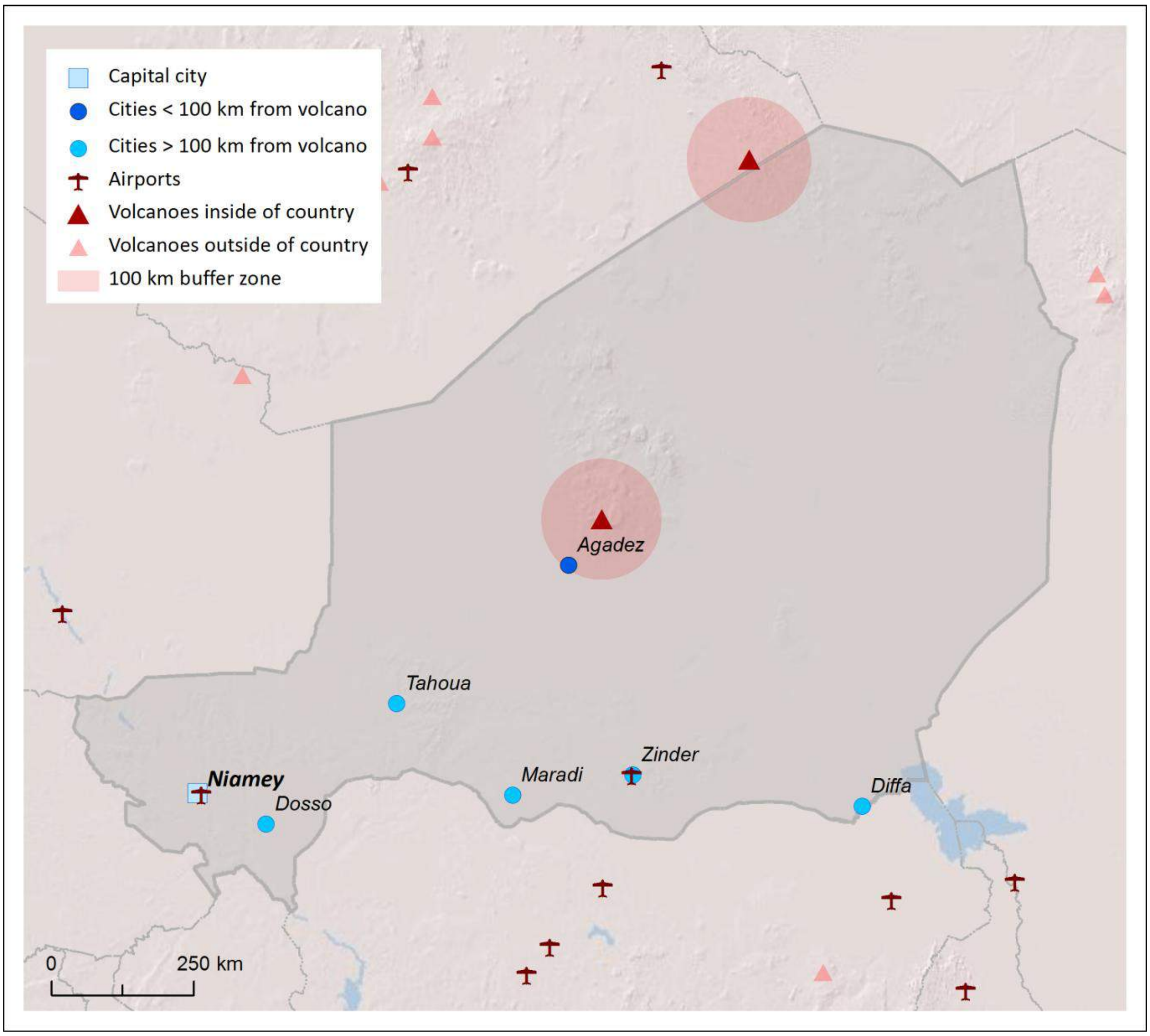

Figure 2.39 The location of Niger's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.35 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 1900 AD, 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

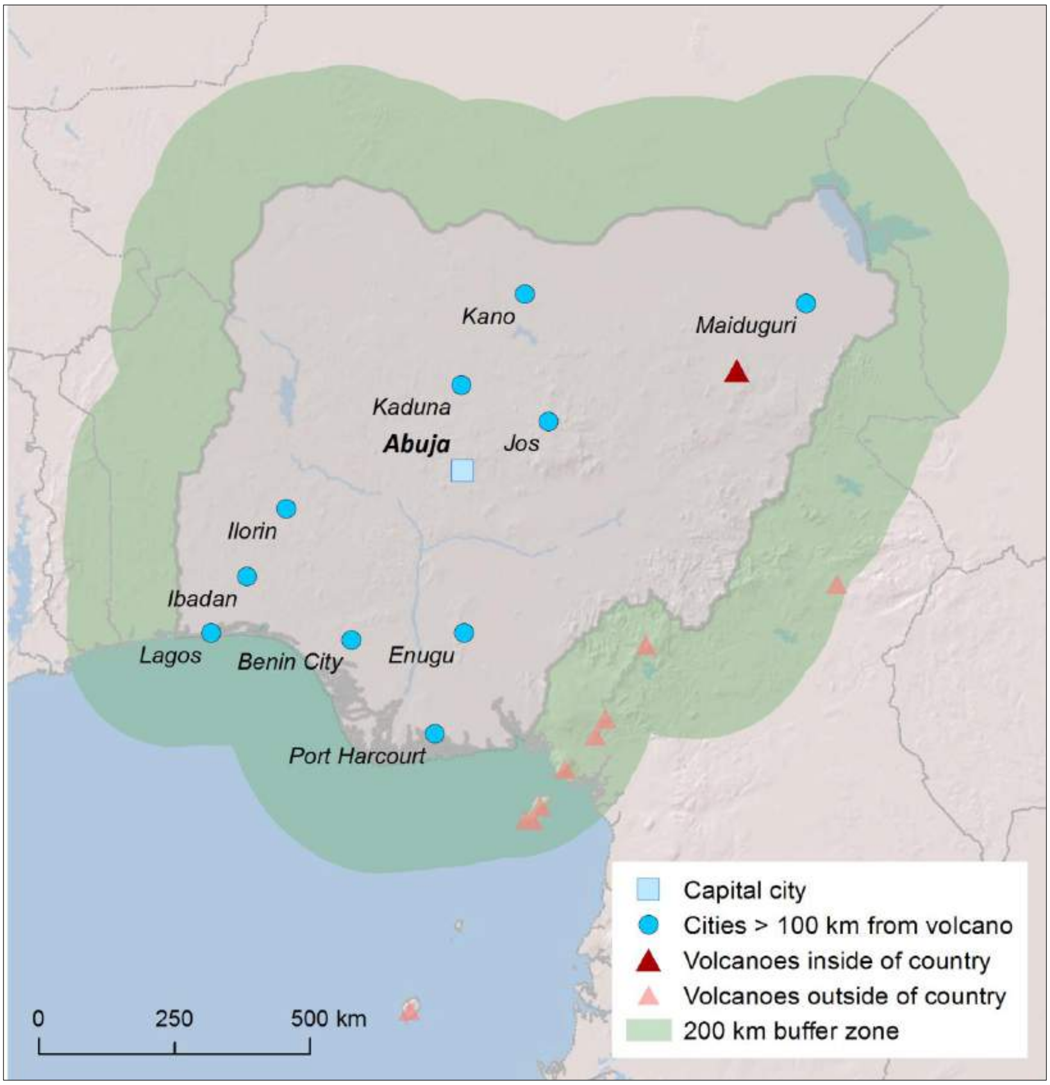

Figure 2.40 Location of Nigeria's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Nigeria.

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 2.36 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 their population size:

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.

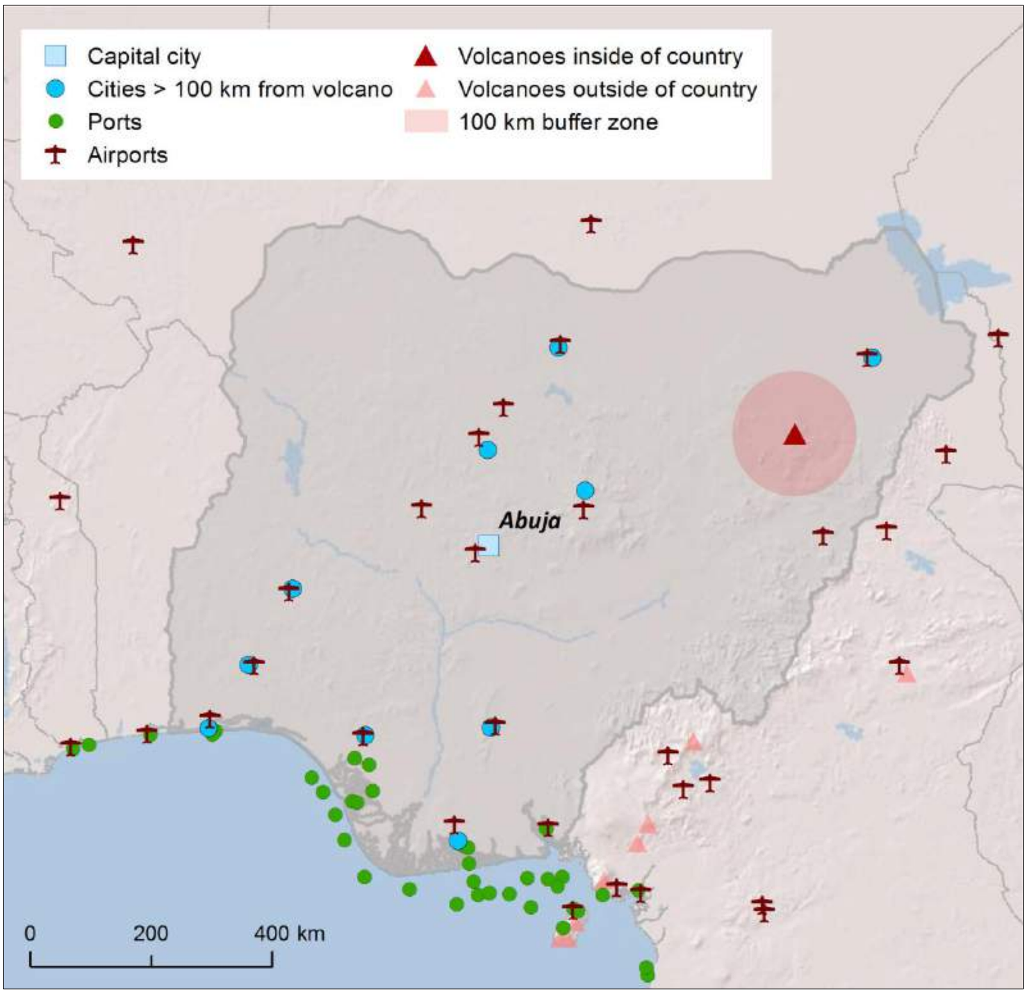

Figure 2.41 The location of Nigeria's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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.

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

*Table 2.37 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 1900 AD, 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

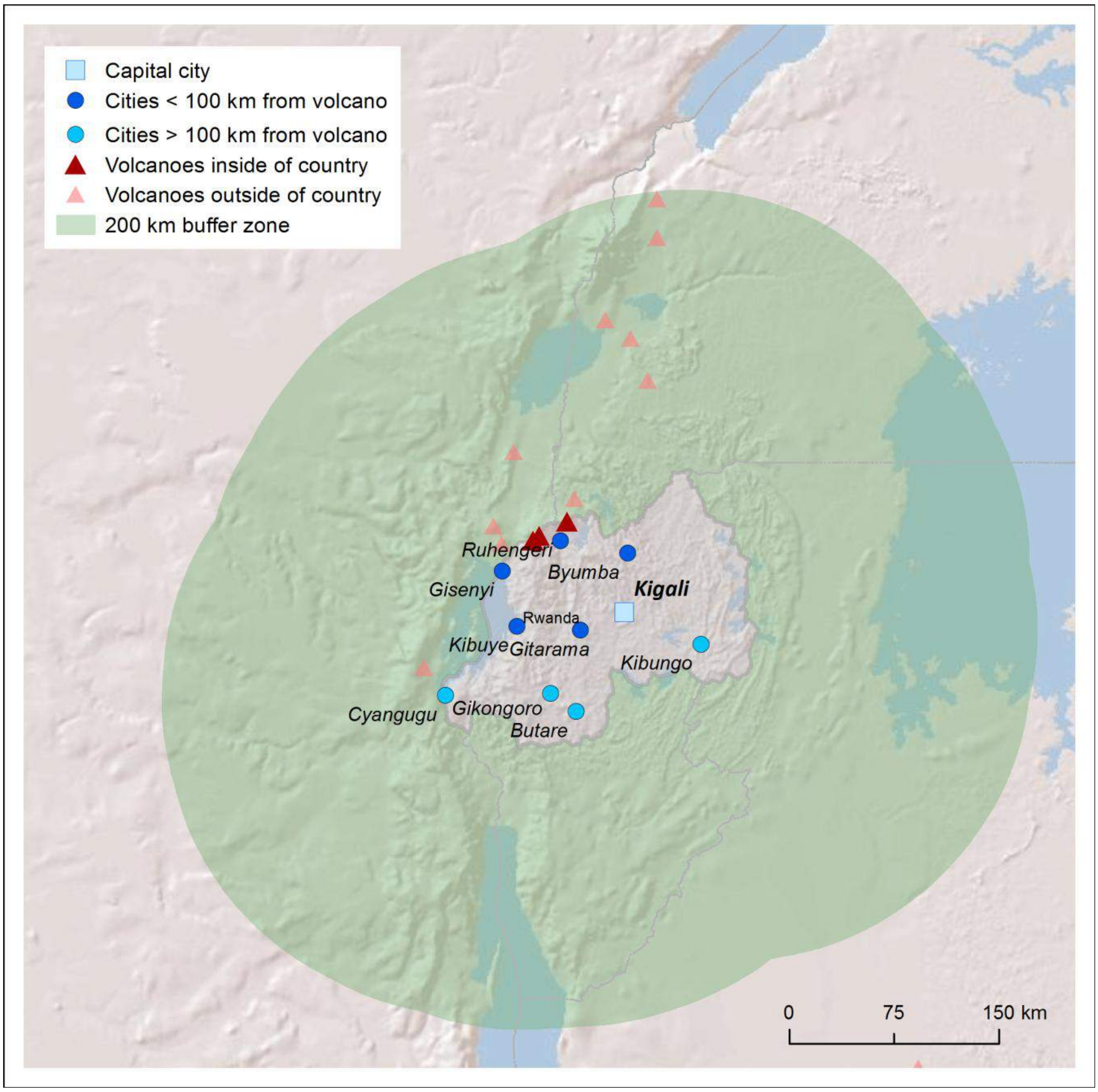

Figure 2.42 Location of Rwanda's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Rwanda.

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 2.38 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 their population size:

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.

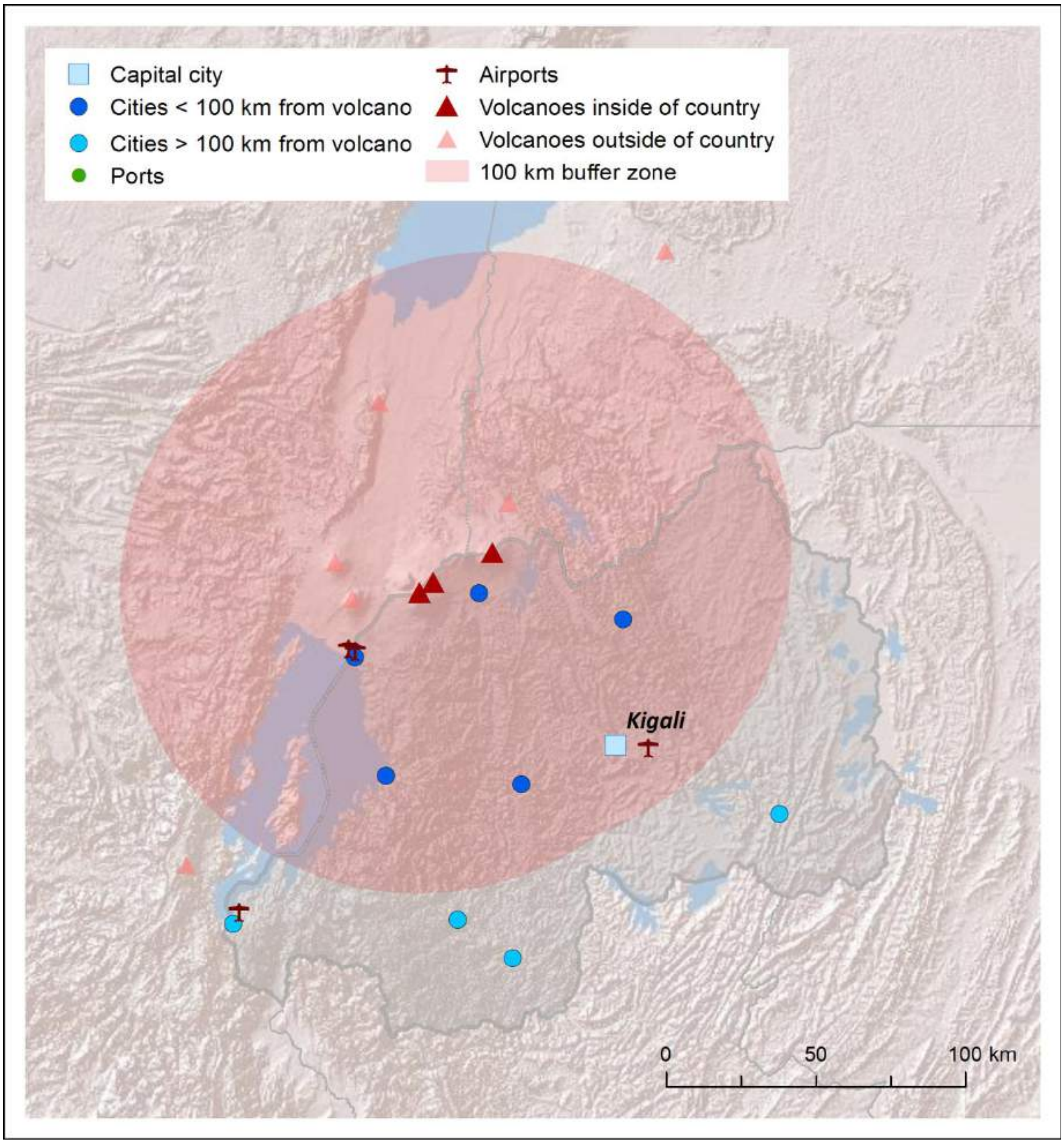

Figure 2.43 The location of Rwanda's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.393 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 1900 AD, 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.

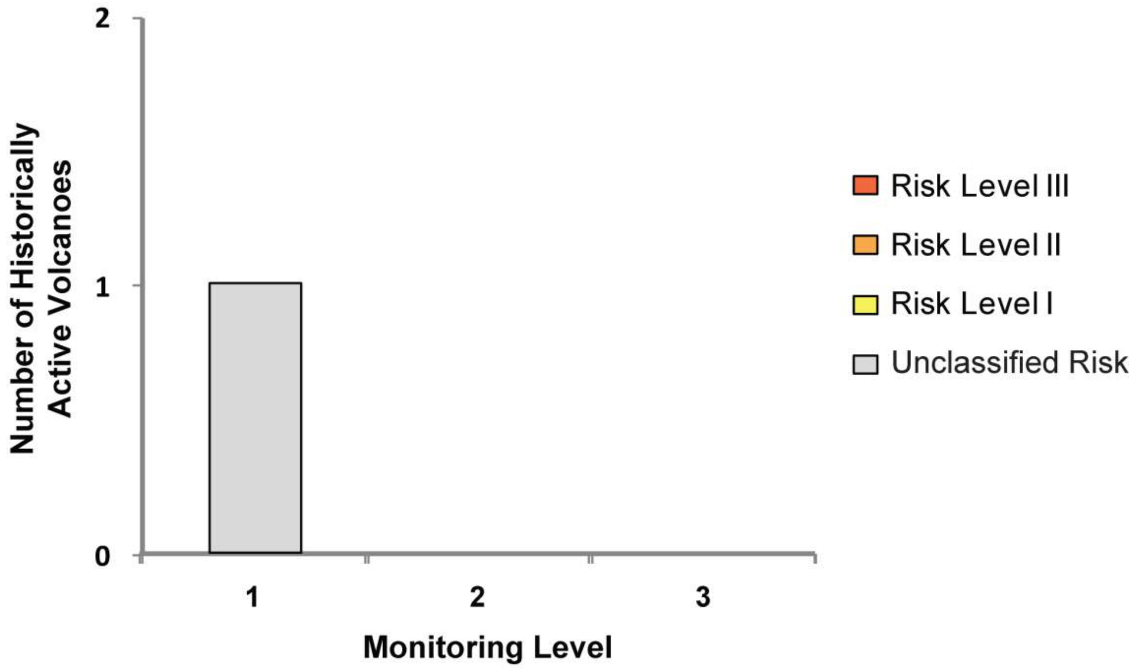

Figure 2.44 The monitoring and risk levels of the historically active volcanoes in Rwanda. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates 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.

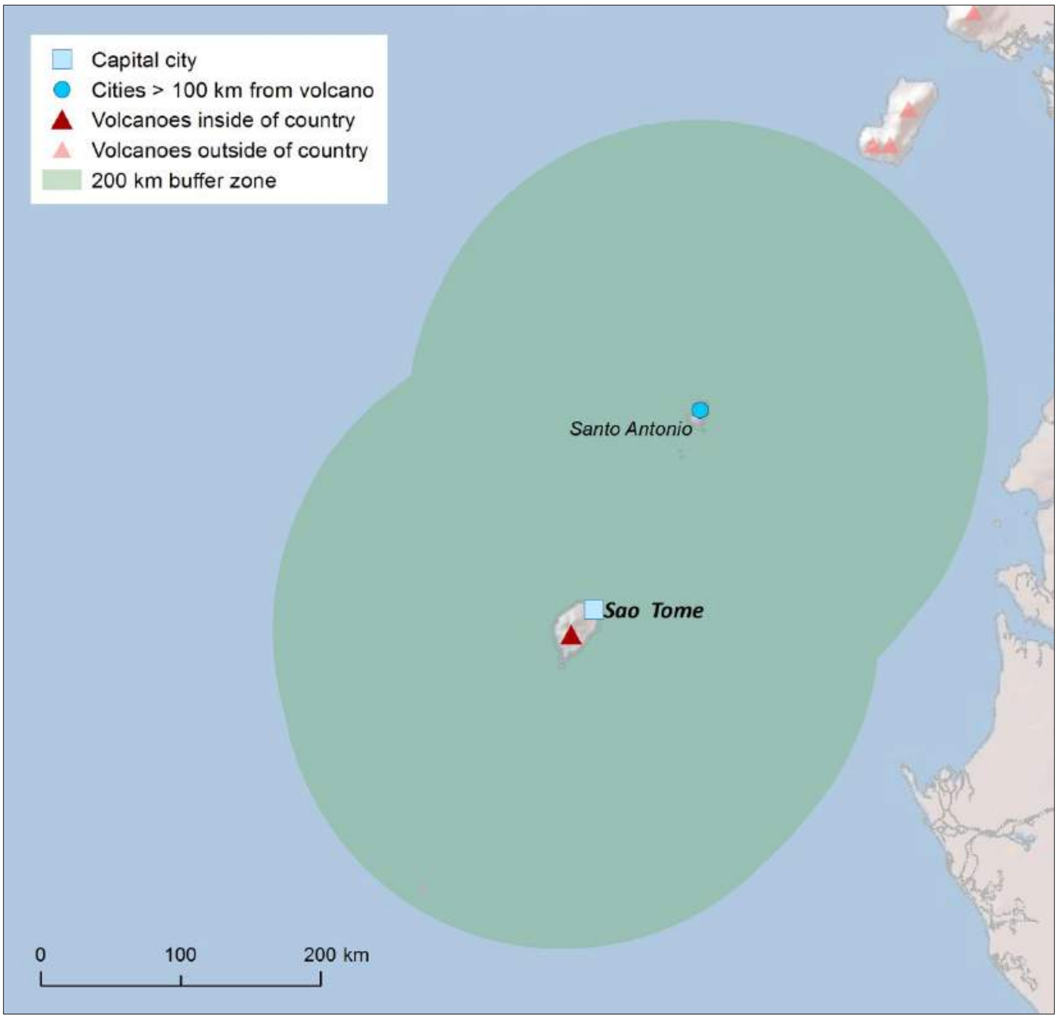

Figure 2.45 Location of Sao Tome and Principe's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Sao Tome.

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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 2.40 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 their population size:

Sao Tome	53,300
Santo Antonio	12,529

Infrastructure Exposure

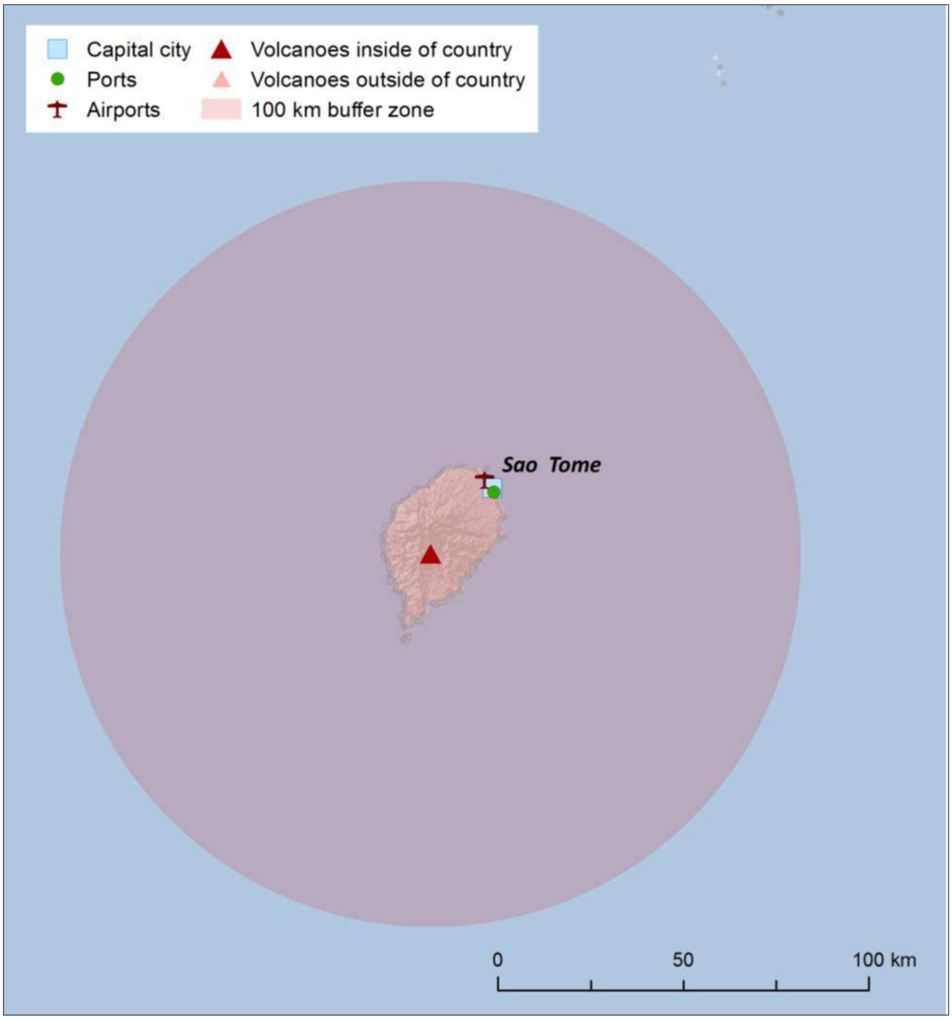

Figure 2.46 The location of Sao Tome and Principe's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.41 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 1900 AD, 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

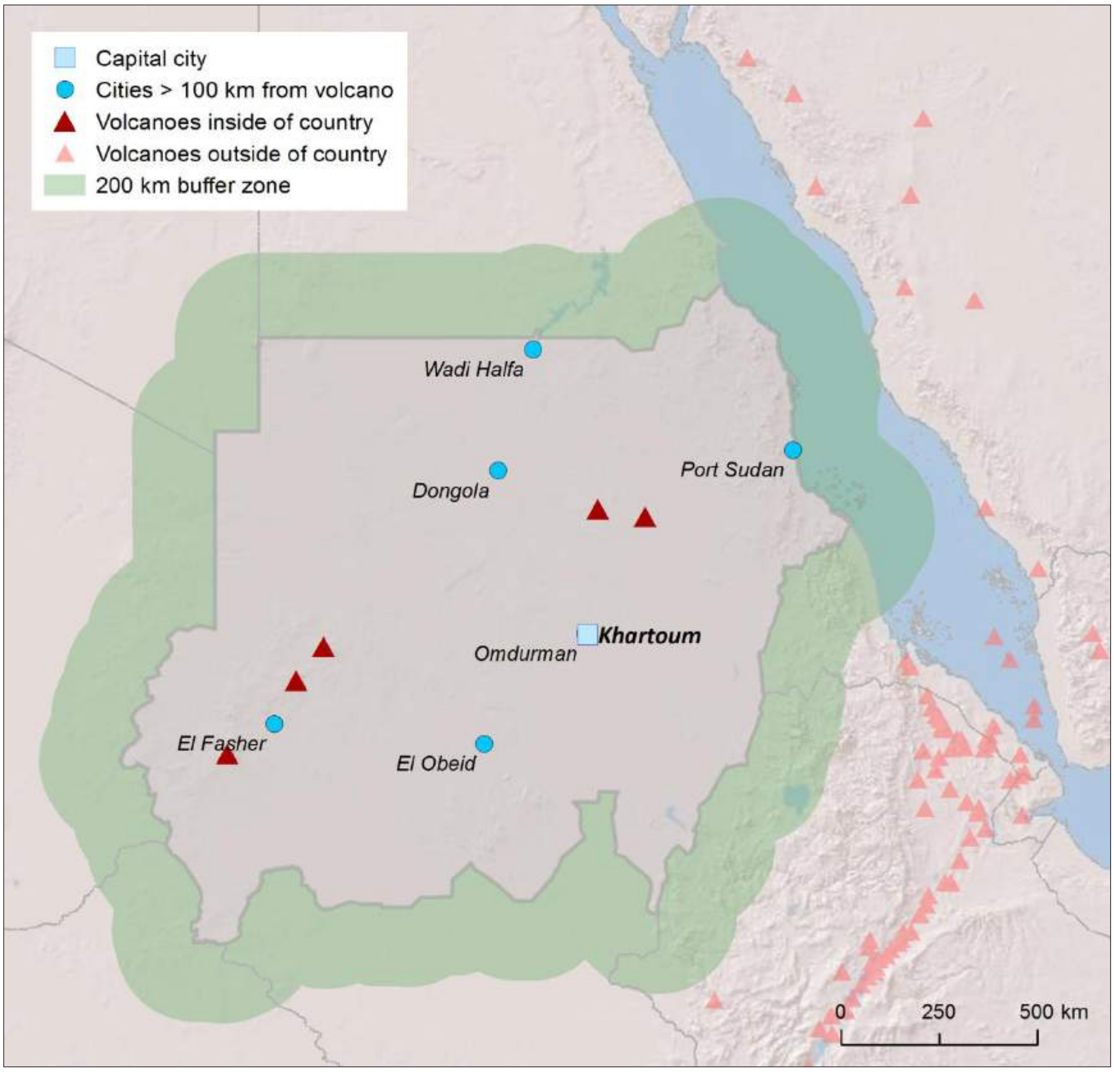

Figure 2.47 Location of Sudan's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Sudan.

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 2.42 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 their population size:

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.

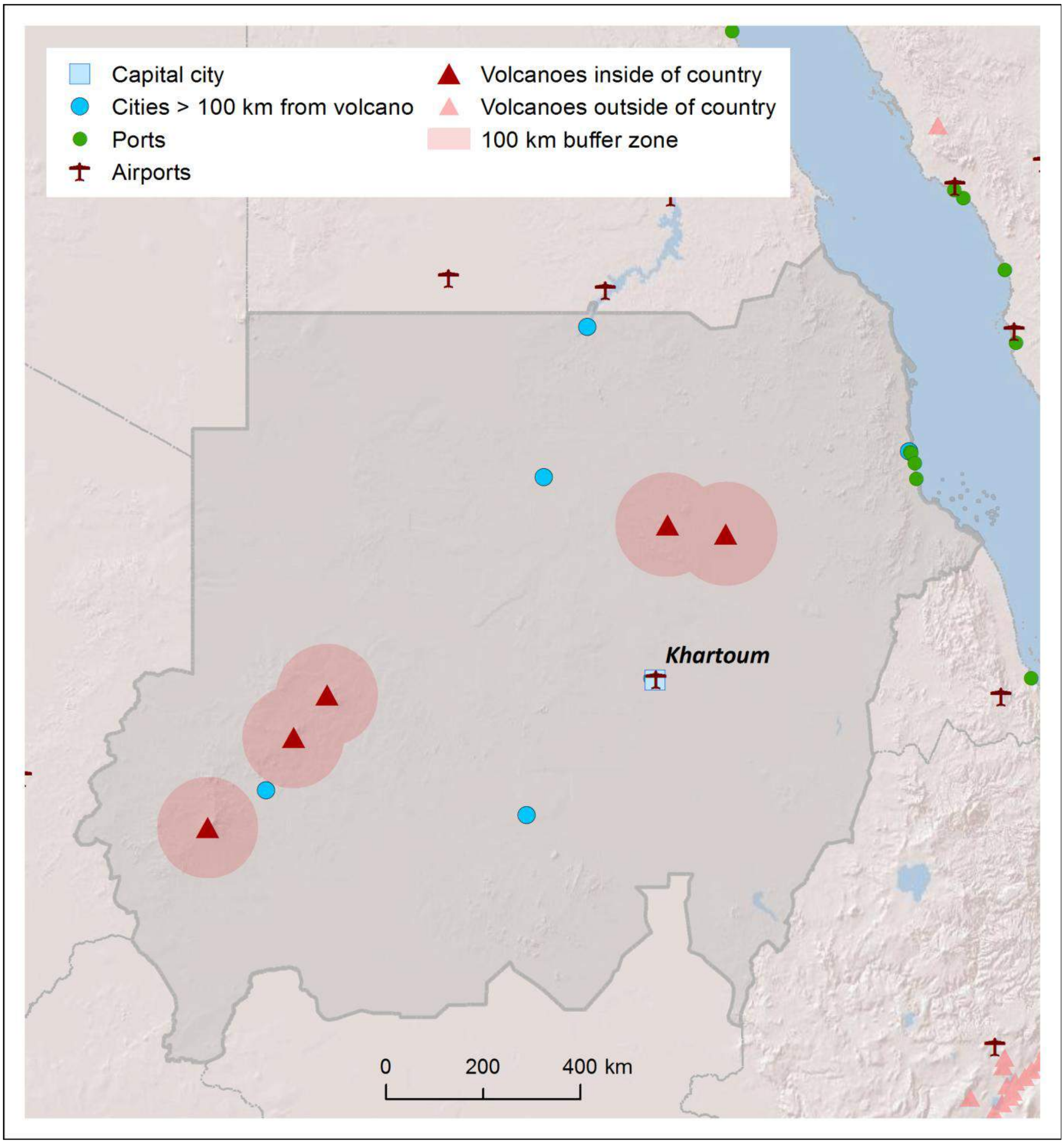

Figure 2.48 The location of Sudan's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.43 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 1900 AD, 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 2.44 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.

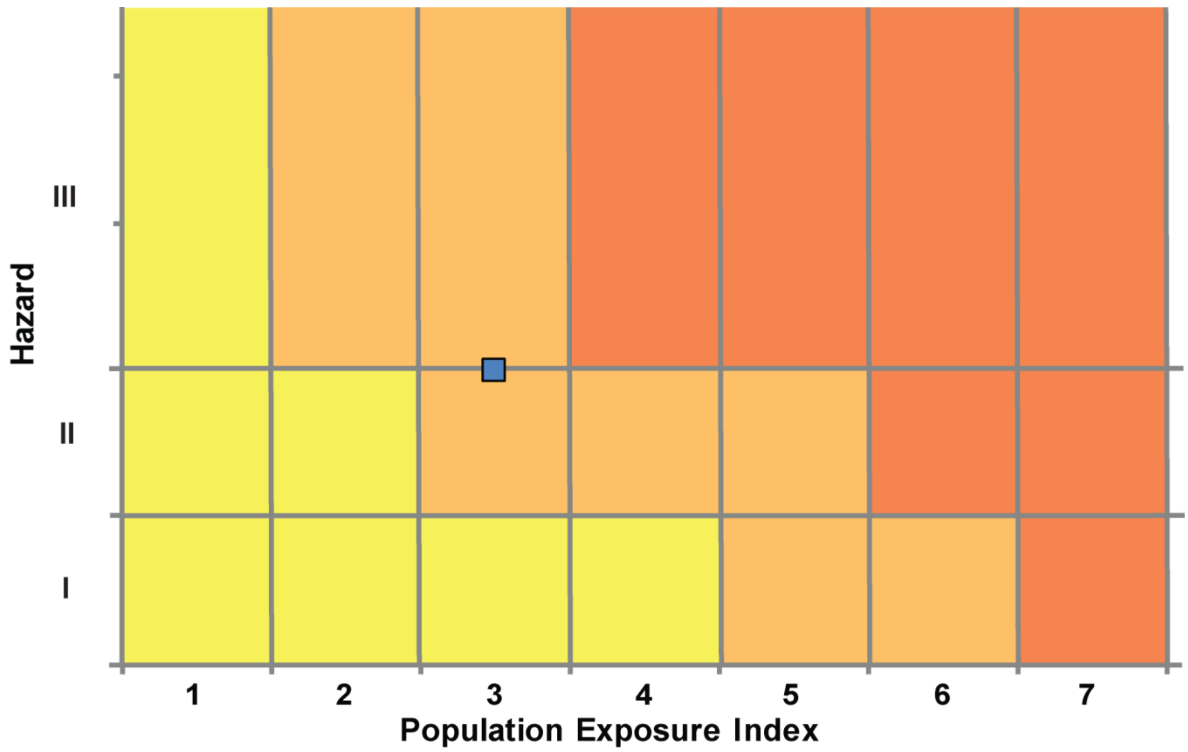

Figure 2.49 Distribution of Sudan's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

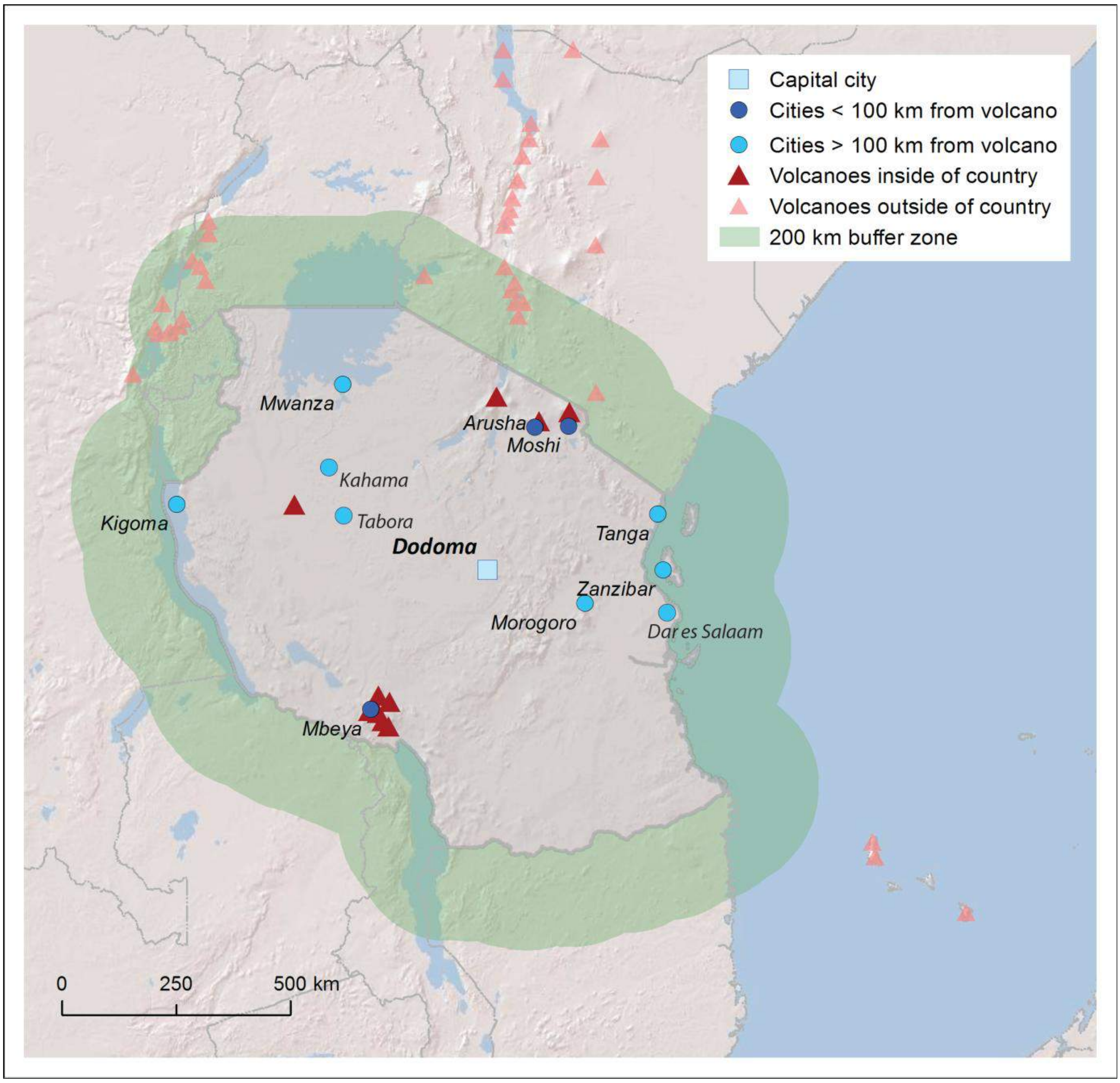

Figure 2.50 Location of Tanzania's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Tanzania.

This profile and the data therein should not be used in place of focussed assessments and information provided by local monitoring and research institutions.

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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 2.45 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 their population size:

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.

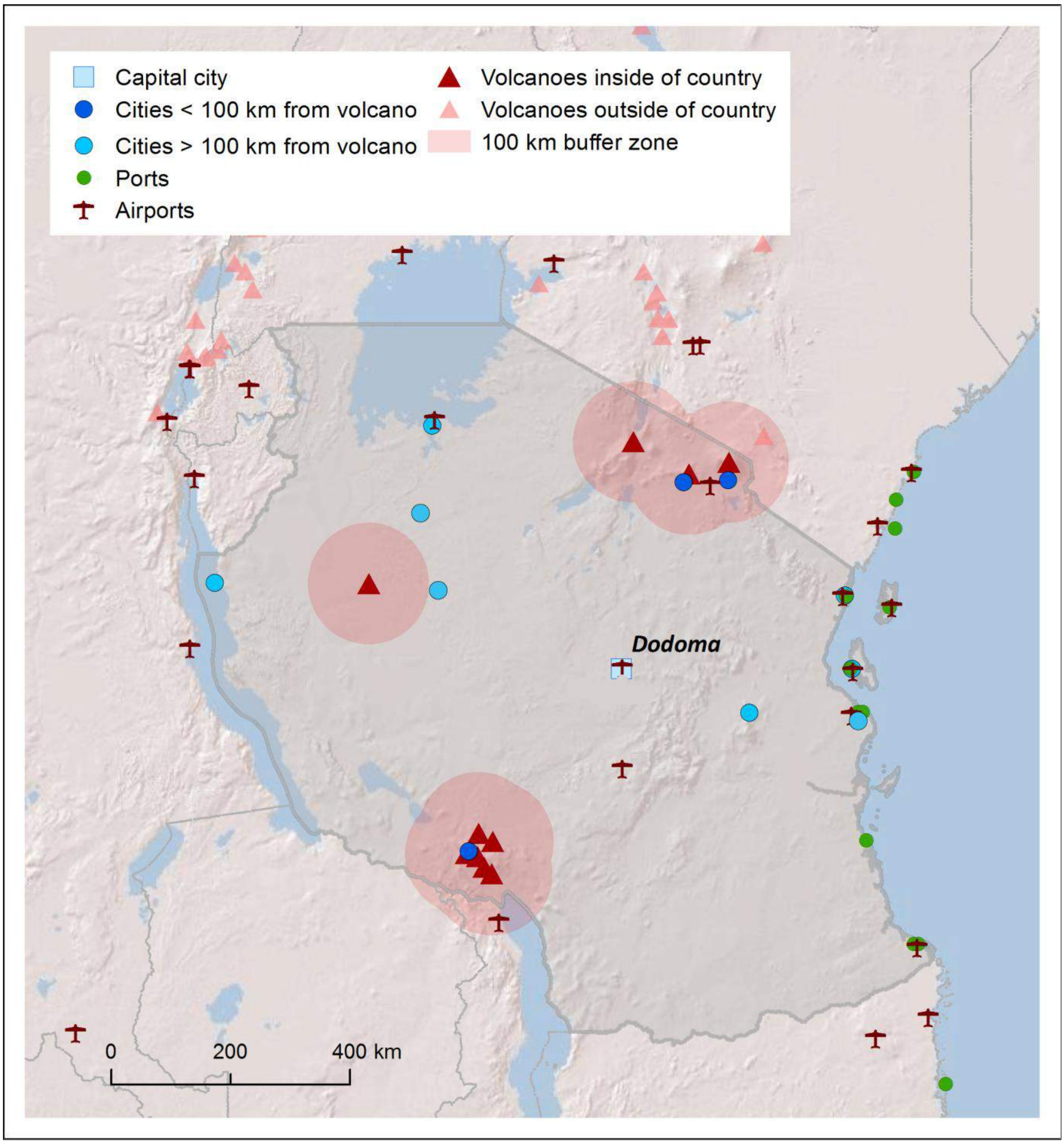

Figure 2.51 The location of Tanzania's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.46 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 1900 AD, 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 2.47 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.

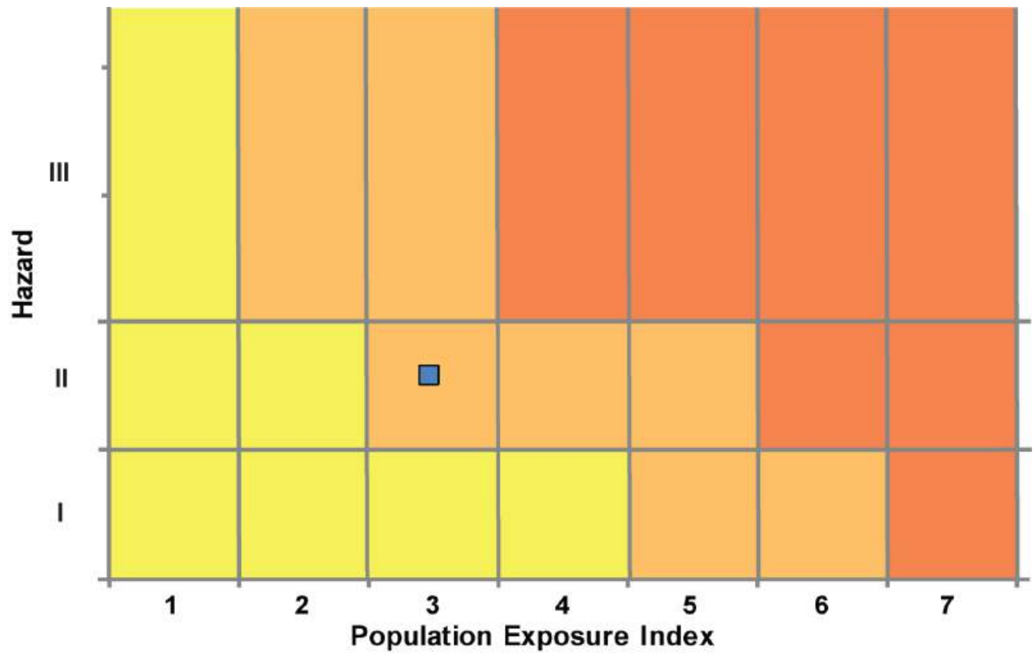

Figure 2.52 Distribution of Tanzania's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

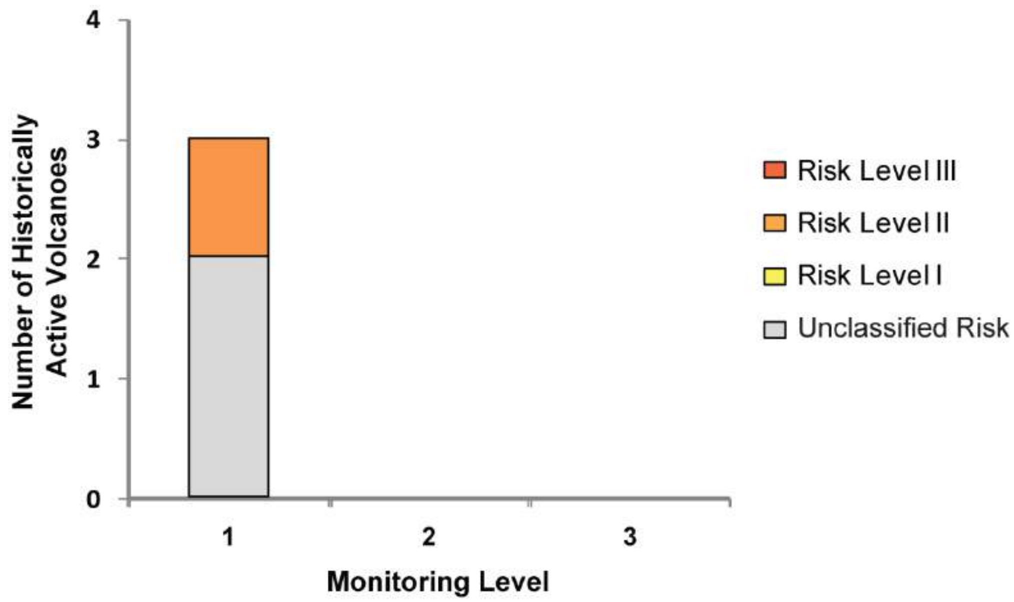

Figure 2.53 The monitoring and risk levels of the historically active volcanoes in Tanzania. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Uganda

Description

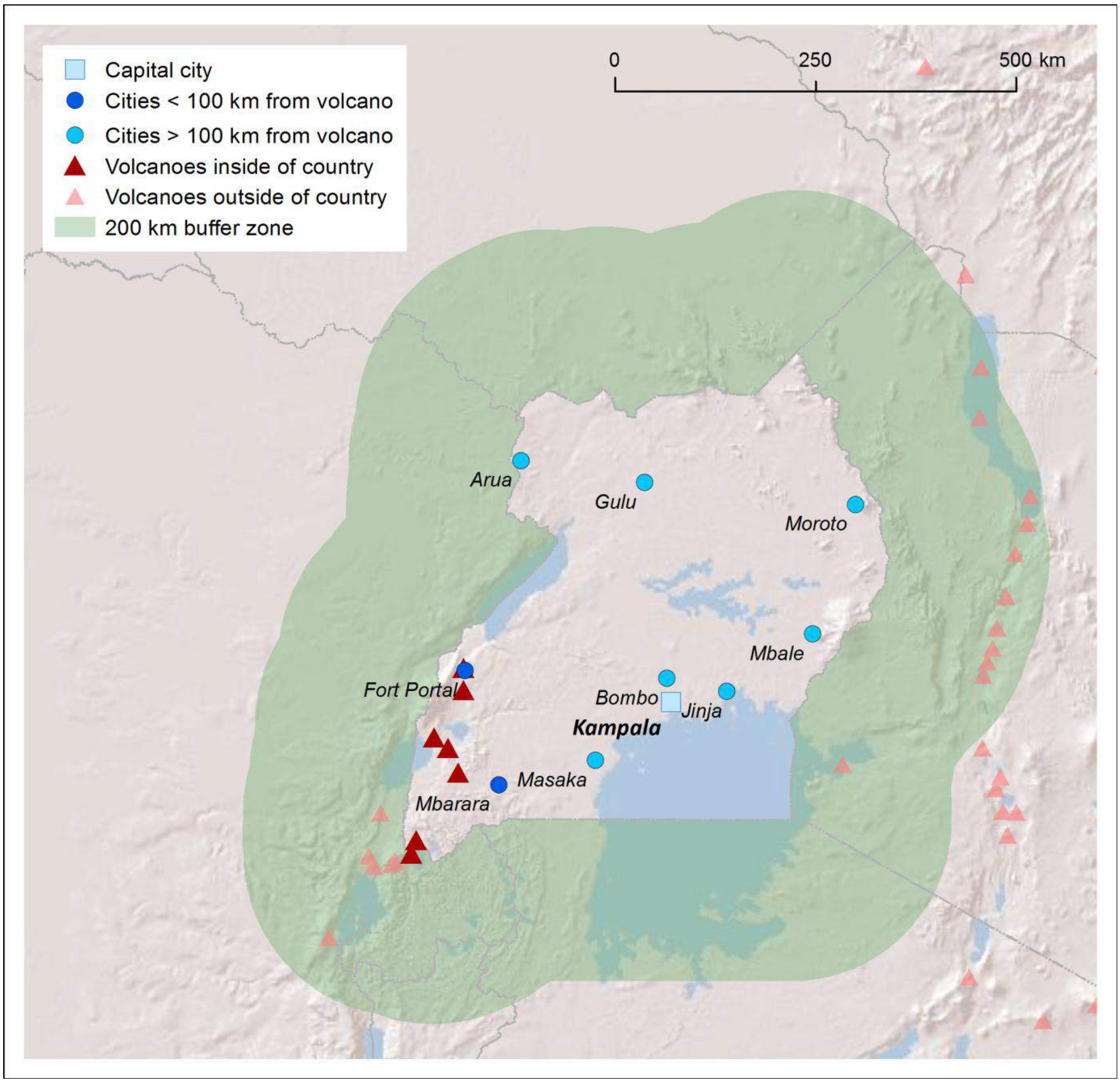

Figure 2.54 Location of Uganda's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Uganda.

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 2.48 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 their population size:

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.

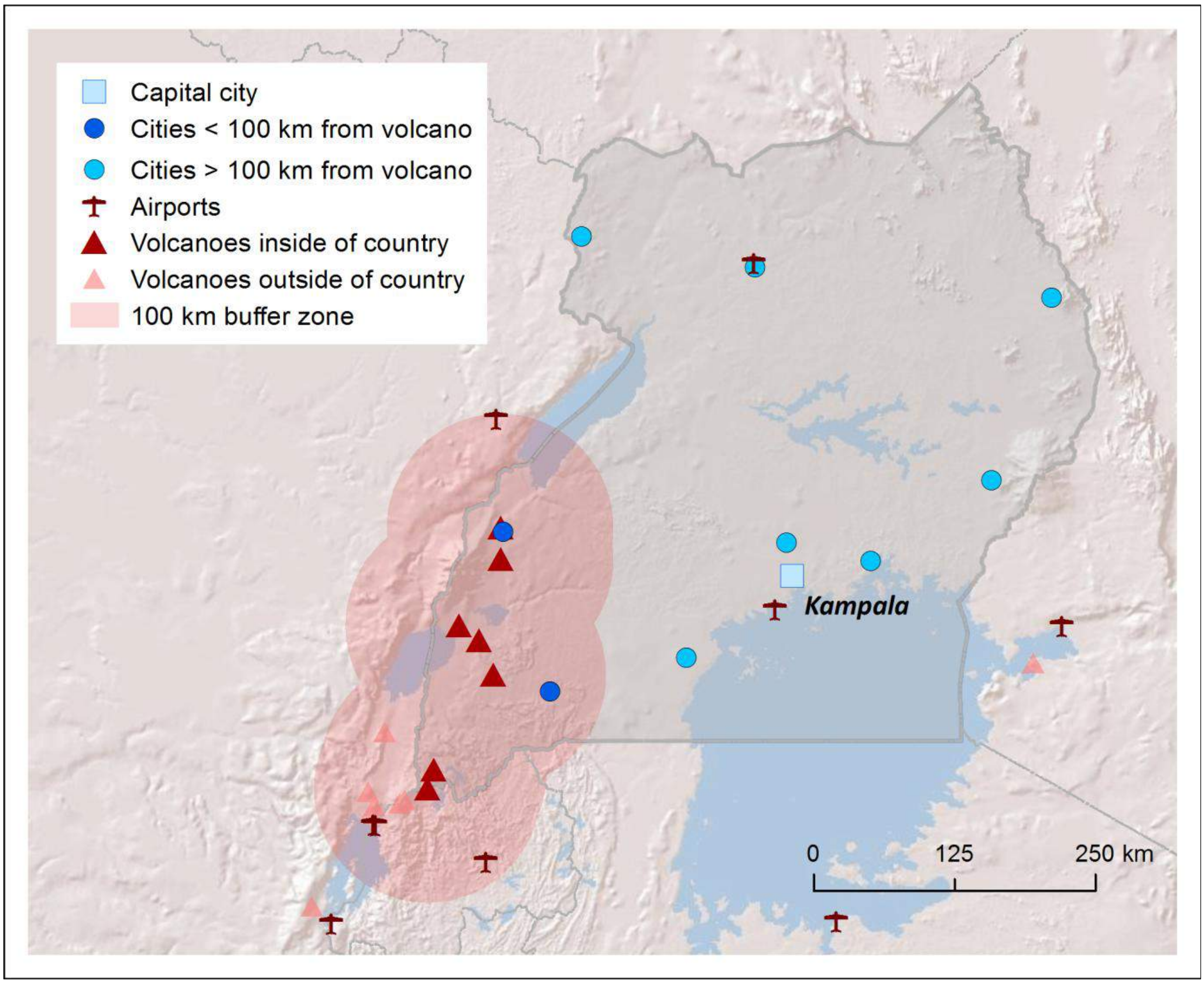

Figure 2.55 The location of Uganda's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 2.49 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 1900 AD, 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

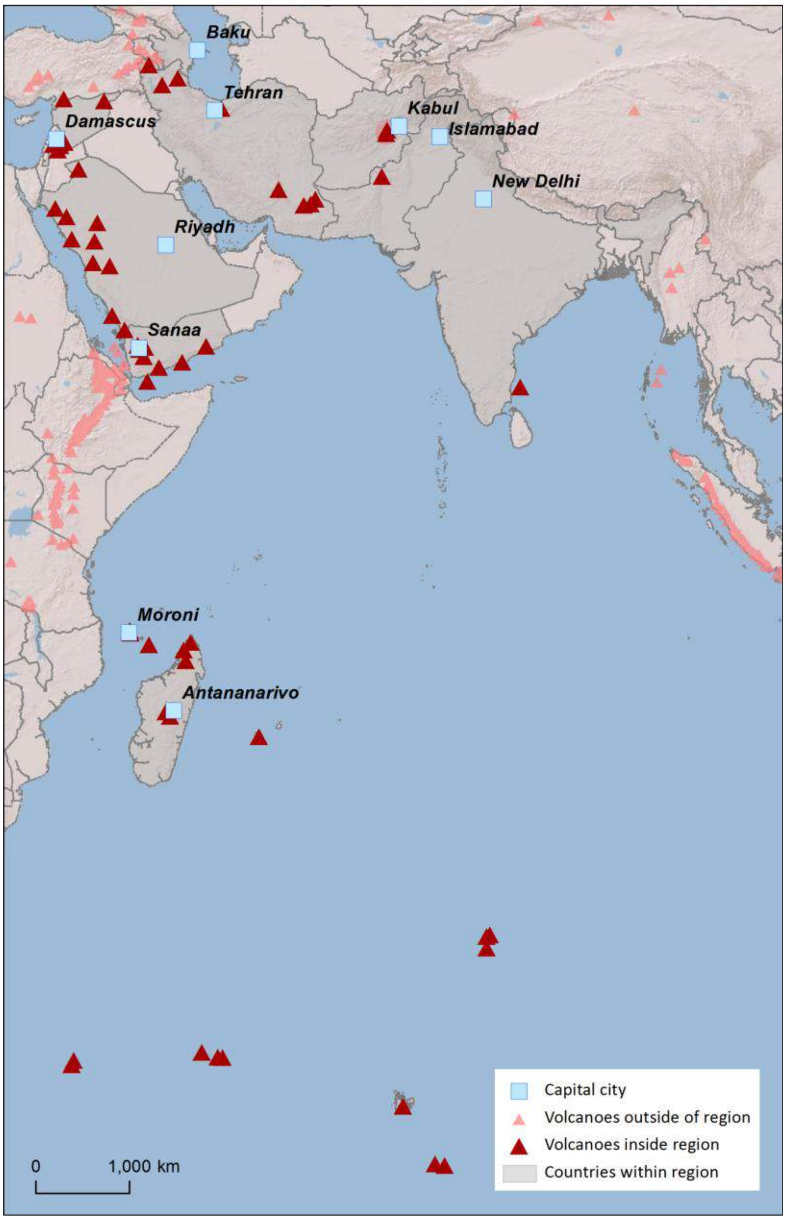

Figure 3.1 The distribution of Holocene volcanoes through the Middle East and Indian Ocean region. The capital cities of the constituent countries are shown.

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.

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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 3.1 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.

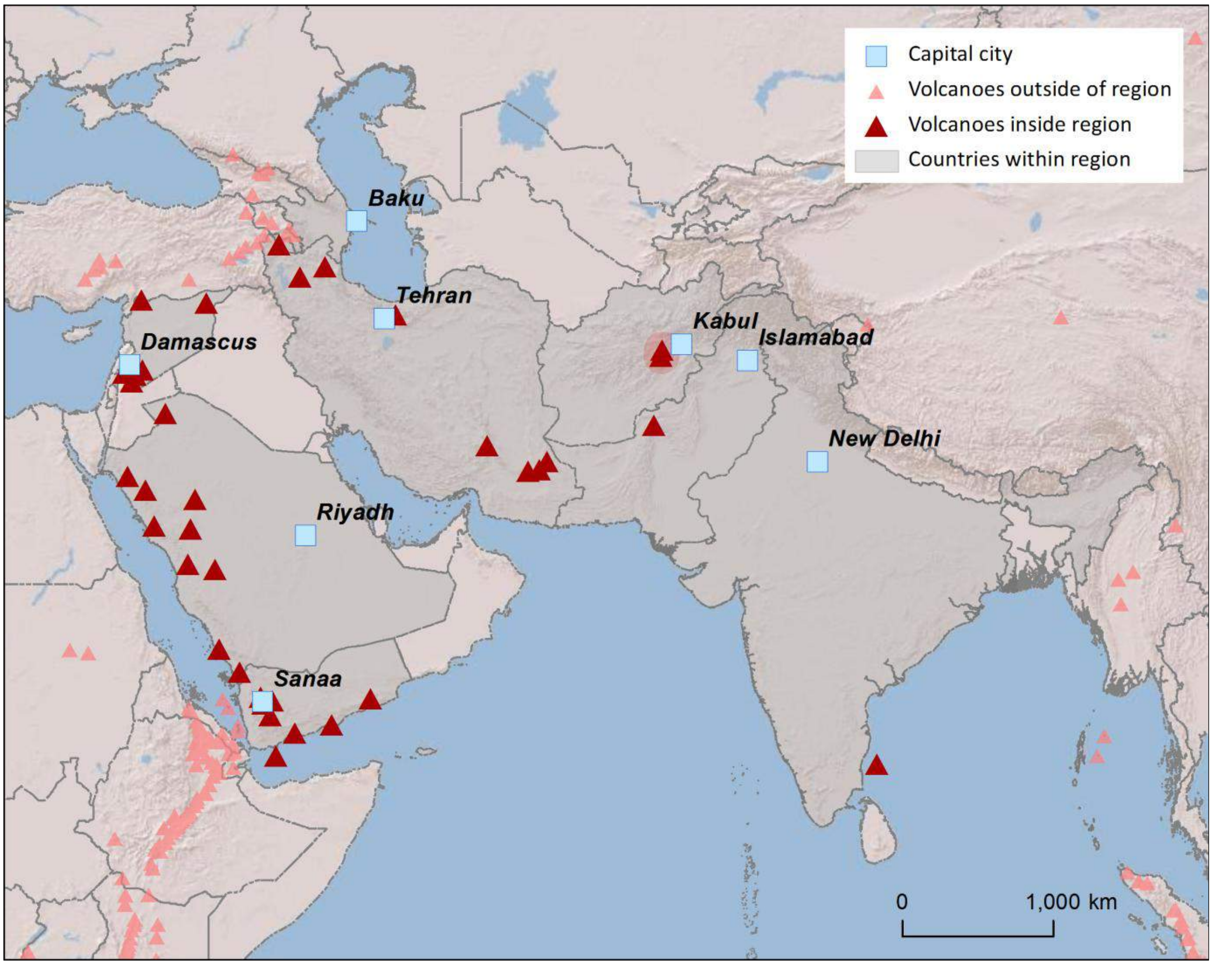

Figure 3.2 The Middle East section of Region 3.

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

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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 3.2 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 3.3 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 occur 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 (Figure 3.3). 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.

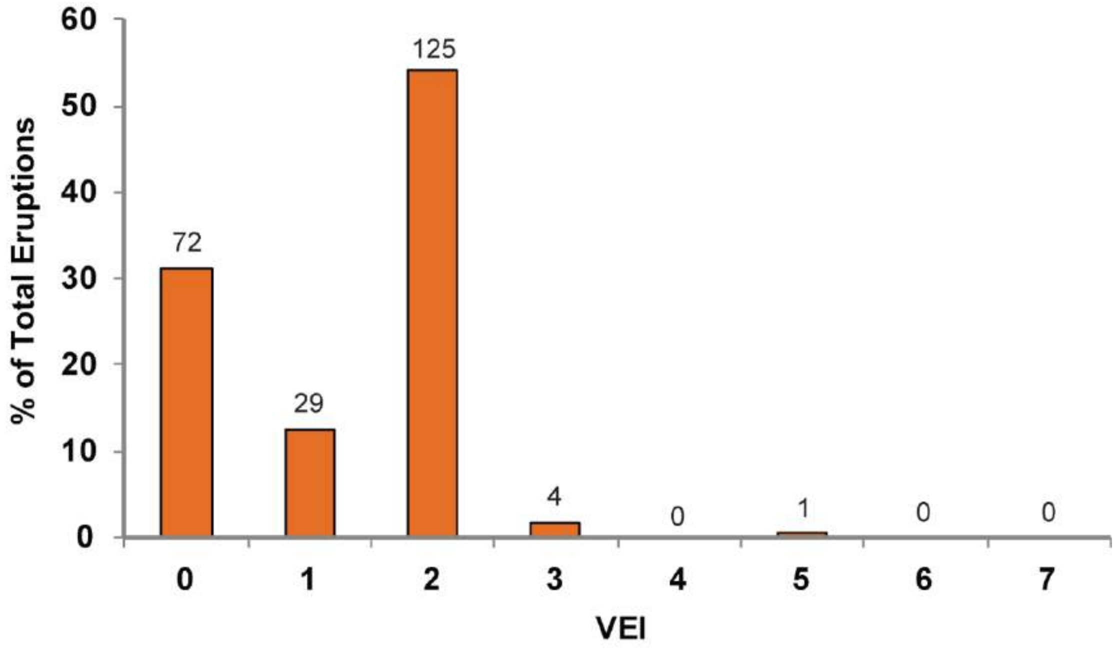

Figure 3.3 Percentage of eruptions in this region recorded at each VEI level; number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 21 eruptions were recorded with unknown VEI.

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 3.4 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 1900 AD, 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 3.5 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 3.6 The number of volcanoes in the Middle East and Indian Ocean region classified at each Risk Level.

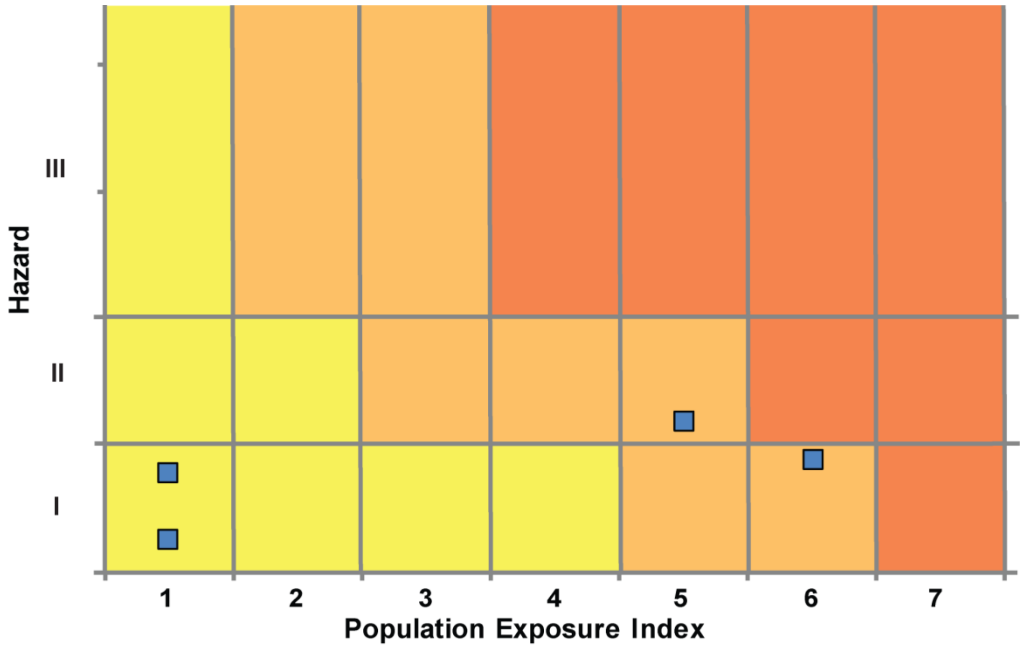

Figure 3.4 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional Monitoring Capacity

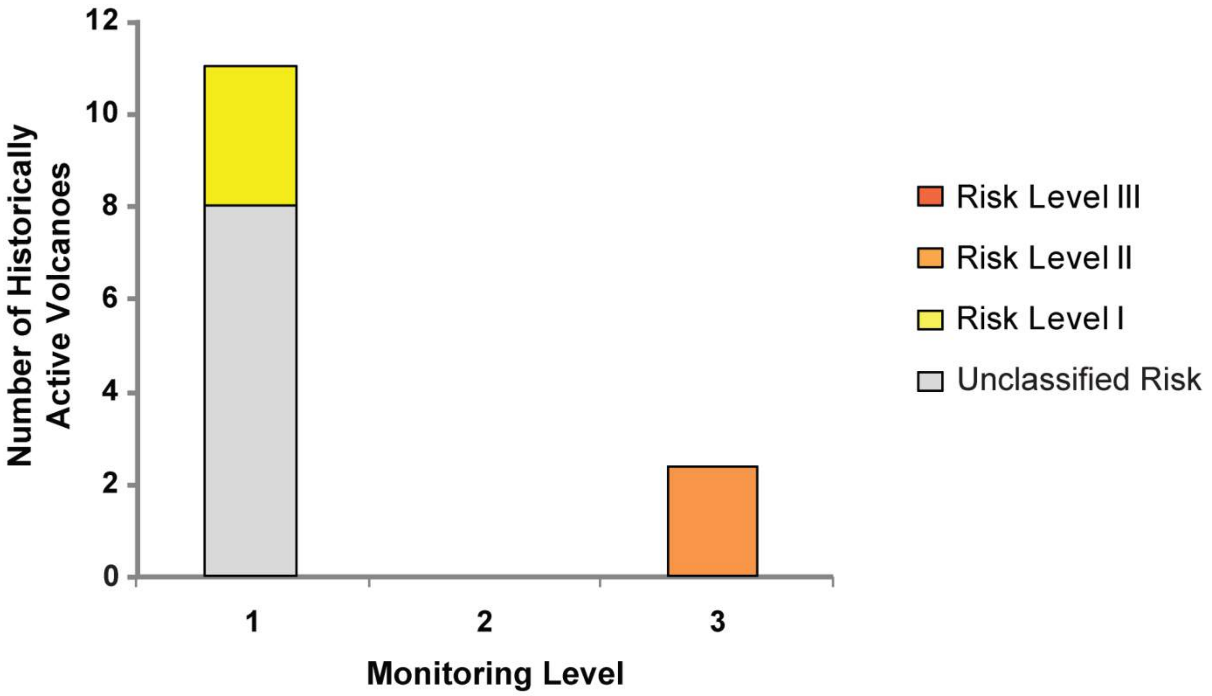

Figure 3.5 The monitoring and risk levels of the historically active volcanoes in the Middle East and Indian Ocean. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Afghanistan

Description

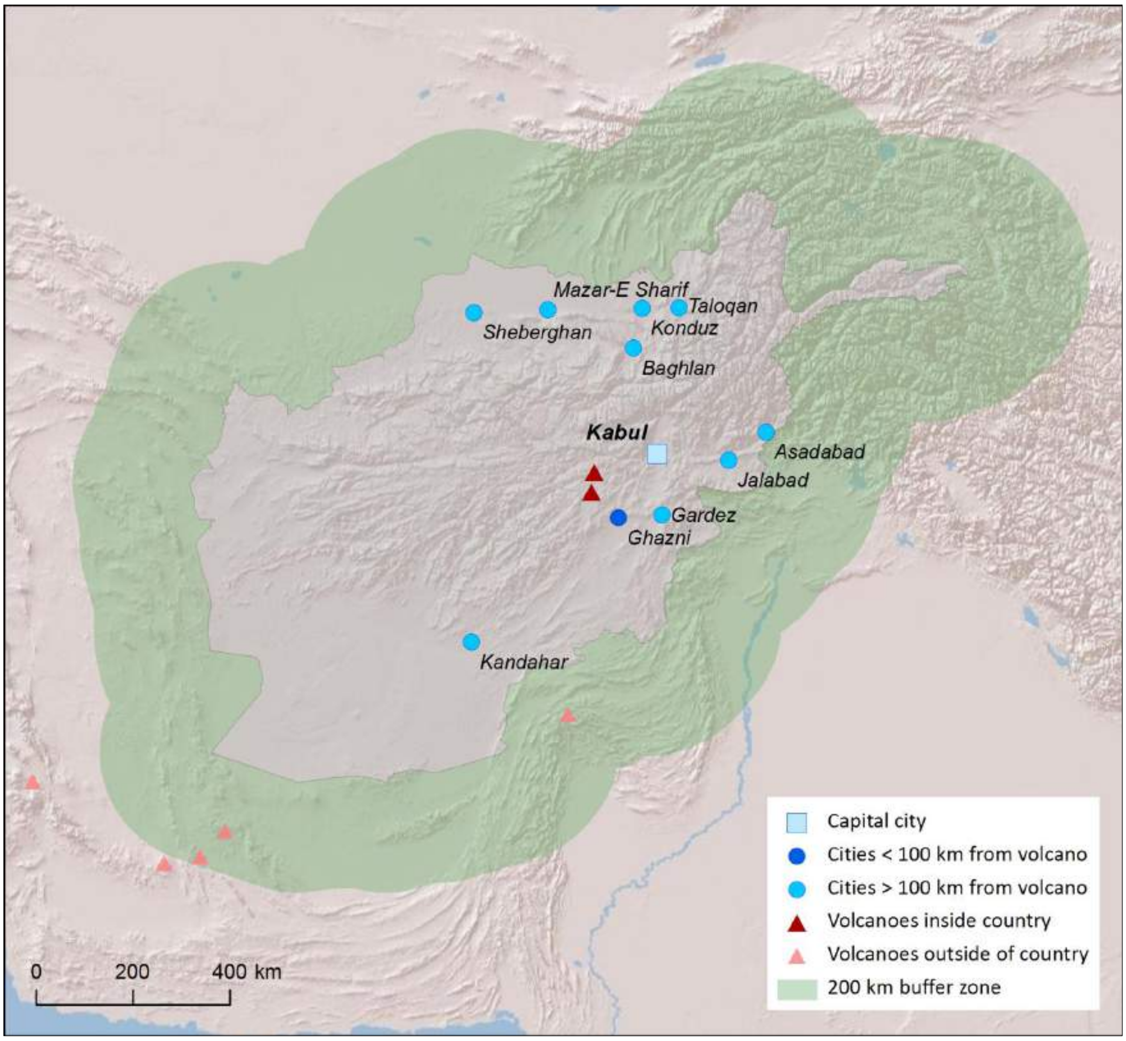

Figure 3.6 Location of Afghanistan's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Afghanistan.

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 3.7 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 their population size:

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.

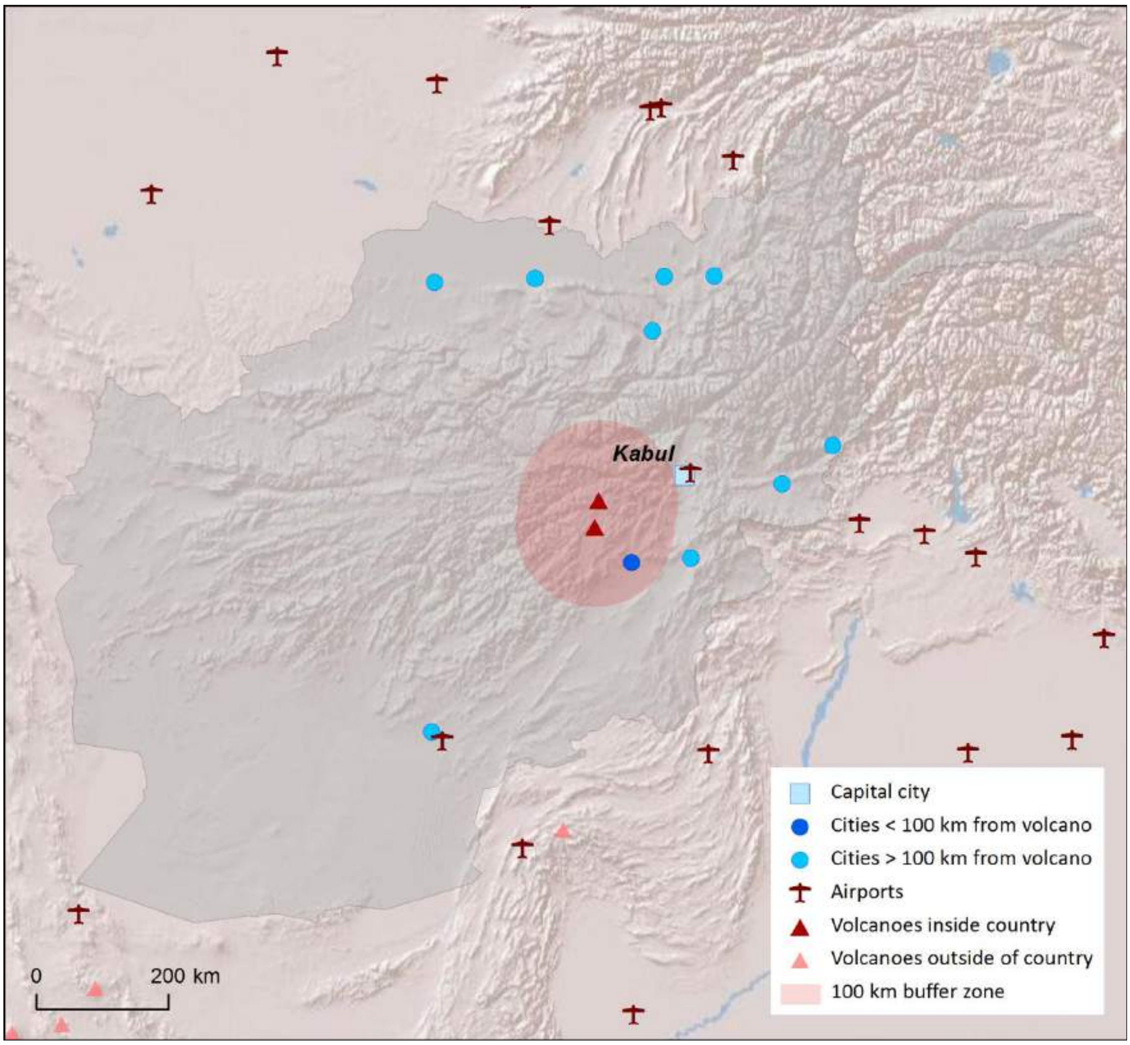

Figure 3.7 The location of Afghanistan's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 3.8 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 1900 AD, 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

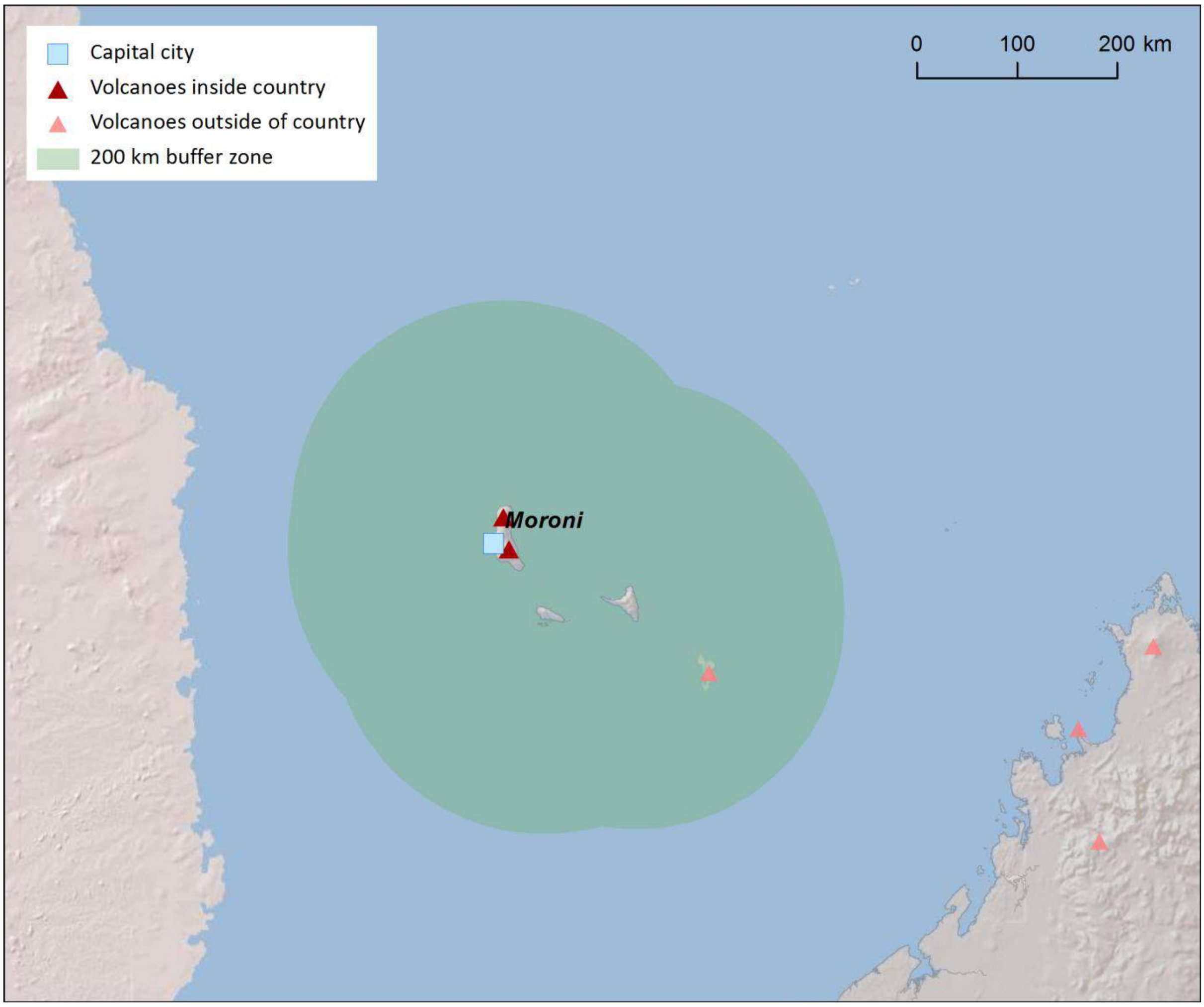

Figure 3.8 Location of the Comoros volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Comoros.

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 3.9 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.

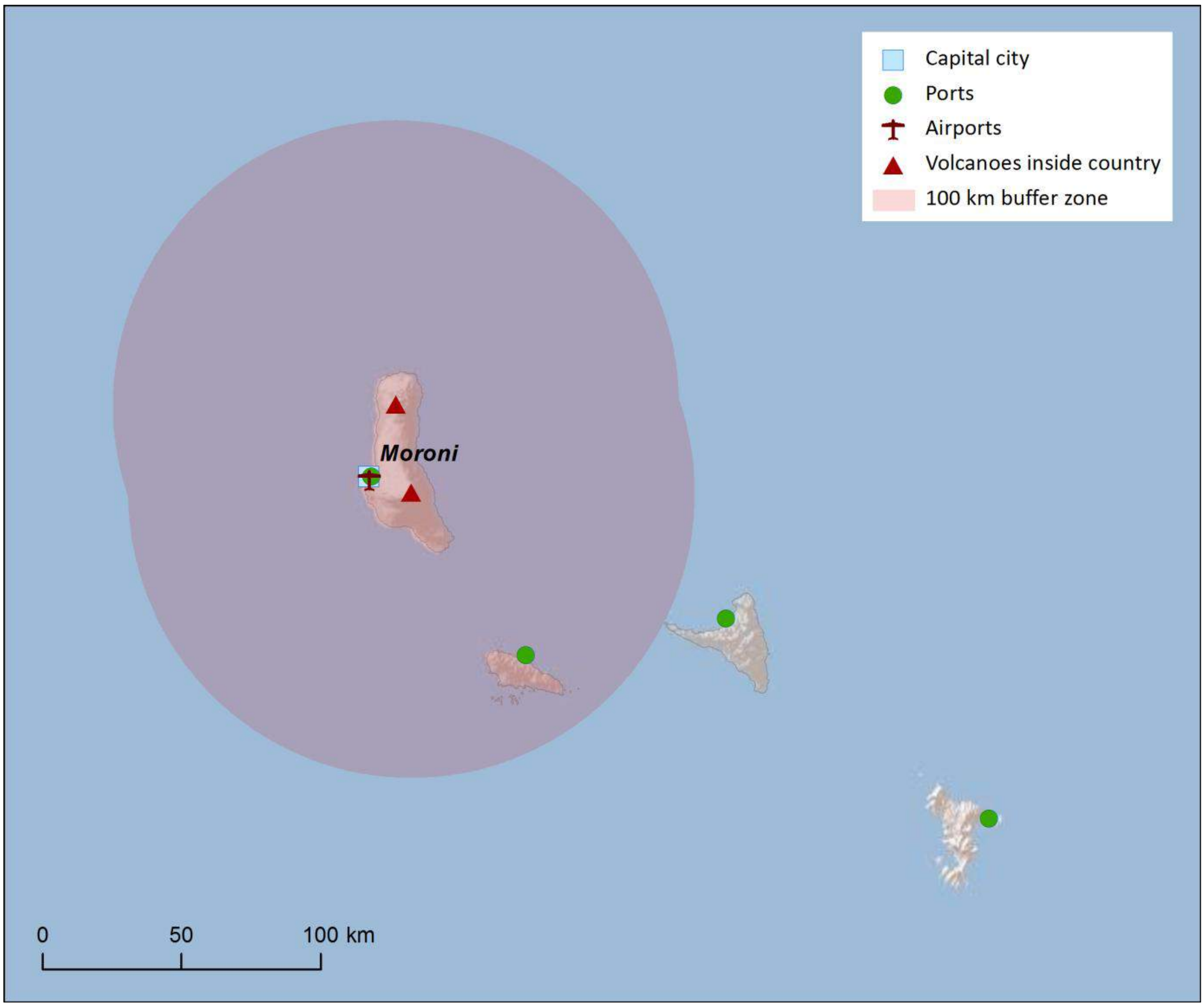

Figure 3.9 The location of the Comoros' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 3.104 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 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Karthala	6	II

Table 3.11 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.

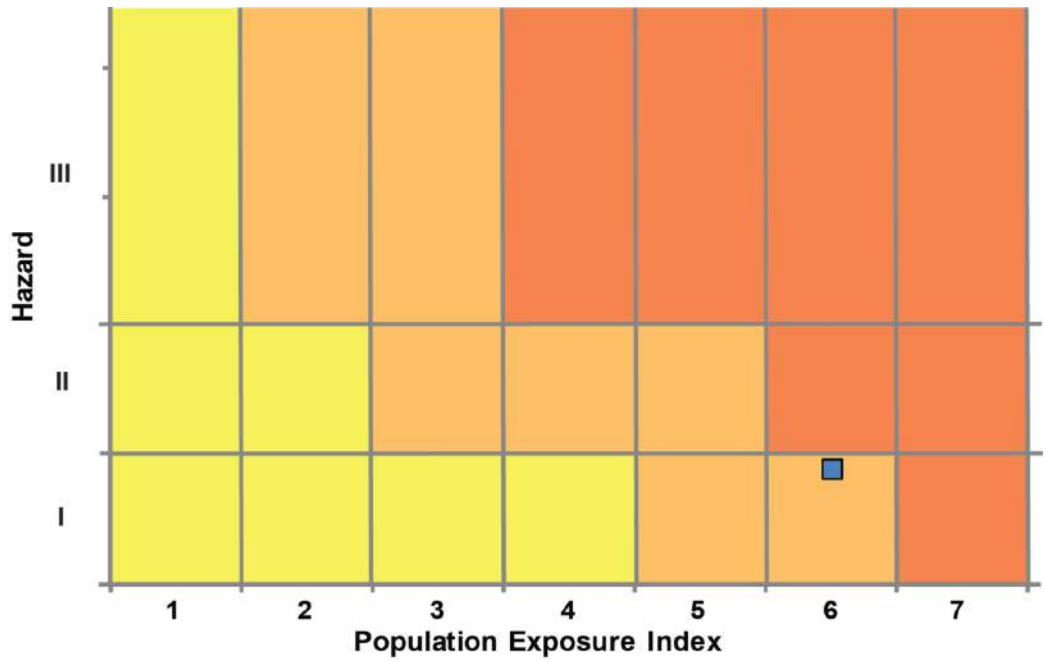

Figure 3.10 Distribution of the Comoros' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

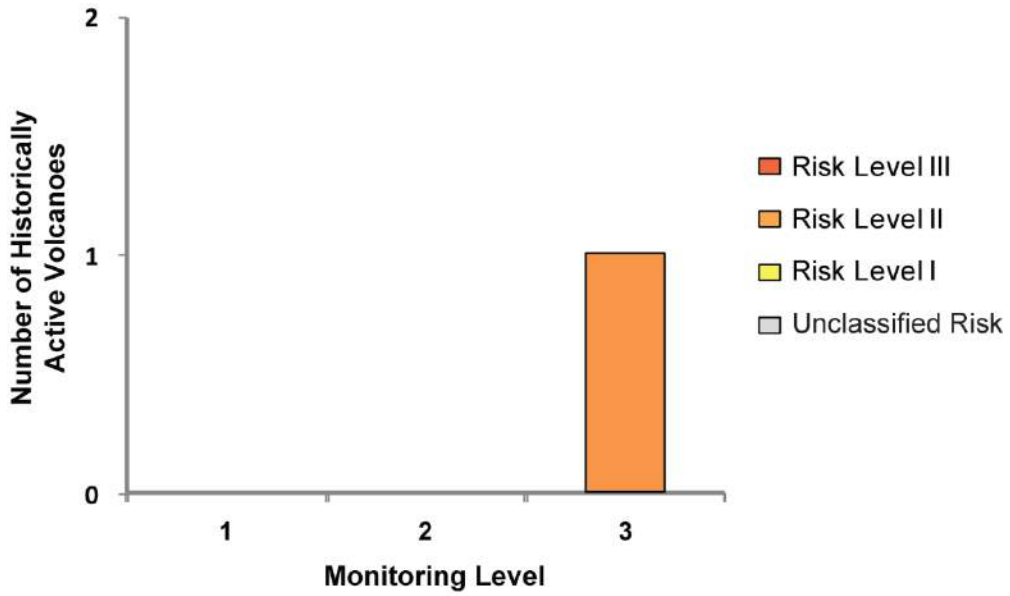

Figure 3.11 The monitoring and risk levels of the historically active volcanoes in the Comoros. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 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

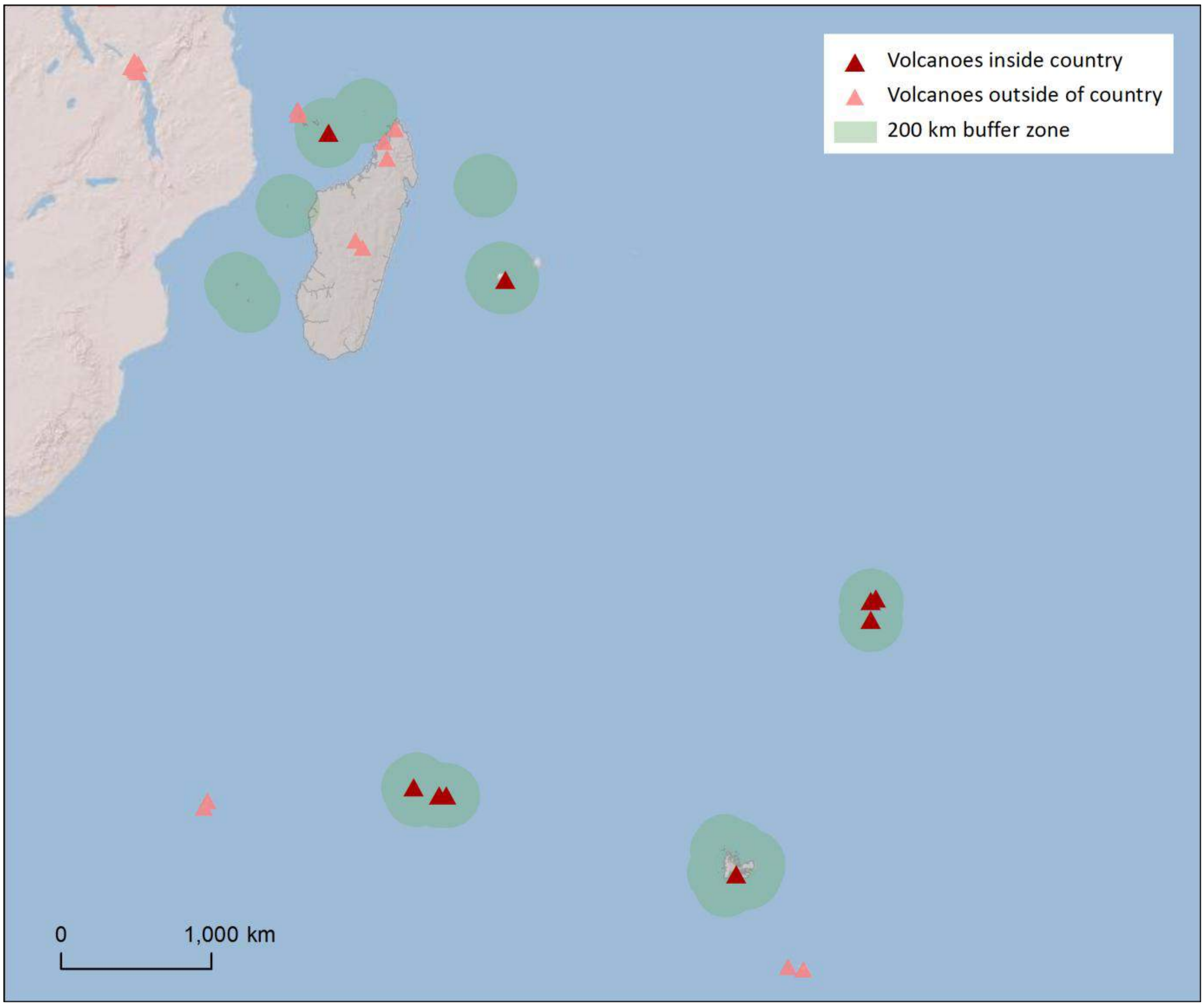

Figure 3.12 Location of the Indian Ocean French territories volcanoes. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect these islands.

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 programme of hazard education for the public and participate in risk assessments, management and mitigation of risk.

See also:

L'observatoire de la Réunion – OVPF, 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 3.12 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 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.

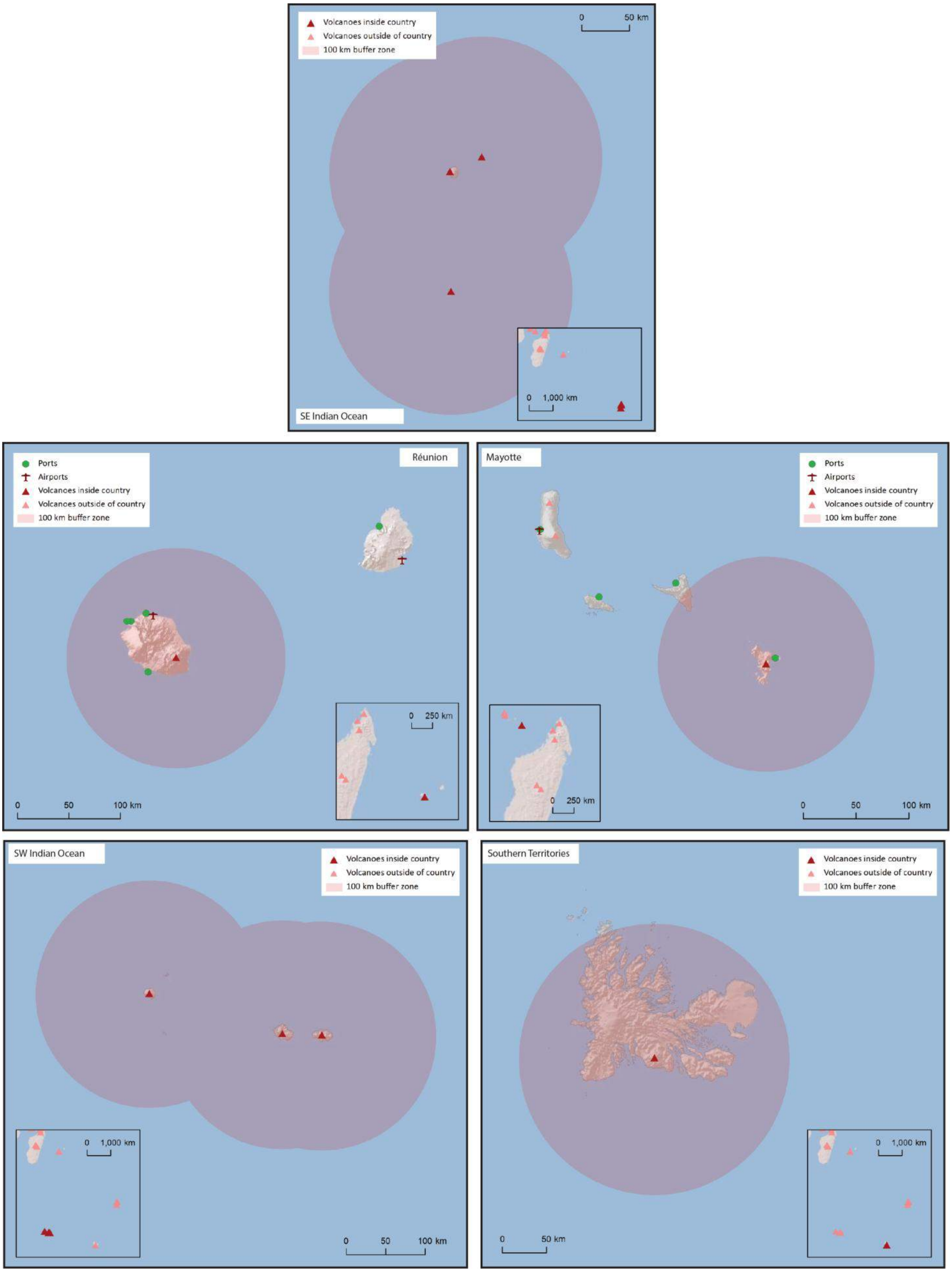

Figure 3.13 The location of France's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 3.13 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 1900 AD, 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 3.14 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.

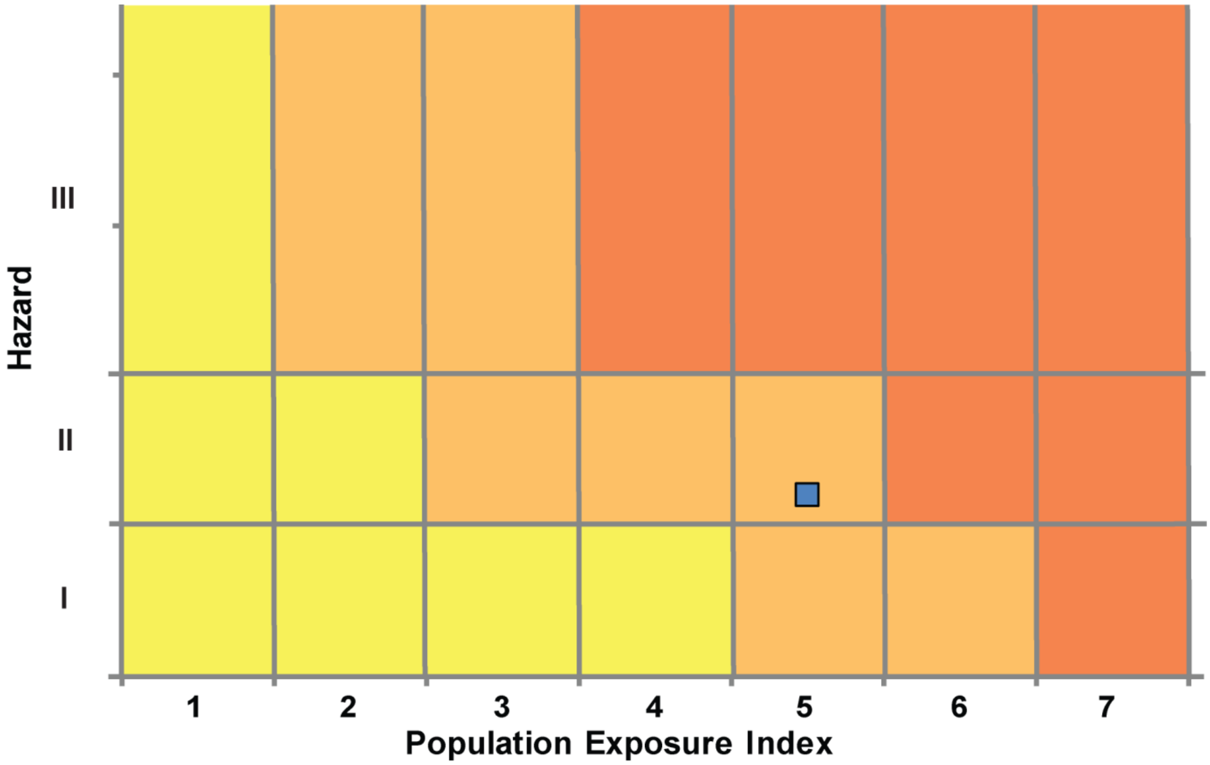

Figure 3.14 Distribution of the classified volcanoes of France's territories in the Indian Ocean across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

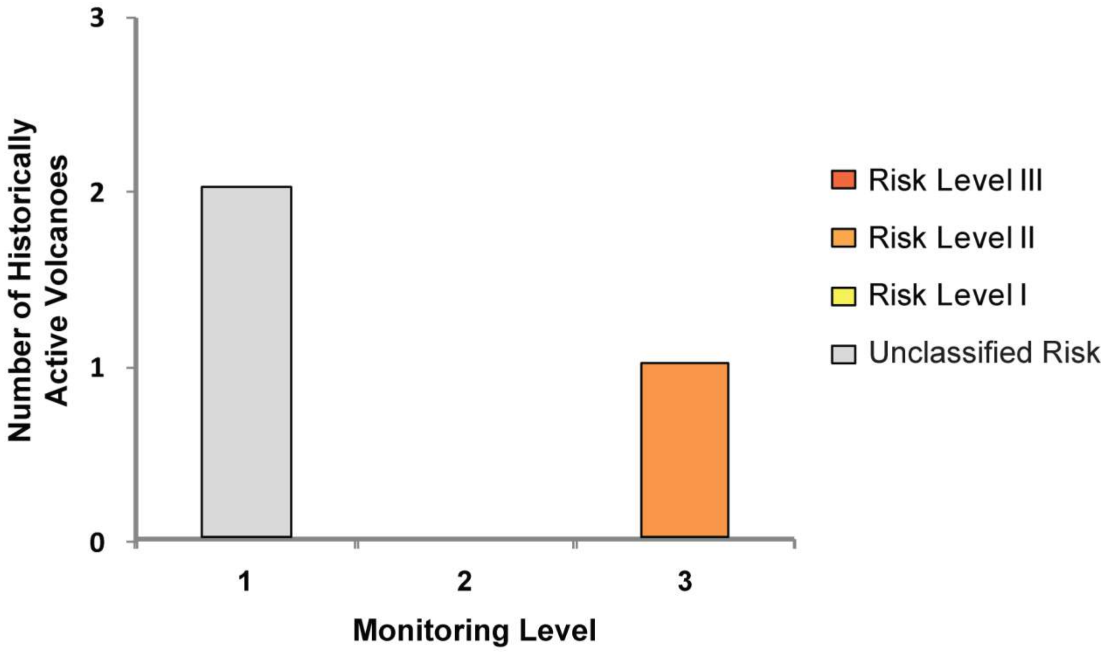

Figure 3.15 The monitoring and risk levels of the historically active volcanoes in the French territories in the Indian Ocean. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Iran

Description

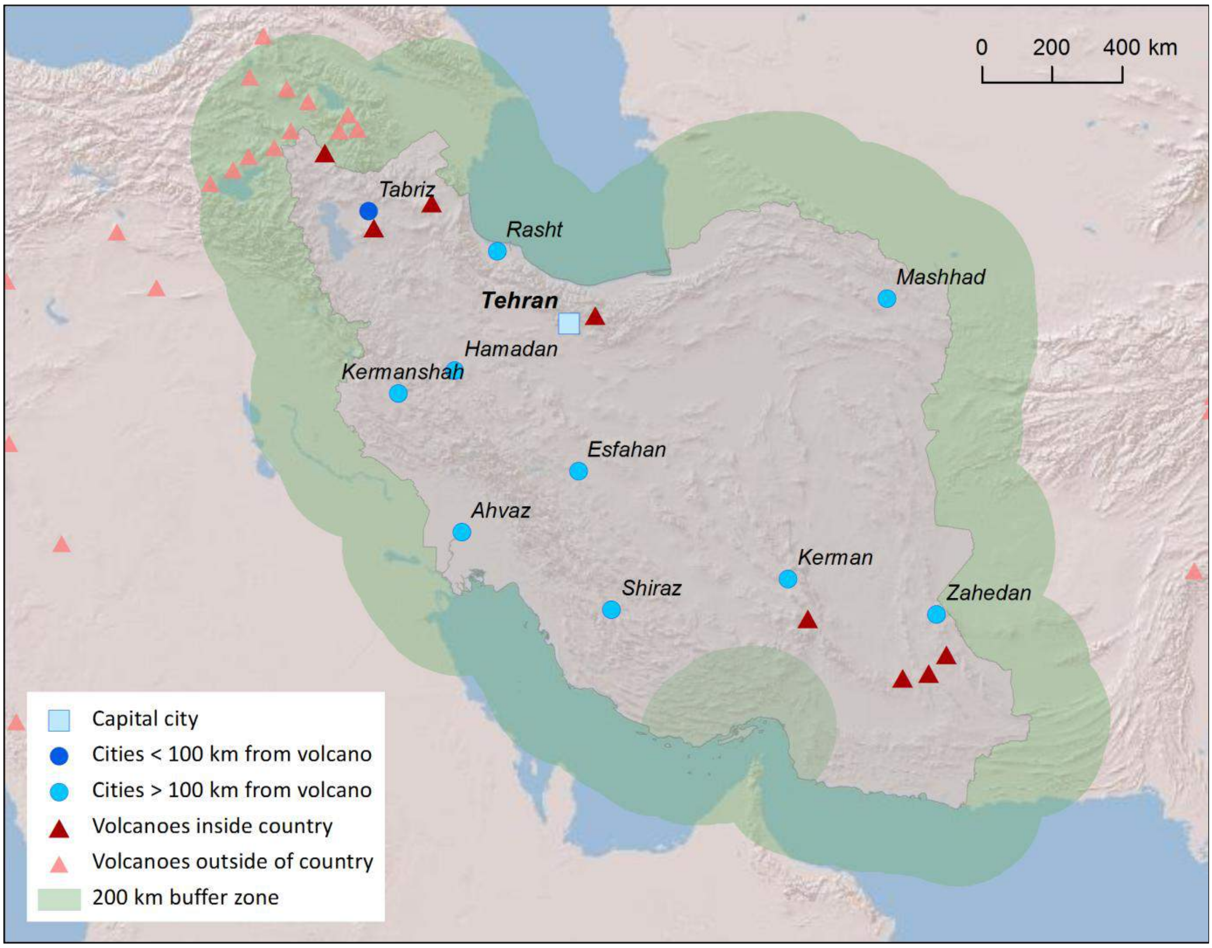

Figure 3.16 Location of Iran's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Iran.

Eight volcanoes are located in Iran, including one on the border with Azerbaijan. All but one volcano, the Qal'eh Hasan Ali maar, are andesitic stratovolcanoes or basaltic volcanic fields. Although VOTW4.0 classes Iran's volcanoes as dominantly intra-plate features, there is some evidence of subduction related magmatism in the country. Most volcanic centres in Iran are within the syn-collision Turkish-Iranian plateau; some in the east are related to the Makran subduction and their magmatism is affected by subduction processes. Most of the Quaternary volcanism is related to the continental collision between the Arabian and Iranian plates. Iran has many Cenozoic volcanic centres that relate to either i) the pre-collisional, subduction of NeoTethys under Eurasia, or, ii) melting of mantle under Eurasia during the subsequent Arabia-Eurasia collision. Damavand volcano is a large intraplate Quaternary composite cone overlying the active fold and thrust belt of the Central Alborz Mountains in northern Iran with no evidence of subduction-related fluids (Davidson et al., 2004, Mirnejad et al., 2010). The Qa'le Hasan Ali maars in central Iran show compositions indicative of the subduction of the Neotethys oceanic lithosphere below Iran (Saadat et al., 2014). There is evidence of further Quaternary volcanic activity with lavas identified in the Kurdistan Province of western Iran (Allen et al., 2013).

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).

References

Allen, M.B., Kheirkhah, M., Neill, I., Emami, M.H., and McLeod, C.L. (2013) Generation of arc and within-plate chemical signatures in collision zone magmatism: Quaternary lavas from Kurdistan Province, Iran. *Journal of Petrology*, 54: 887-911.

Asian Disaster Reduction Center: Iran: www.adrc.asia/nationinformation.php?NationCode=364&Lang=en&NationNum=38

Davidson, J., Hassanzadeh, J., Berzins, R., Stockli, D.F., Bashukooh, B., Turrin, B. And Pandamouz, A. (2004) The geology of Damavand volcano, Alborz Mountains, northern Iran. *Geological Society of America Bulletin*, 116: 16-29.

Mirnejad, H., Hassanzadeh, J., Cousens, B.L. and Taylor, B.E. (2010) Geochemical evidence for deep mantle melting and lithospheric delamination as the origin of the inland Damavand volcanic rocks of northern Iran. Journal of Volcanology and Geothermal Research, 198: 288-296.

National Disaster Management Organisation: www.ndmo.org/

Saadat, S., Stern, C.R. and Moradian, A. (2014) Petrochemistry of ultrapotassic tephrites and associated cognate plutonic xenoliths with carbonatite affinities from the late Quaternary Qa'le Hasan Ali maars, central Iran. *Journal of Asian Earth Sciences*, 89: 108-122.

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 3.15 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 their 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

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.

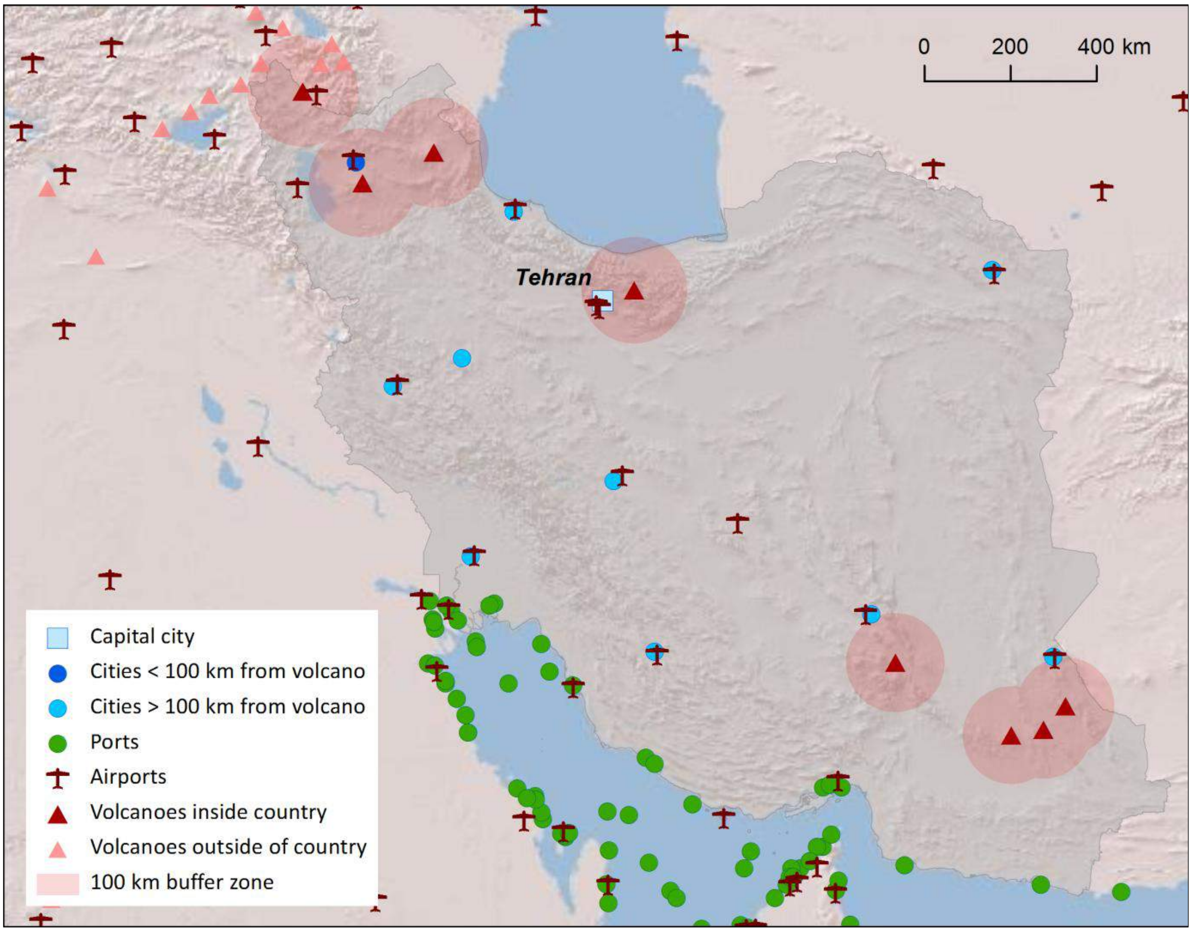

Figure 3.17 The location of Iran's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 3.16 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 1900 AD, 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

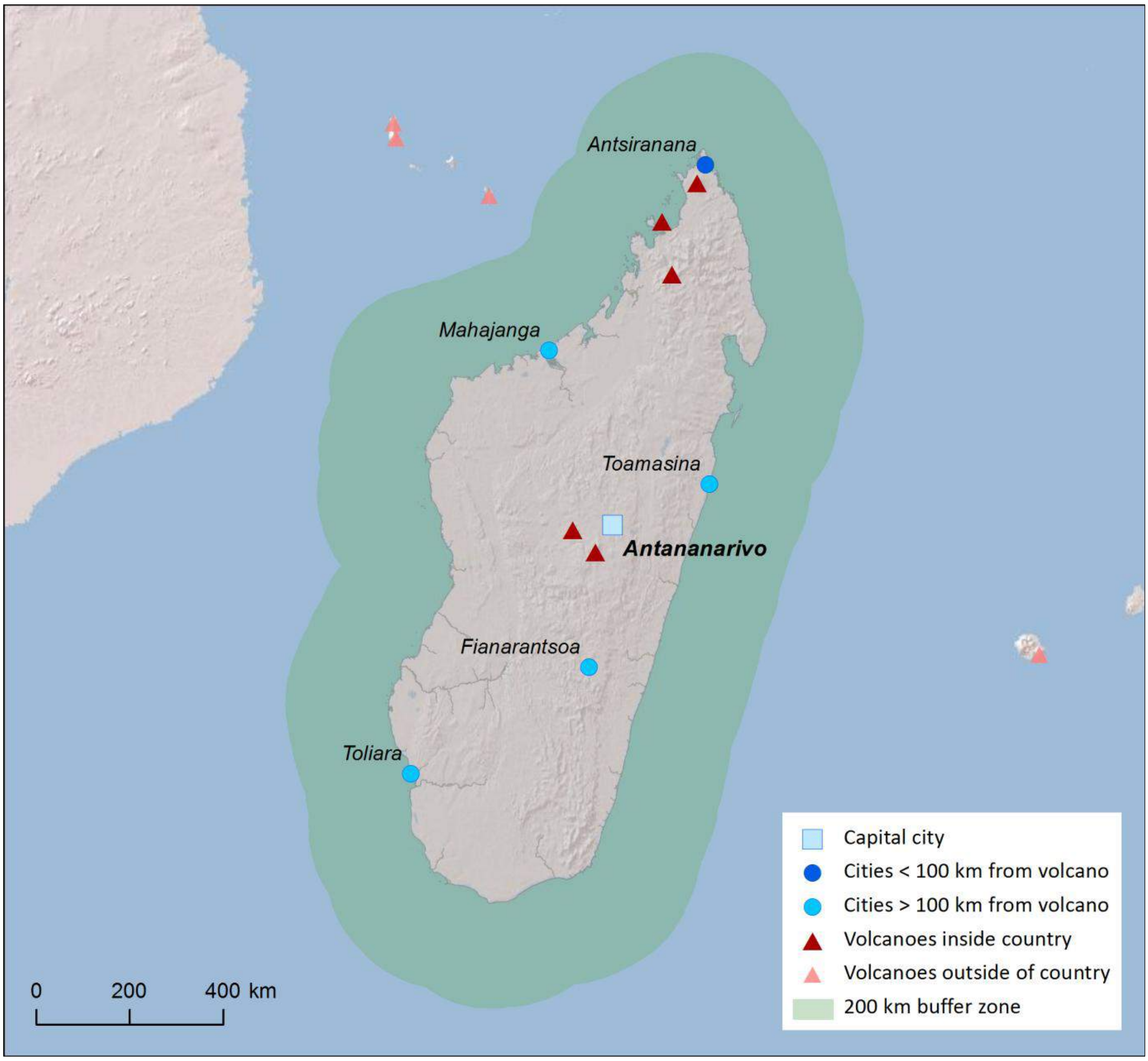

Figure 3.18 Location of Madagascar's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Madagascar.

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.
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 3.17 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 their population size:

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

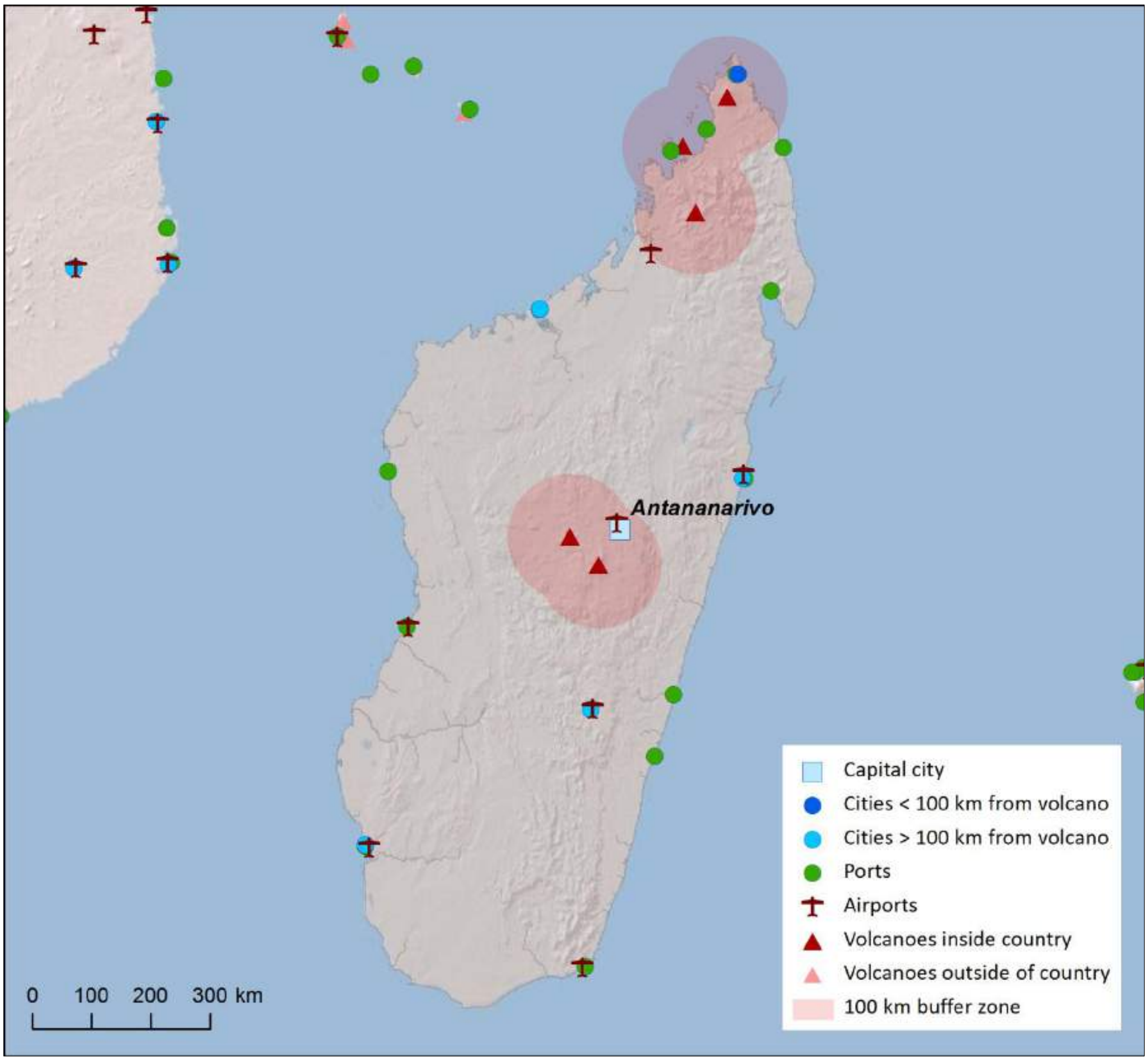

Figure 3.19 The location of Madagascar's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 3.18 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 1900 AD, 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

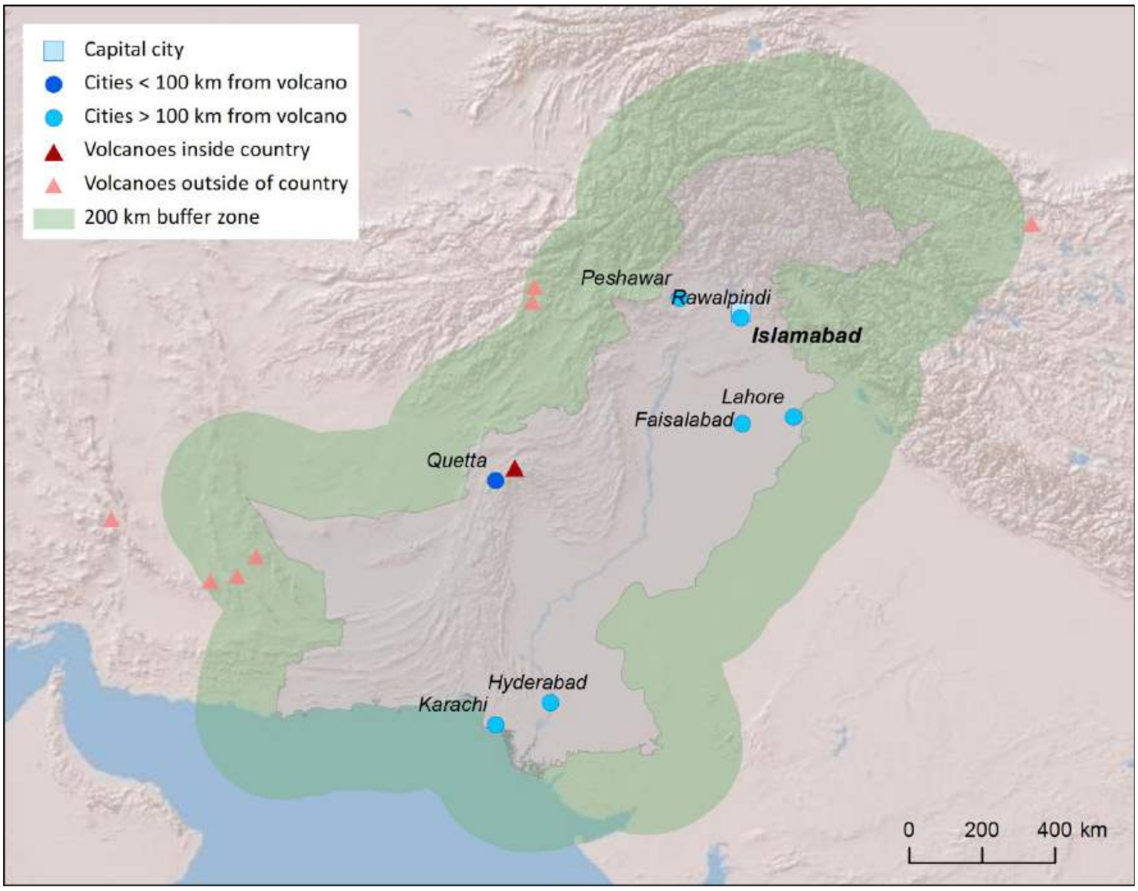

Figure 3.20 Location of Pakistan's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Pakistan.

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: www.adrc.asia/nationinformation.php?NationCode=586&Lang=en&NationNum=31

National Disaster Management Authority: 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 3.19 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 their population size:

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

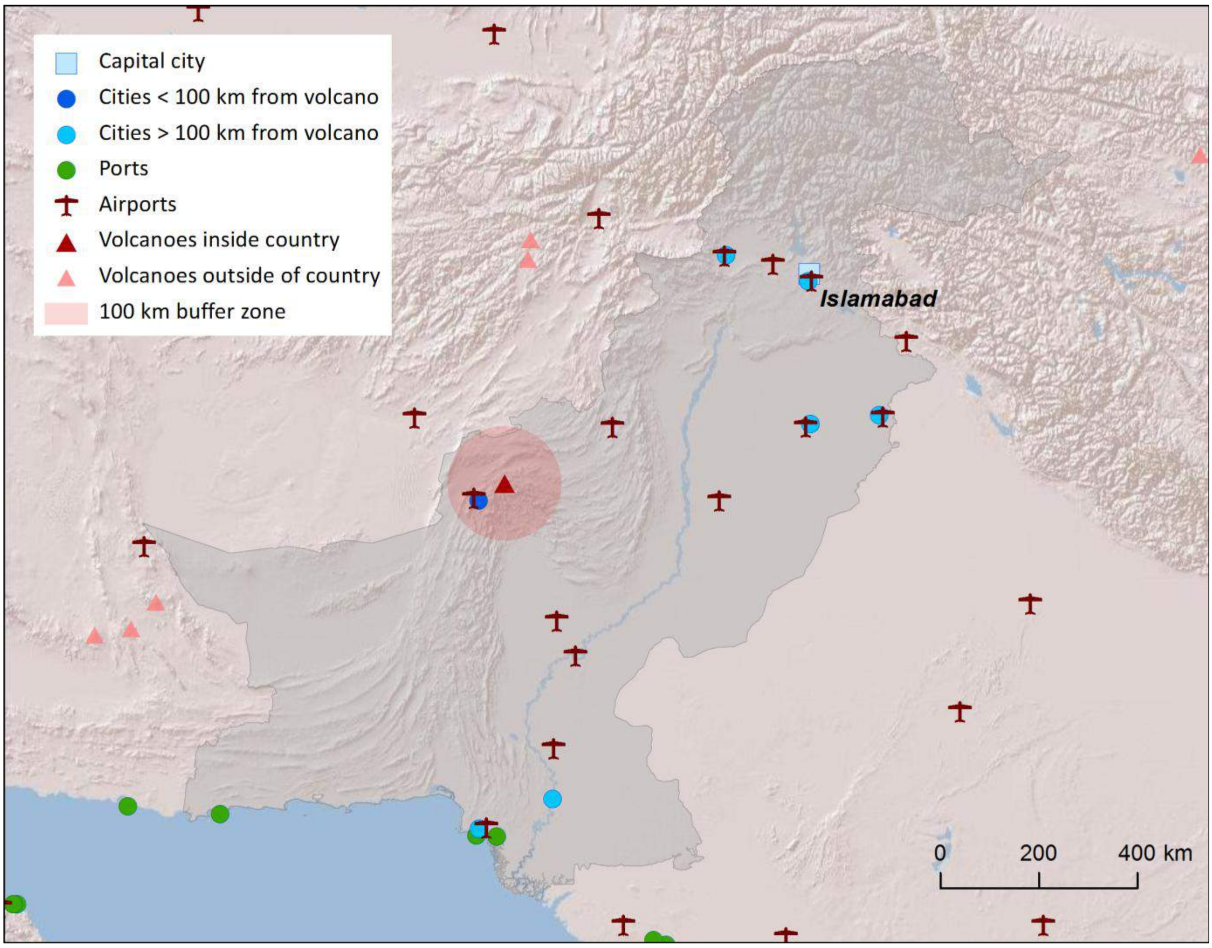

Figure 3.21 The location of Pakistan's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 3.20 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 1900 AD, 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.

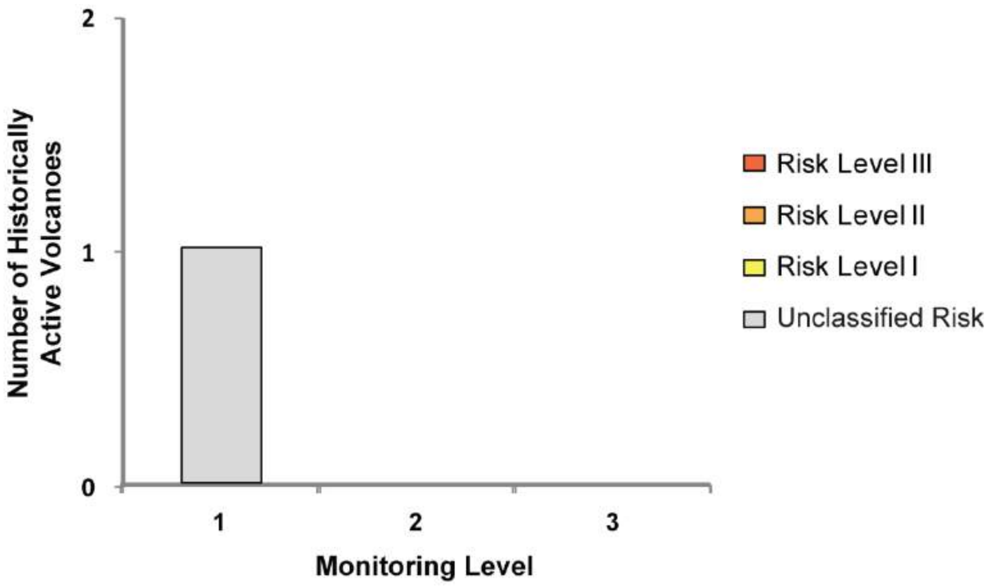

Figure 3.22 The monitoring and risk levels of the historically active volcanoes in Pakistan. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Saudi Arabia

Description

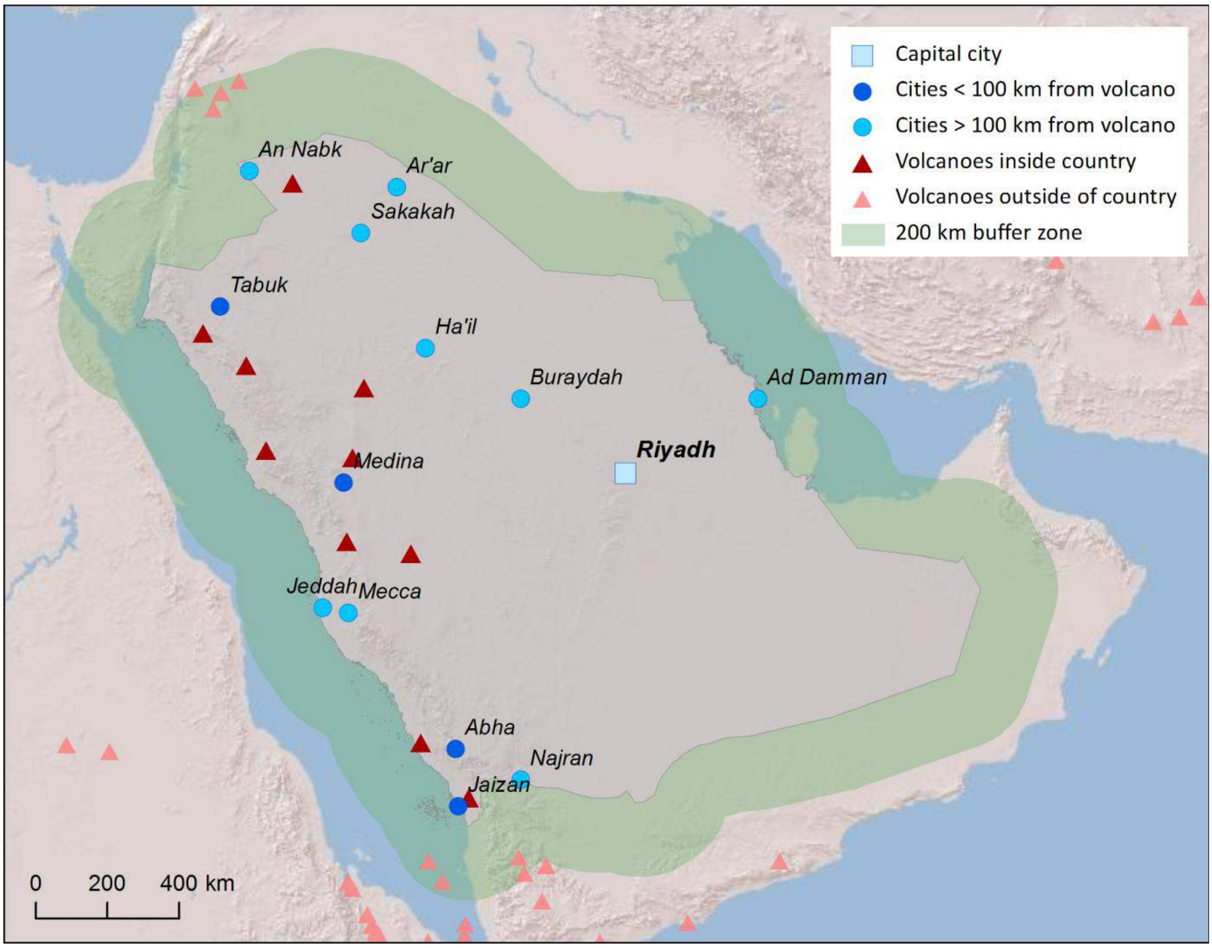

Figure 3.23 Location of Saudi Arabia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Saudi Arabia.

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.

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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 programme. 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
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 3.21 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 Holocene volcano	4,623,079 (17.7%)

Ten largest cities, as measured by population and their population size:

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

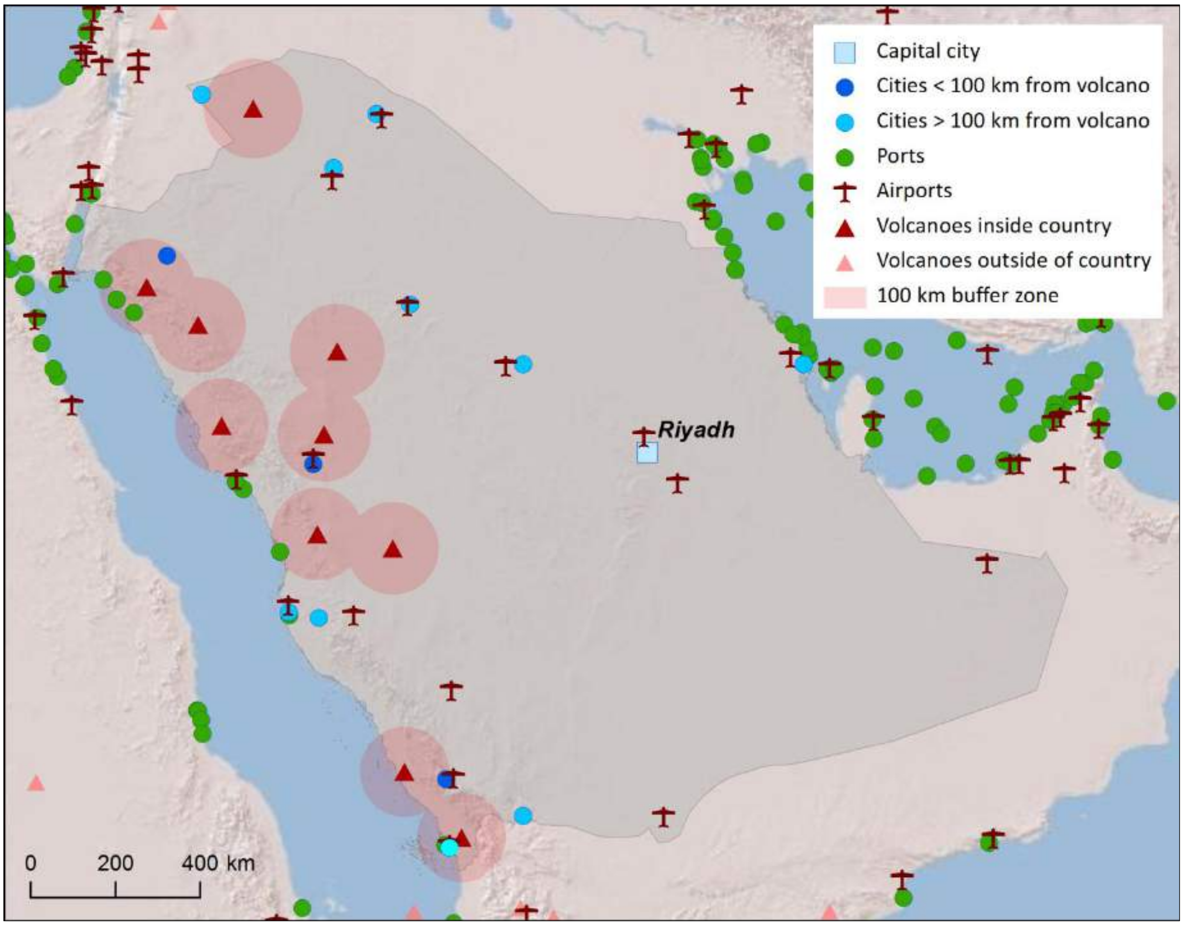


Figure 3.24 The location of Saudi Arabia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 3.22 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 1900 AD, 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.

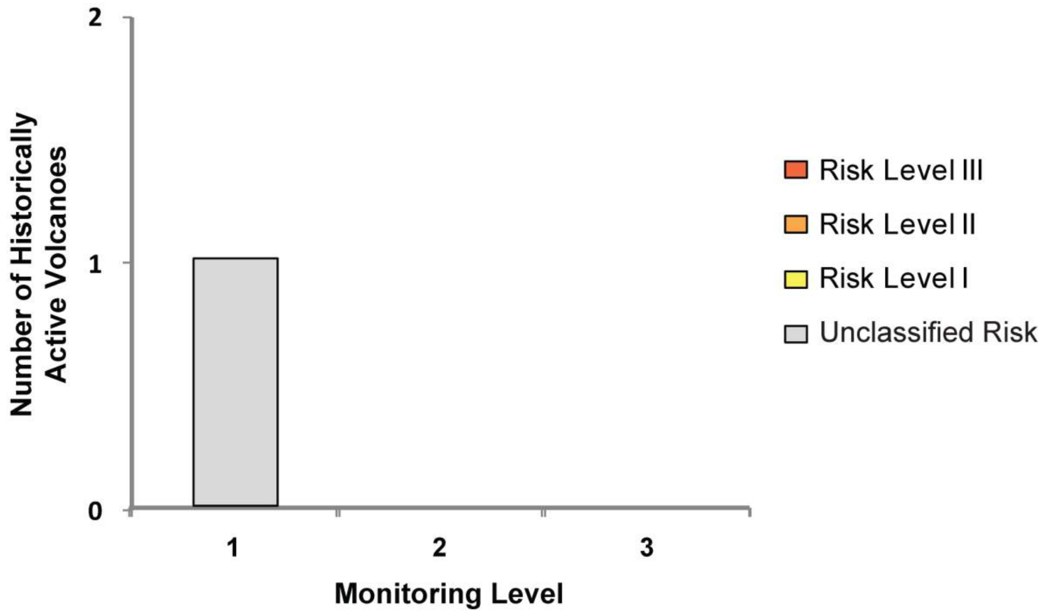


Figure 3.25 The monitoring and risk levels of the historically active volcanoes in Saudi Arabia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

South Africa

Description

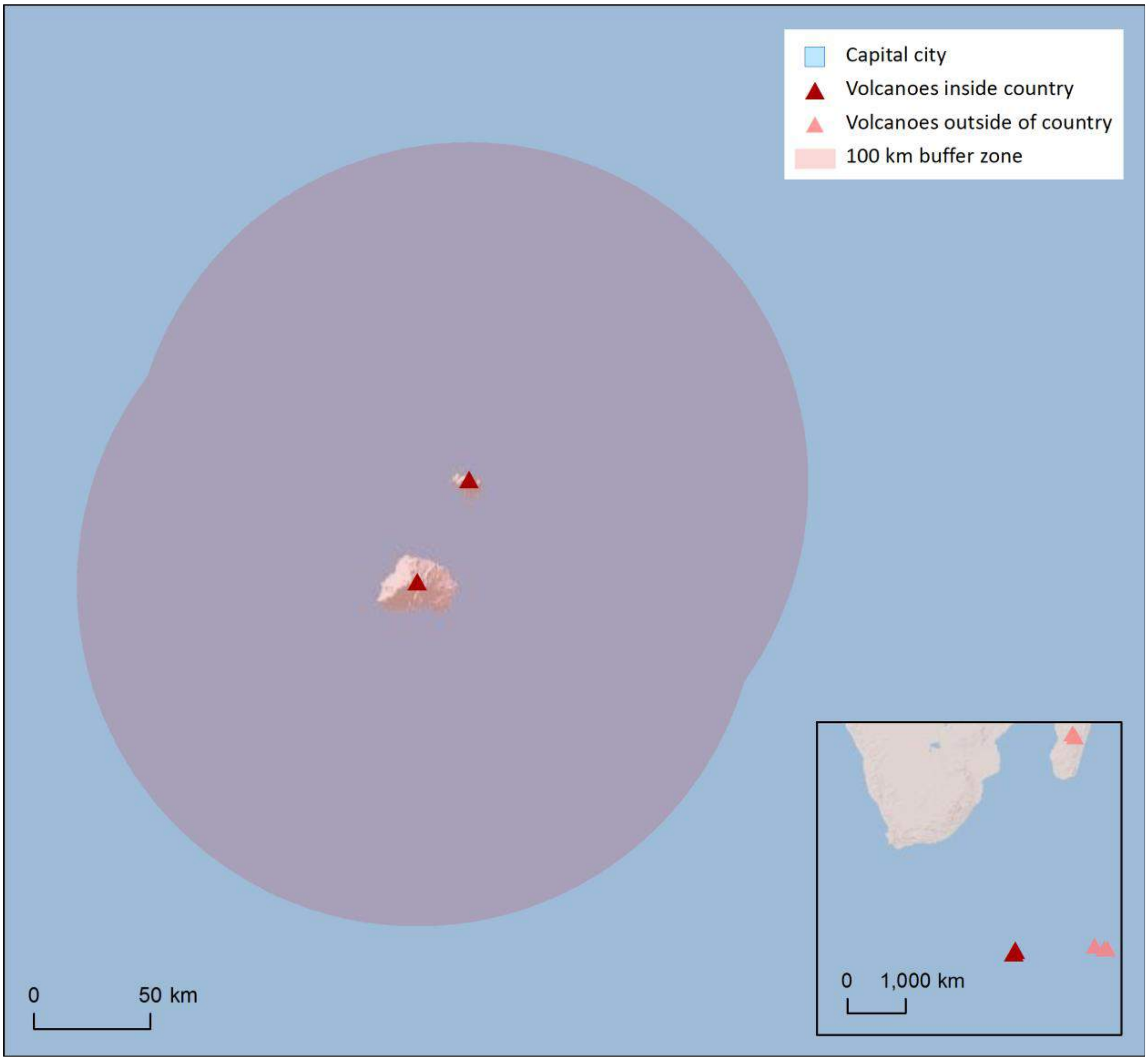


Figure 3.26 Location of South Africa's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect South Africa.

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 3.23 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 their population size:

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 3.24 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 1900 AD, 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.

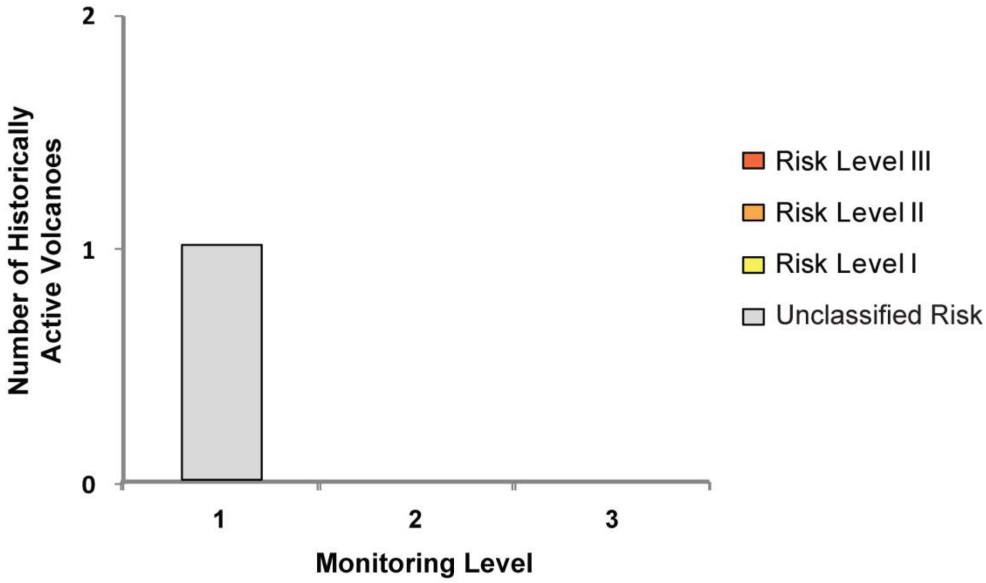


Figure 3.27 The monitoring and risk levels of the historically active volcanoes in South Africa. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Syria

Description

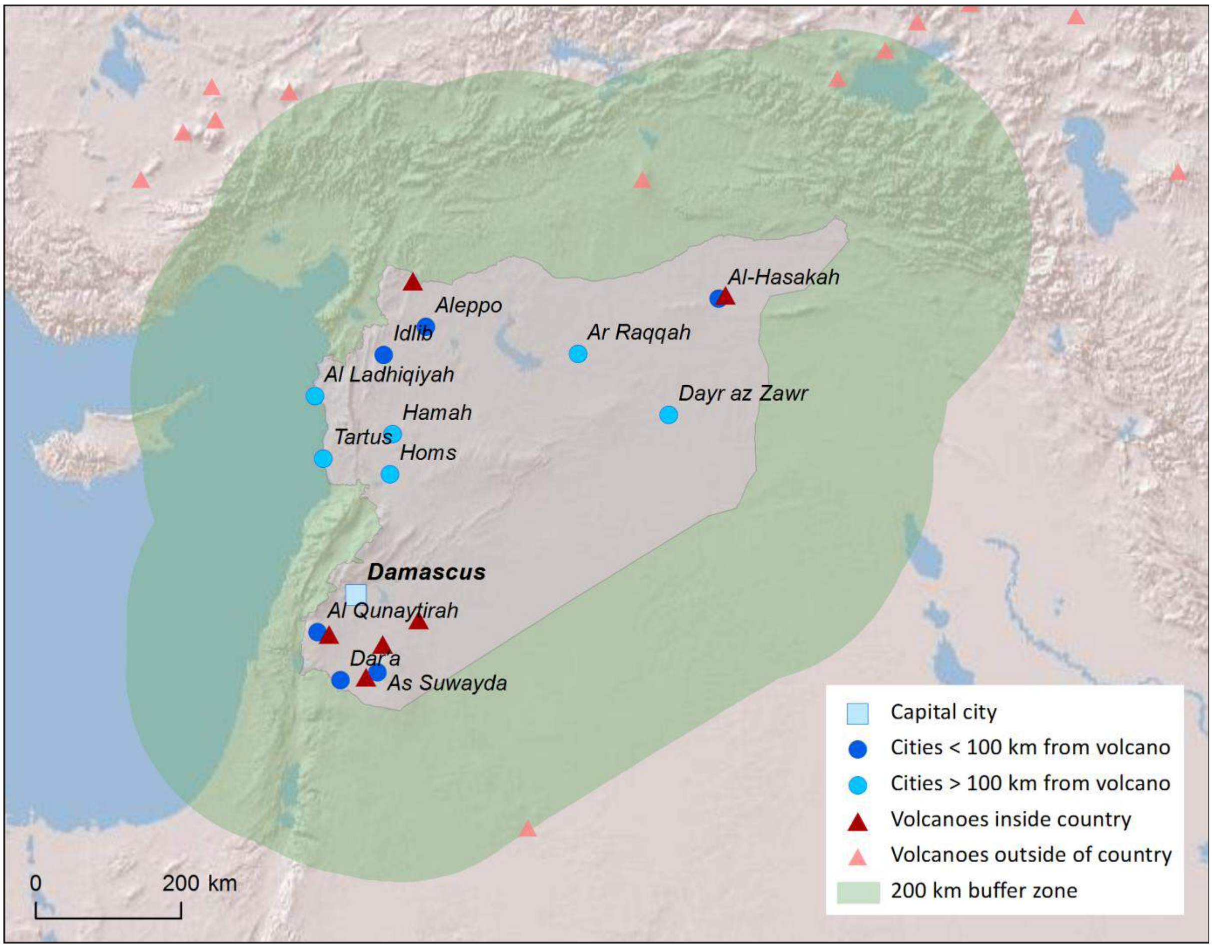


Figure 3.28 Location of Syria's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Syria.

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 3.25 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 their population size:

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

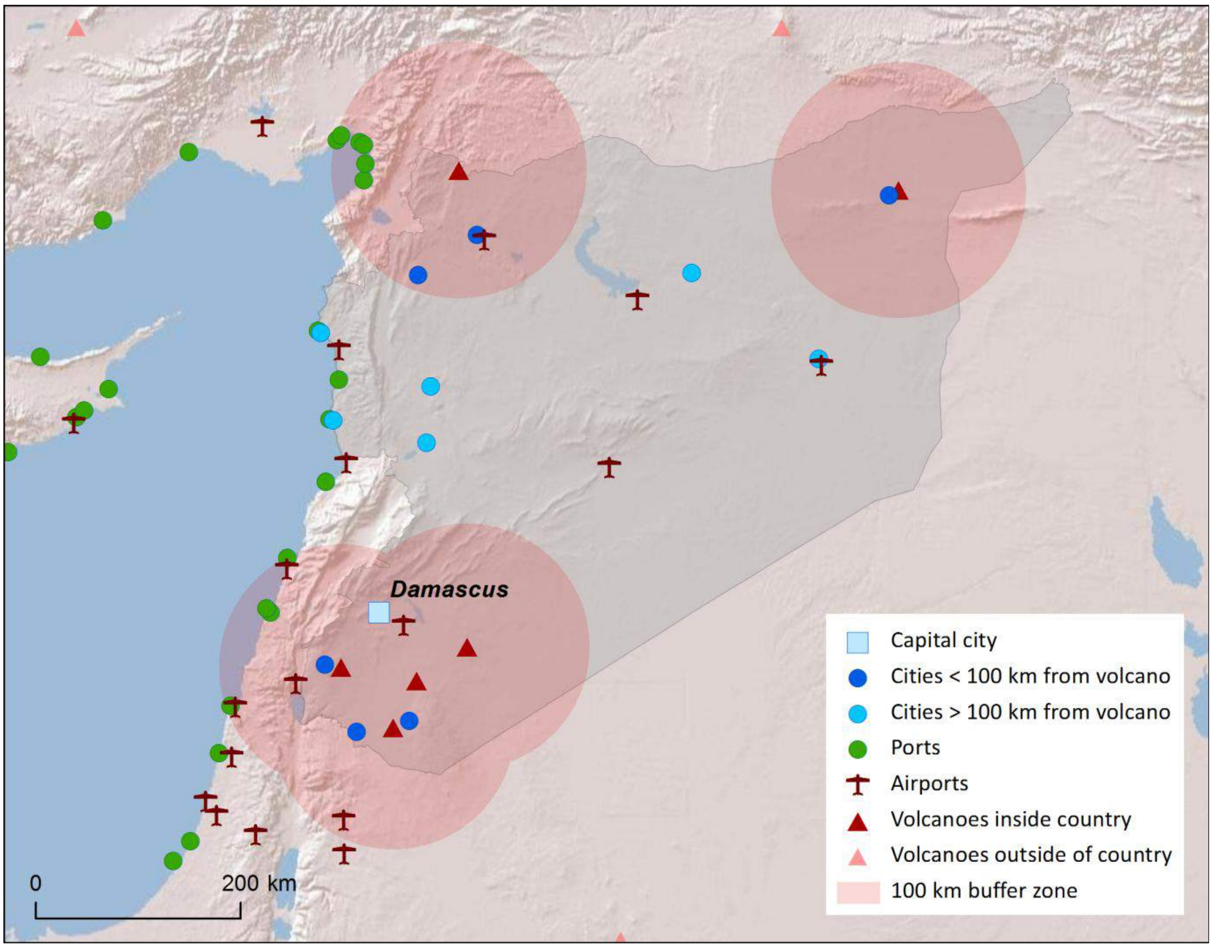


Figure 3.29 The location of Syria's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 3.26 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 1900 AD, 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.

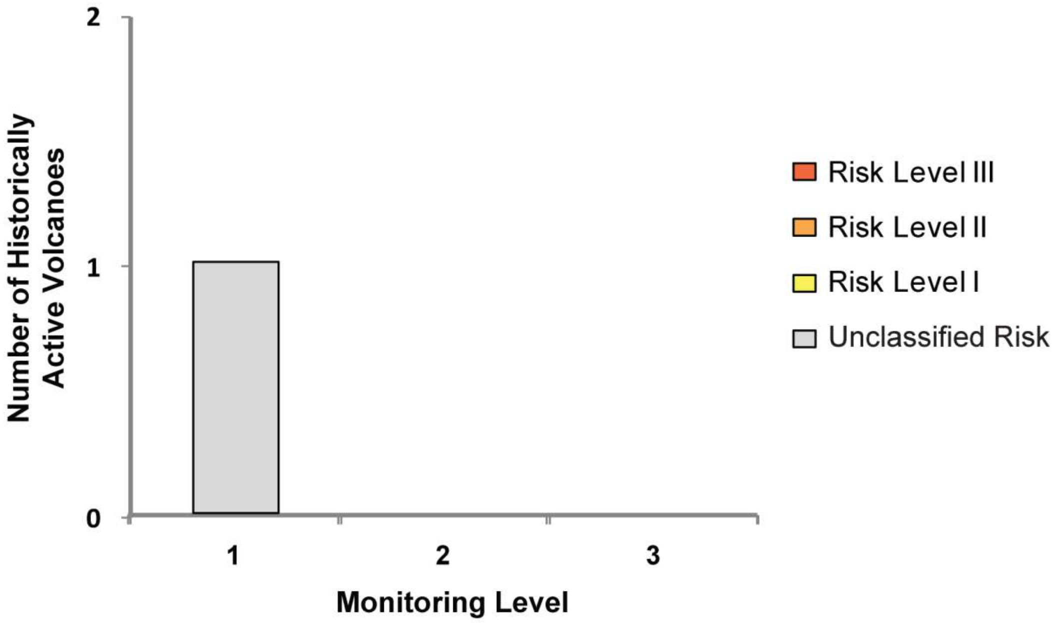


Figure 3.30 The monitoring and risk levels of the historically active volcanoes in Syria. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates 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

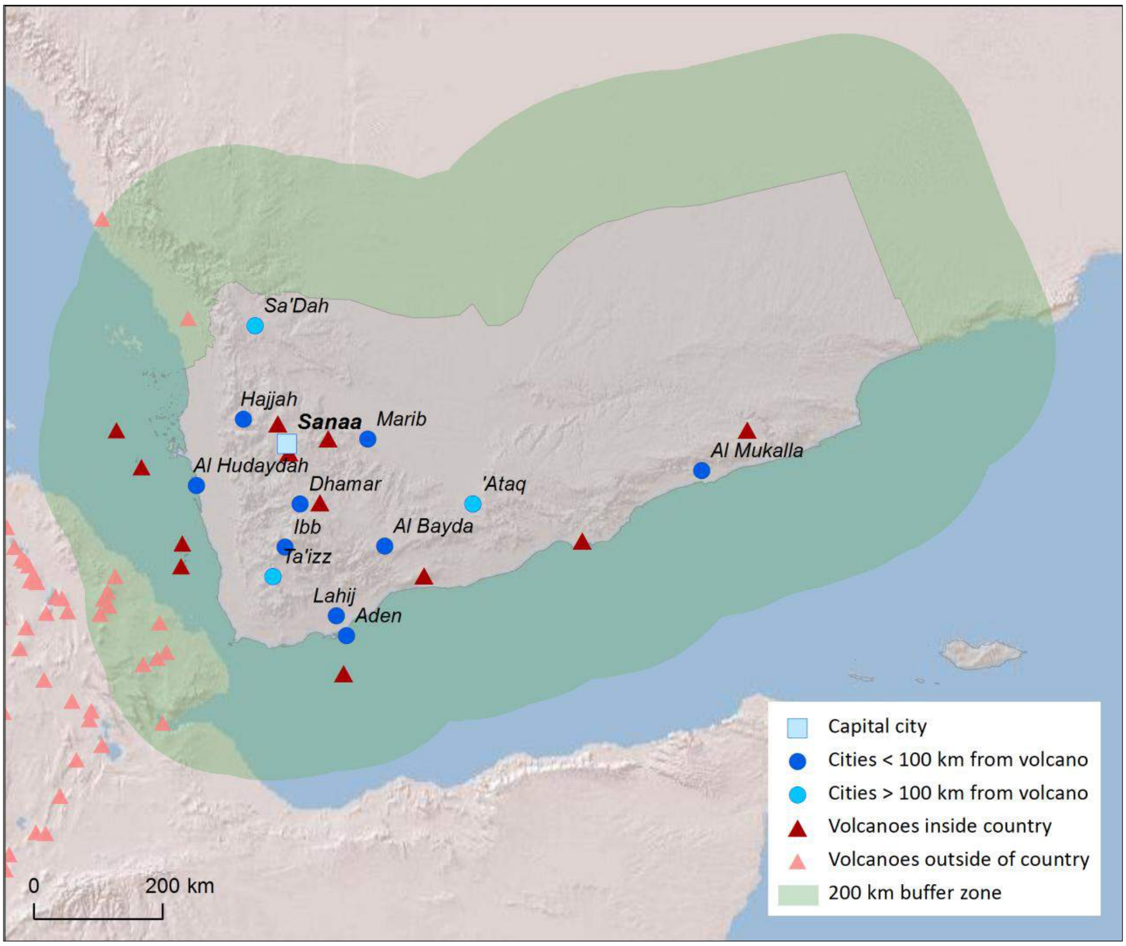


Figure 3.31 Location of Yemen’s volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Yemen.

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, www.nsoc.org.ye/

Asian Disaster Reduction Center: Yemen:
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 3.27 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 their population size:

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.

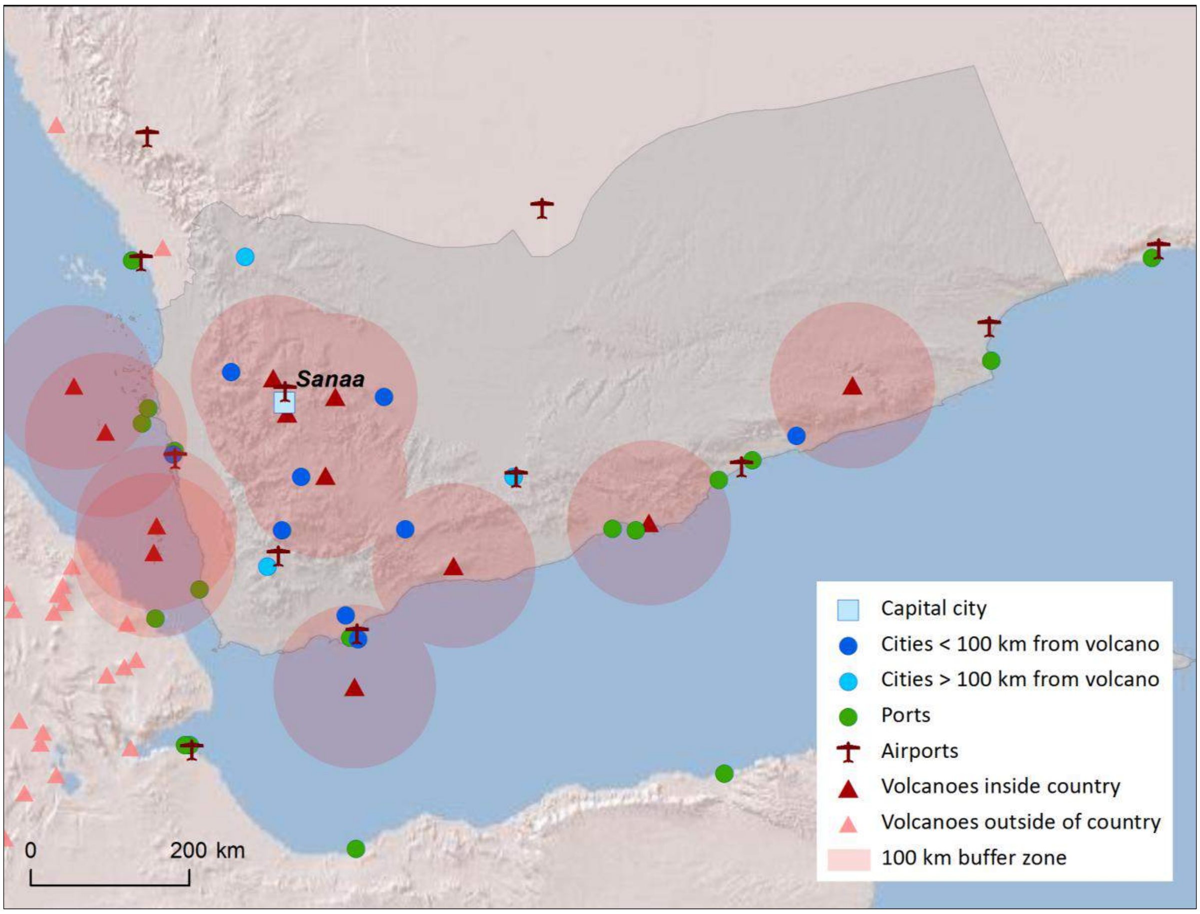


Figure 3.32 The location of Yemen's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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.

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	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 3.28 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 1900 AD, 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 3.29 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.

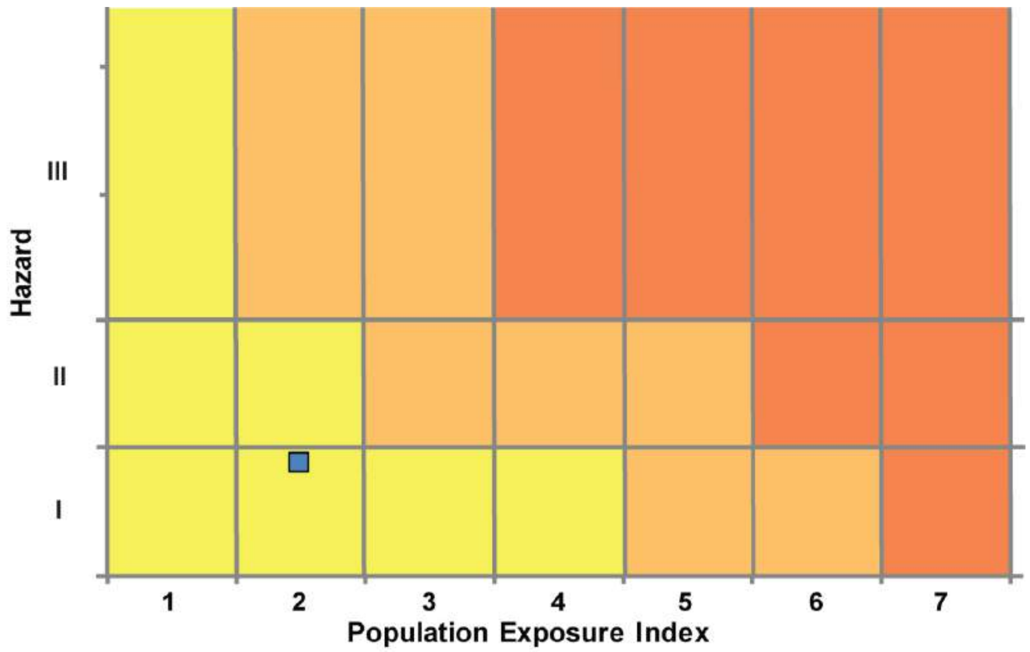


Figure 3.33 Distribution of Yemen's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

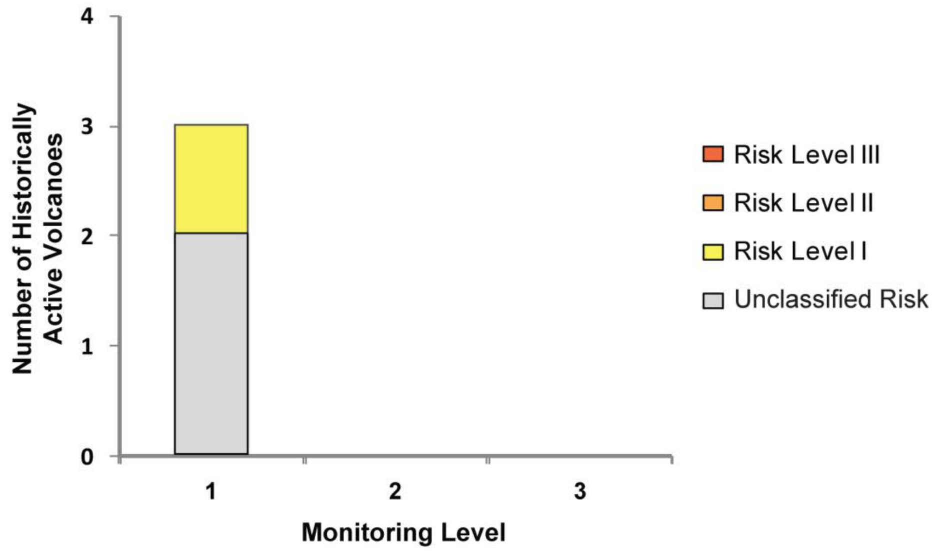
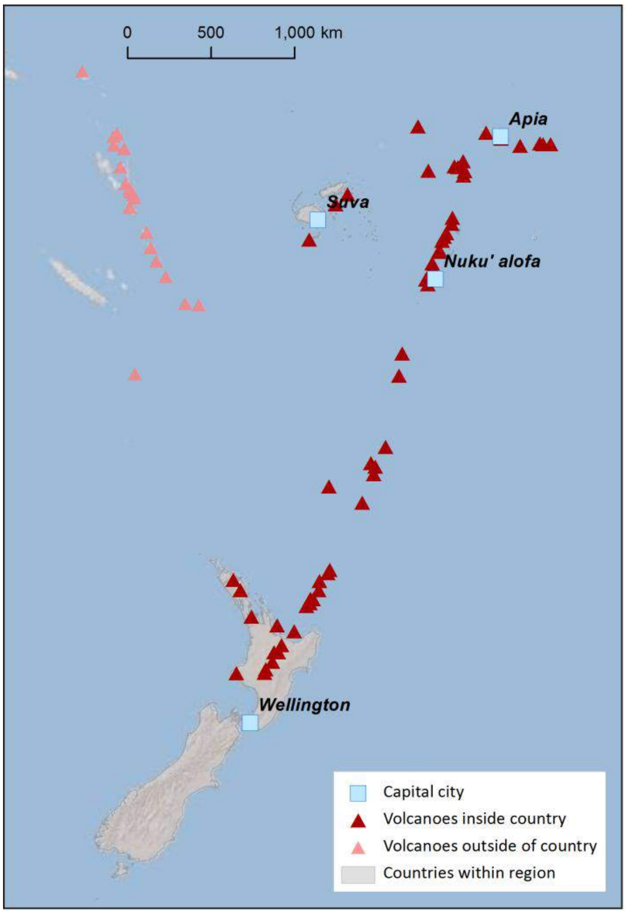


Figure 3.34 The monitoring and risk levels of the historically active volcanoes in Yemen. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 4: New Zealand to Fiji



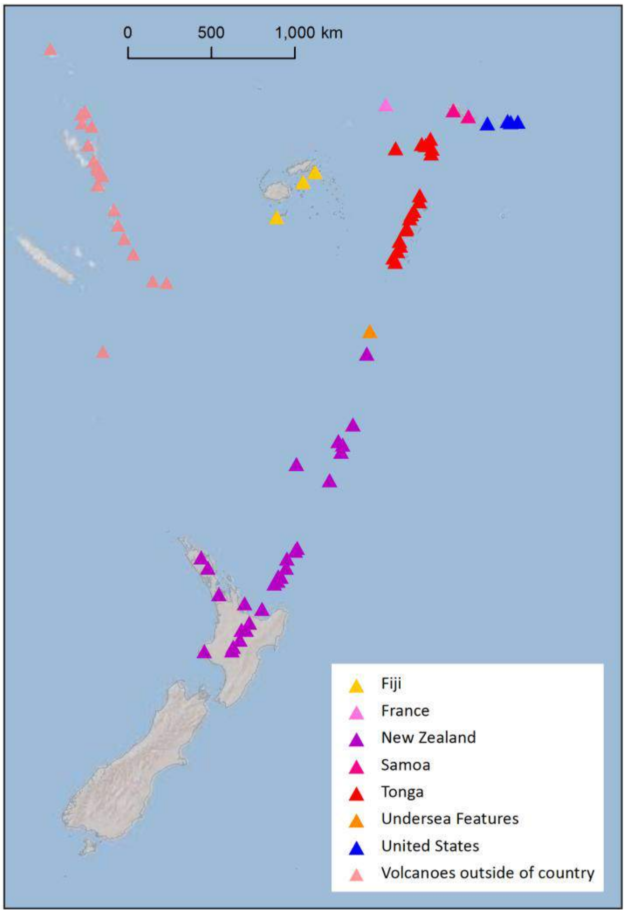


Figure 4.1 The distribution of Holocene volcanoes through the New Zealand to Fiji region. The capital cities of the constituent countries are shown.

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 4.1 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. Of historical events, 6% 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 4.2 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 4.3 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.

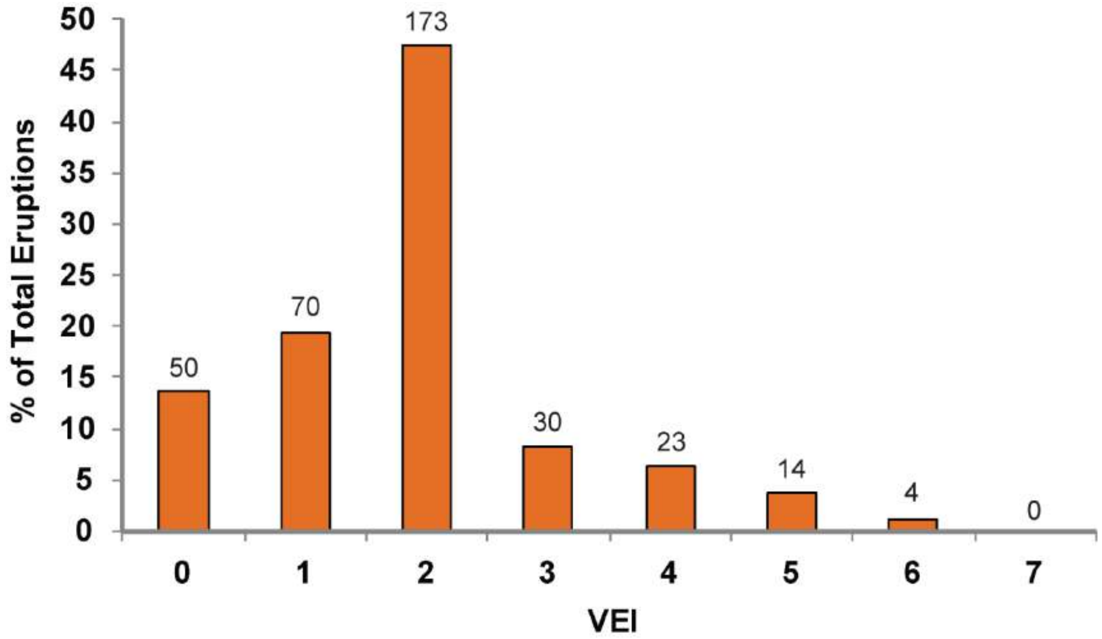


Figure 4.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 73 eruptions were recorded with unknown VEI.

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 4.4 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 1900 AD, 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 4.5 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 4.6 The number of volcanoes in the New Zealand to Fiji region classified at each Risk Level.

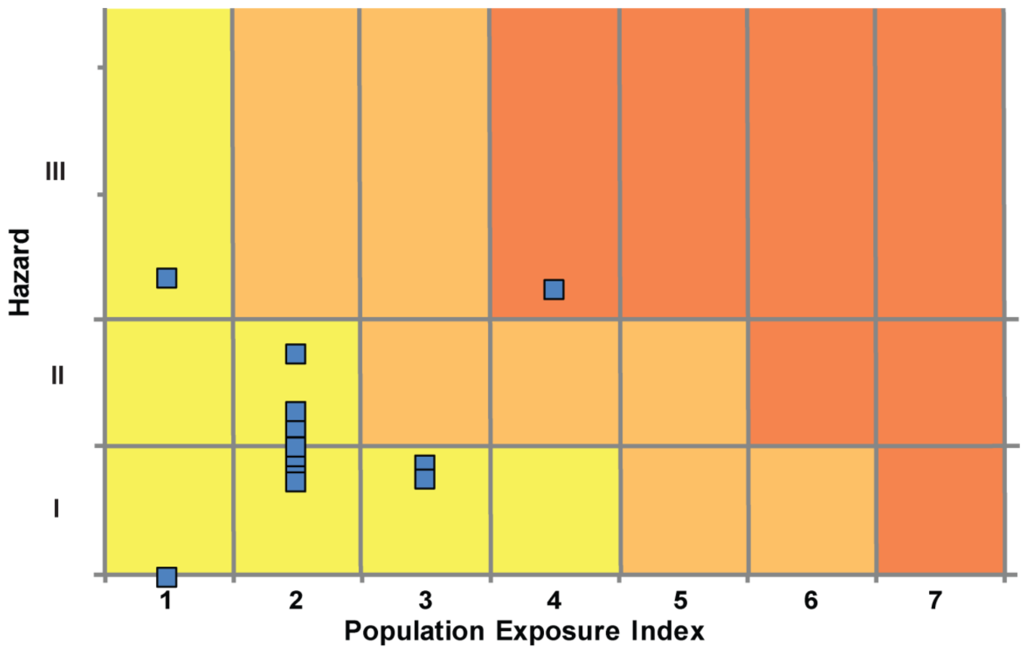


Figure 4.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional Monitoring Capacity

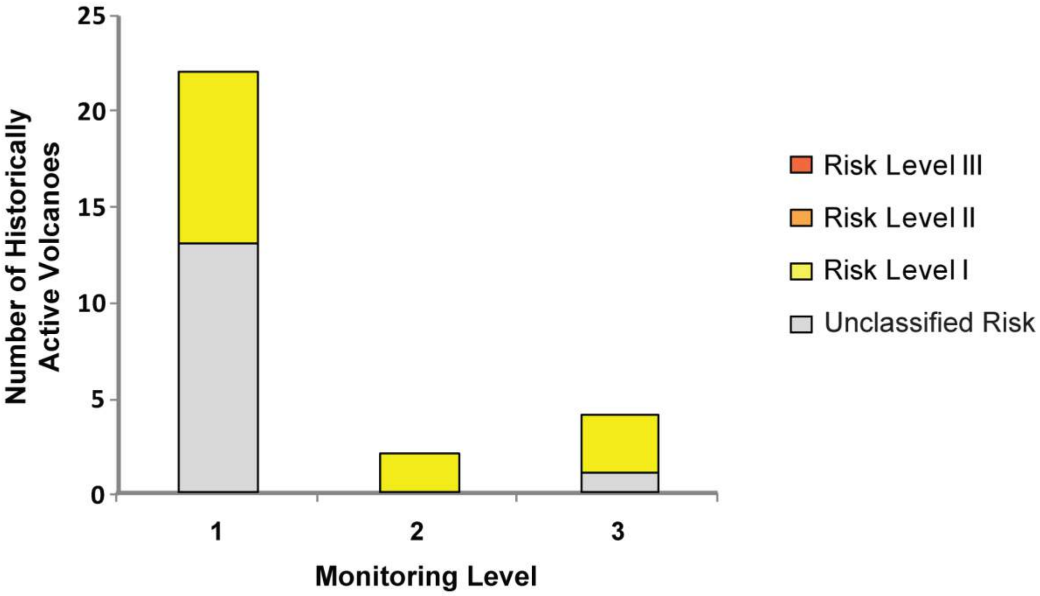


Figure 4.4 The monitoring and risk levels of the historically active volcanoes in New Zealand to Fiji. Monitoring Level 1indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Fiji

Description

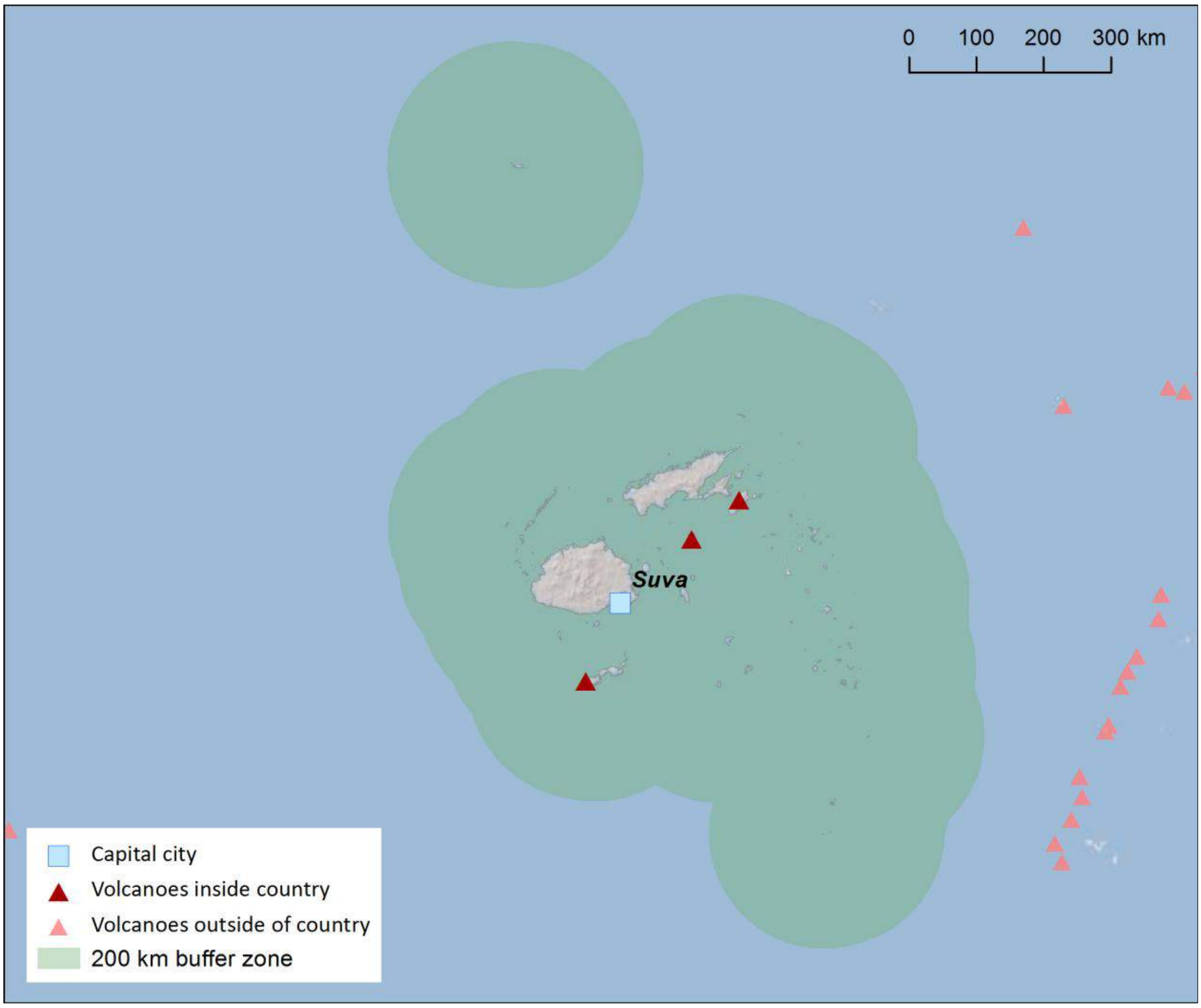


Figure 4.5 Location of Fiji's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Fiji.

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 4.7 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.

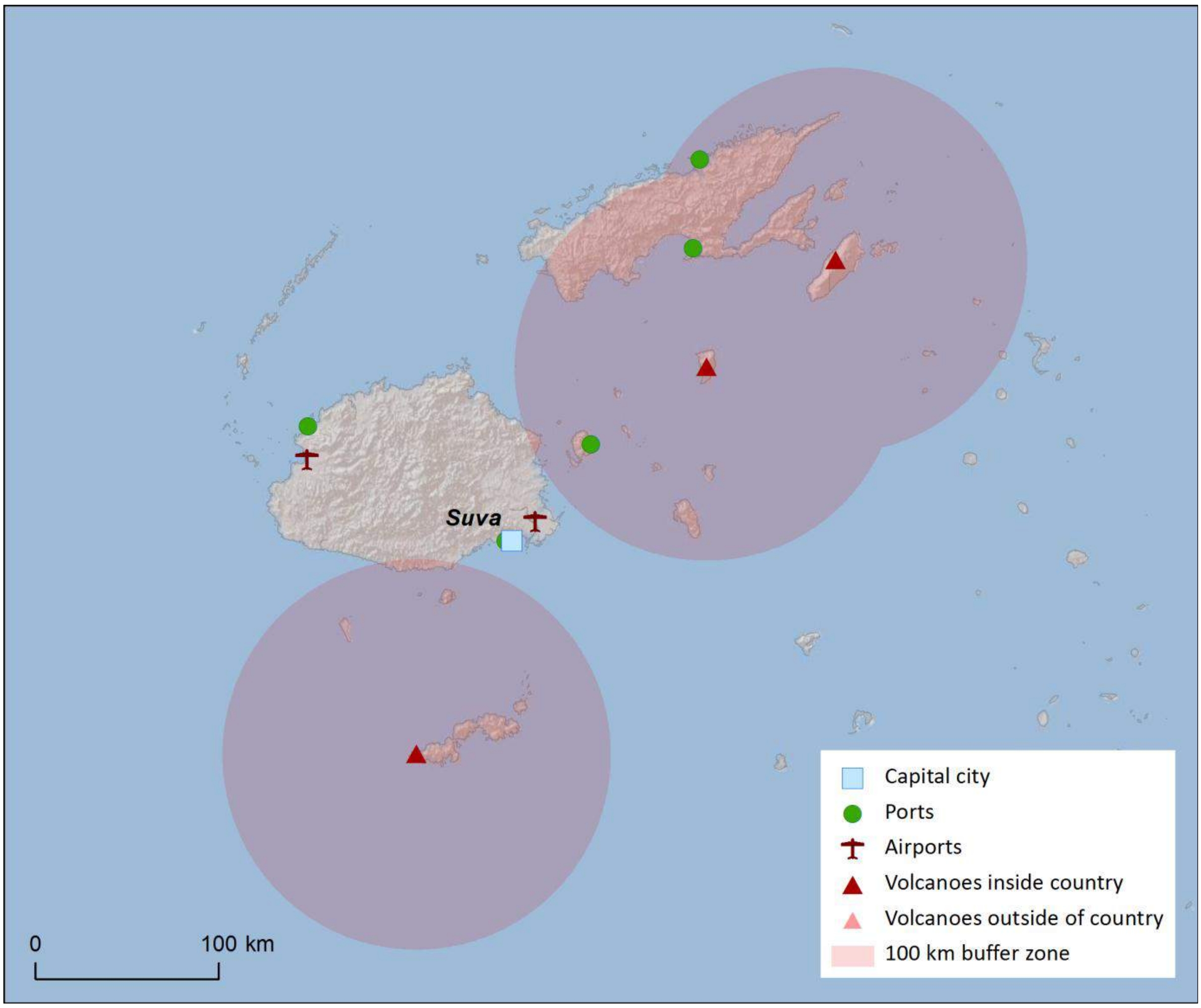


Figure 4.6 The location of Fiji's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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.

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

Table 4.8 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 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Taveuni	3	I

Table 4.9 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.

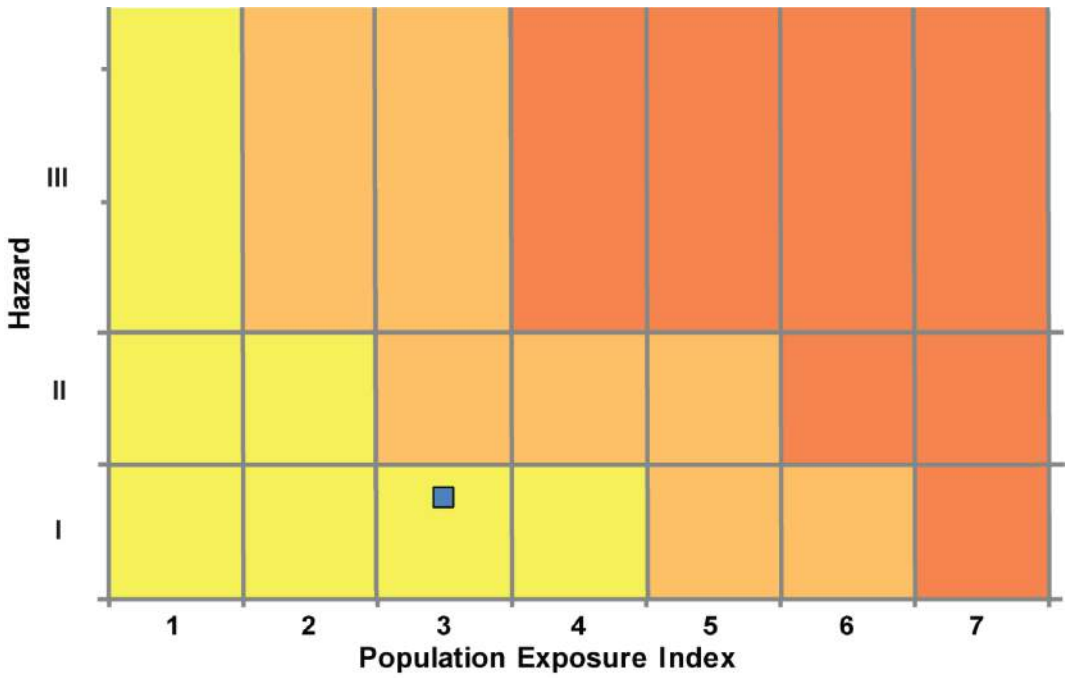


Figure 4.7 Distribution of Fiji's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

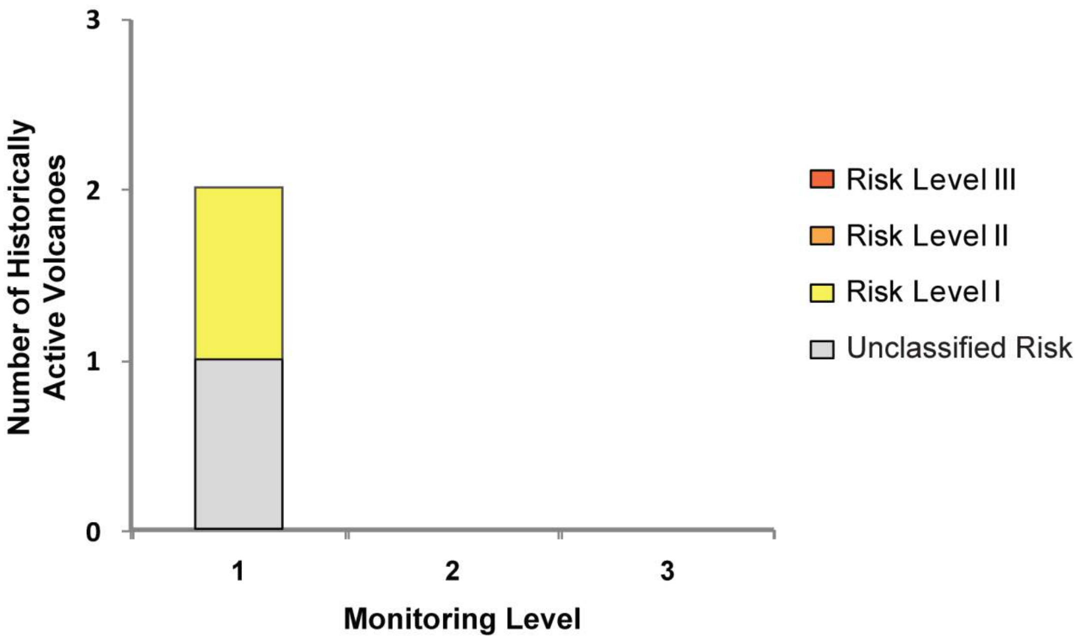


Figure 4.8 The monitoring and risk levels of the historically active volcanoes in Fiji. Monitoring Level 1indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates 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

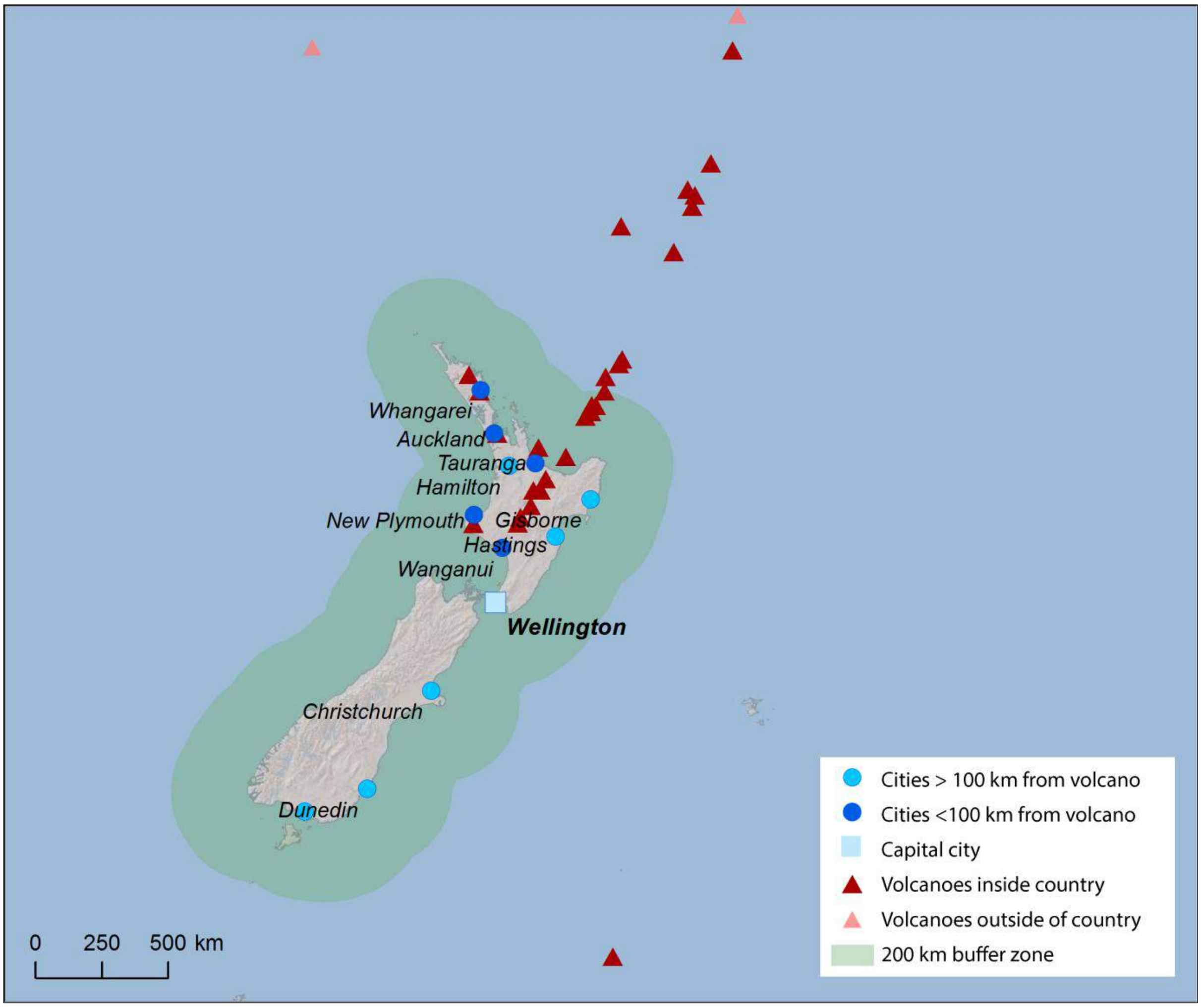


Figure 4.9 Location of New Zealand's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect New Zealand.

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. VOTW4.22 documents 326 Holocene eruptions 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 and 39 eruptions are recorded as having produced pyroclastic flows, with at least 20 resulting 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. At least 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. VOTW4.22 records five historical events in which lives were lost as a result of volcanic activity: at Okataina, Ruapehu and Raoul Island.

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: www.gns.cri.nz/Home/Our-Science/Natural-Hazards/Volcanoes

GeoNet: info.geonet.org.nz/display/volc/Volcano

Get Ready Get Thru: 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 4.10 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 their population size:

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.

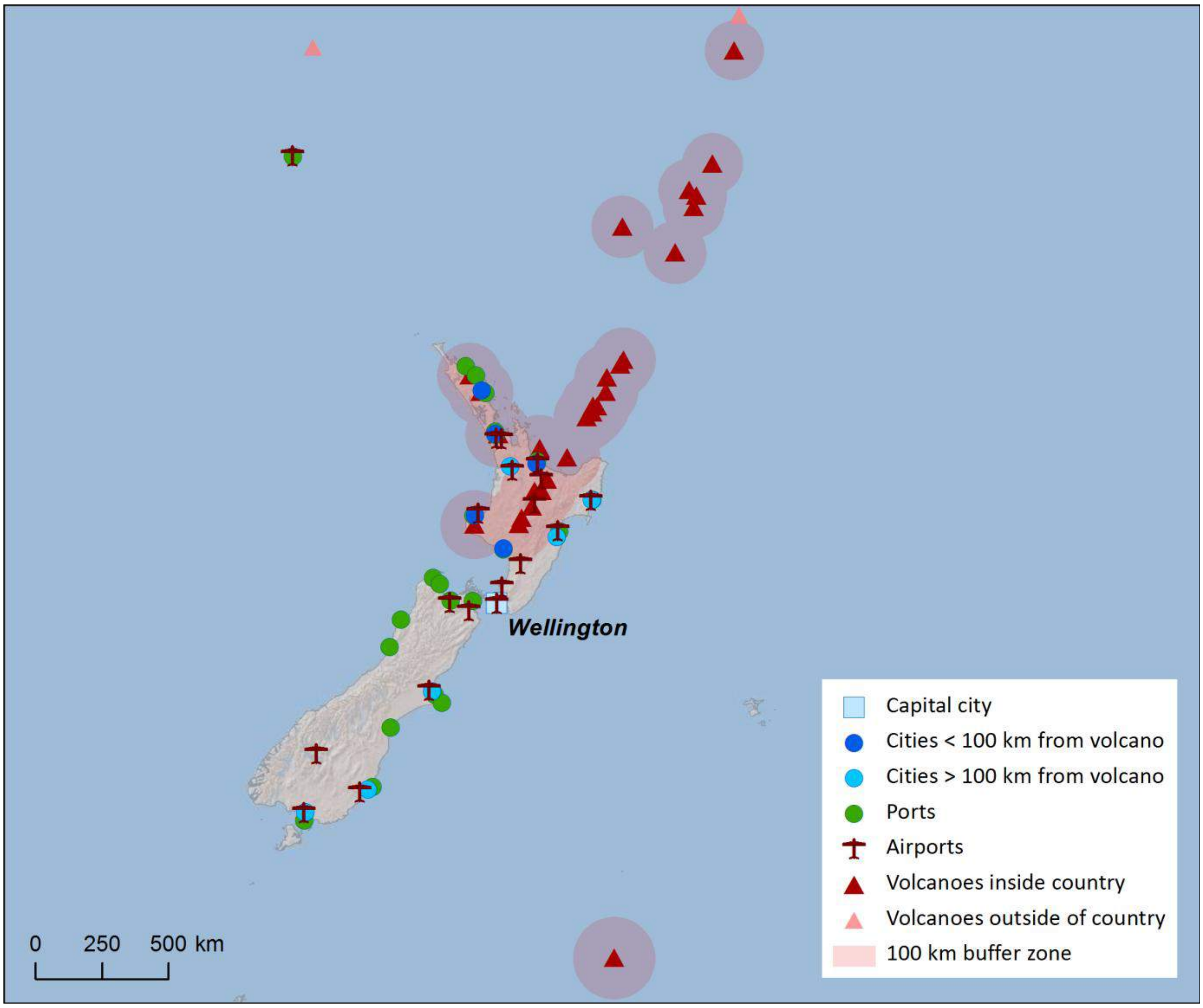


Figure 4.10 The location of New Zealand's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 4.11 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 1900 AD, 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 4.12 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.

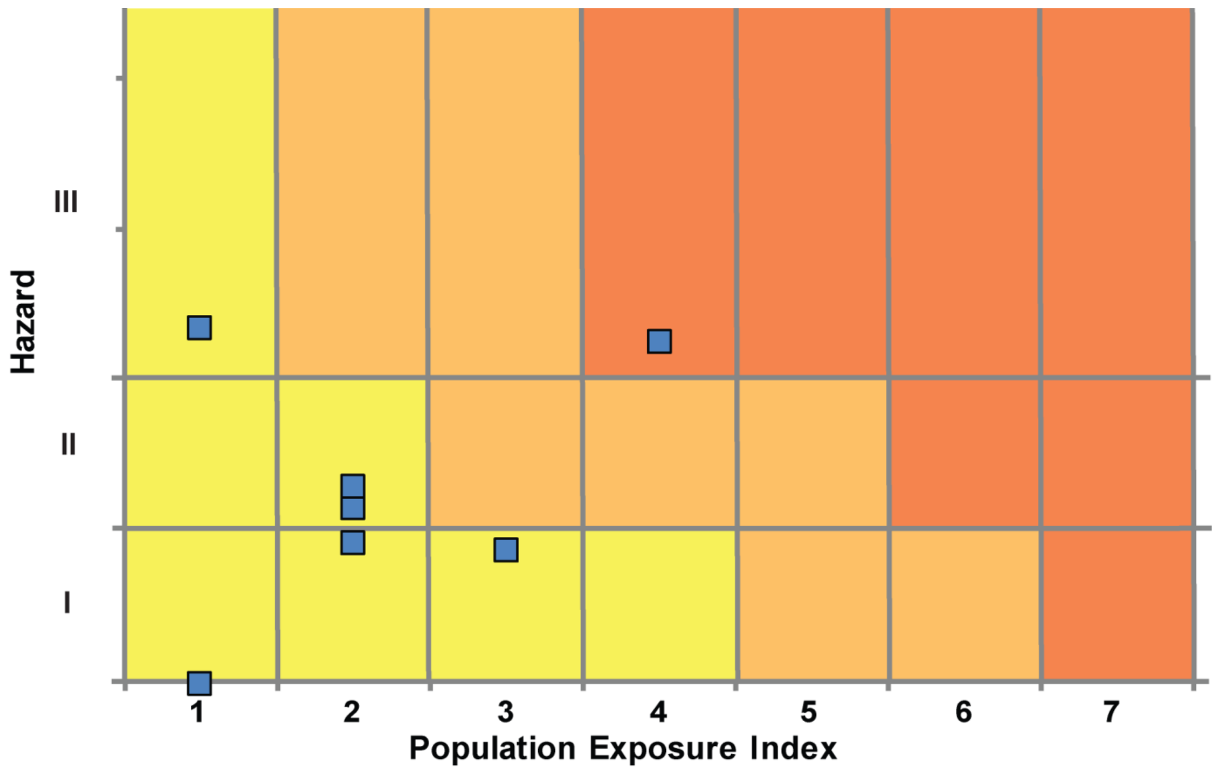


Figure 4.11 Distribution of New Zealand's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

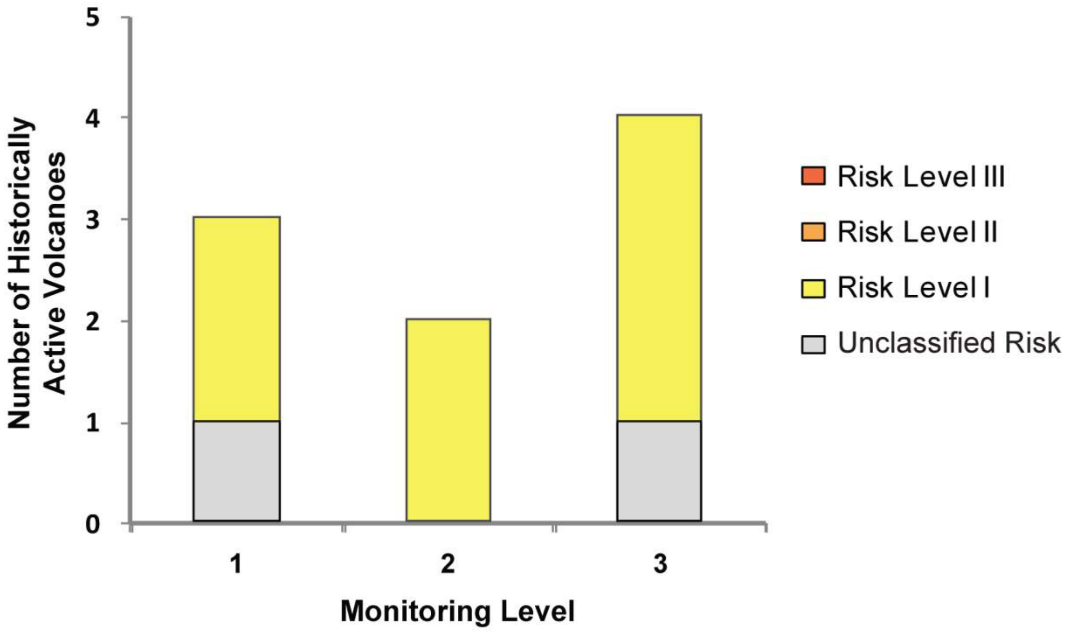


Figure 4.12 The monitoring and risk levels of the historically active volcanoes in New Zealand. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 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

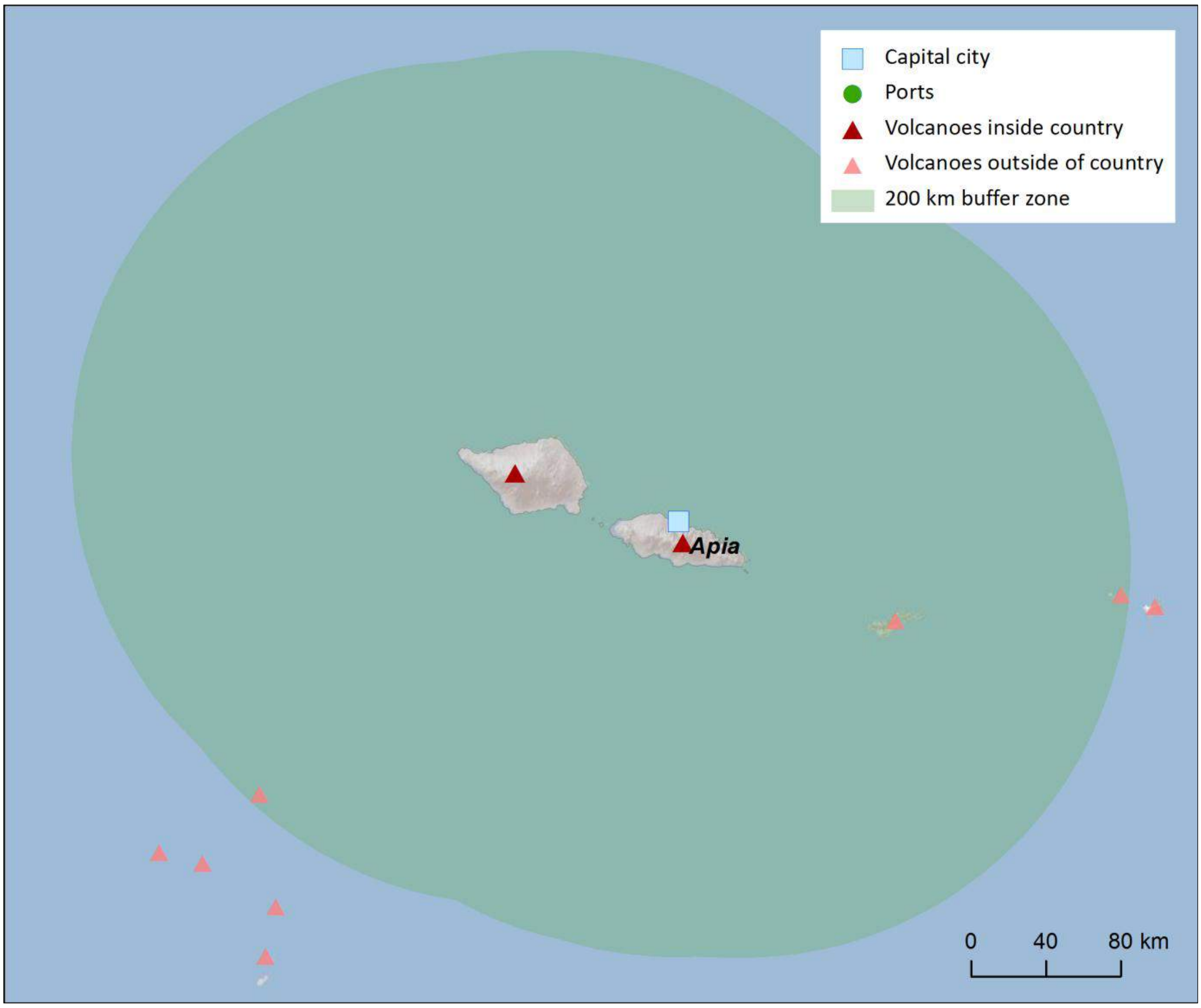


Figure 4.13 Location of Samoa's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Samoa.

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 formation, short-term spatter cone formation, 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. 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 4.13 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

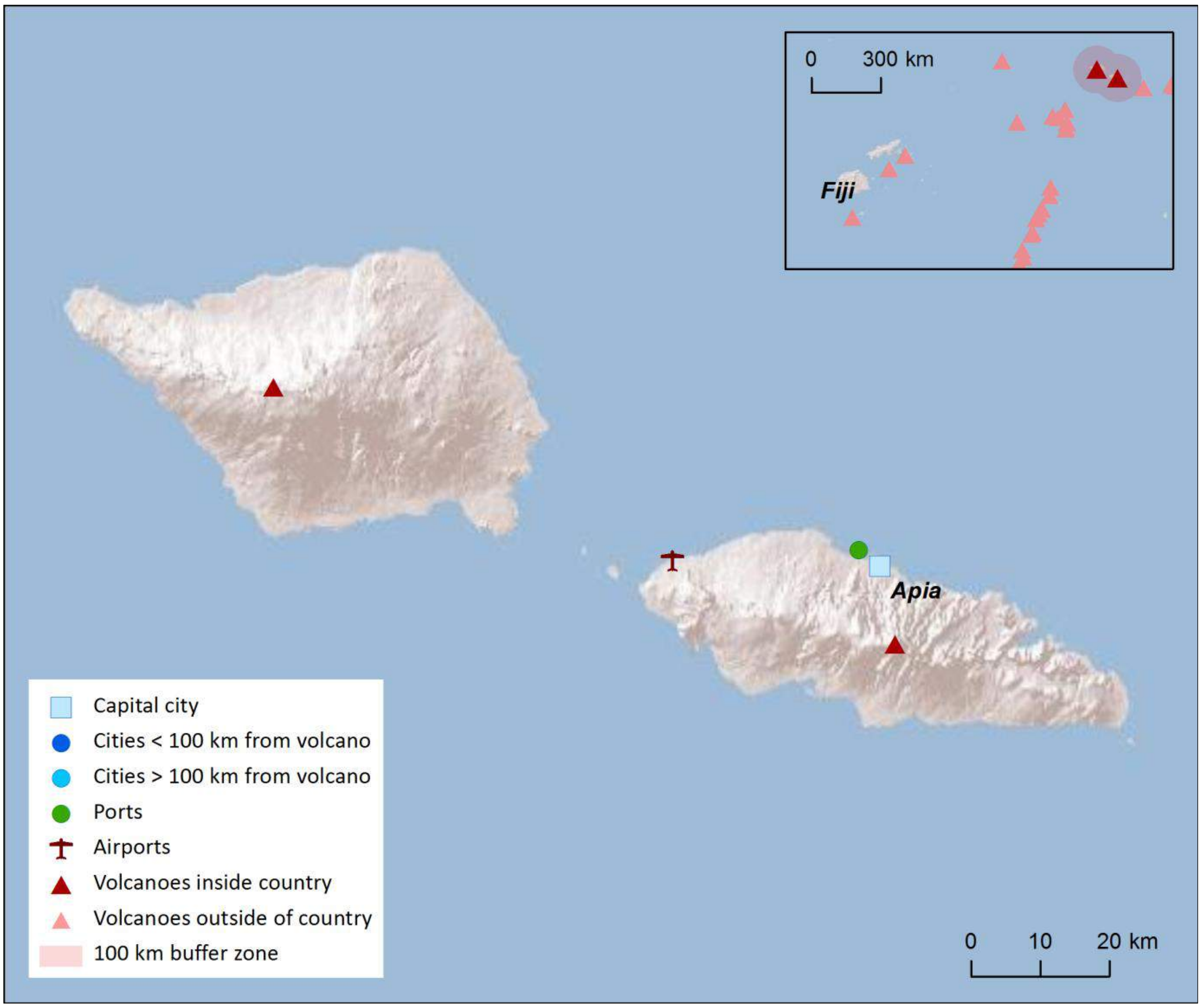


Figure 4.14 The location of Samoa's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 4.14 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 1900 AD, 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.

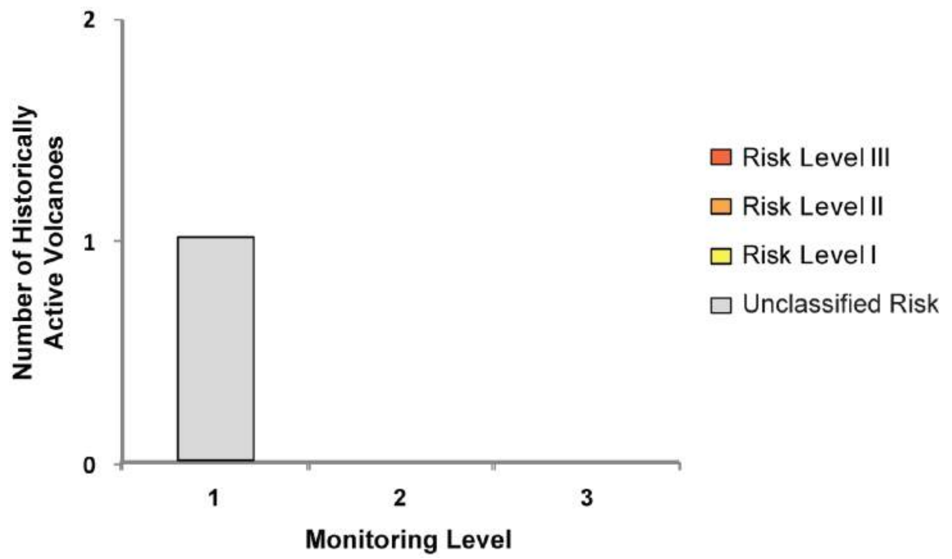


Figure 4.15 The monitoring and risk levels of the historically active volcanoes in Samoa. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates 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

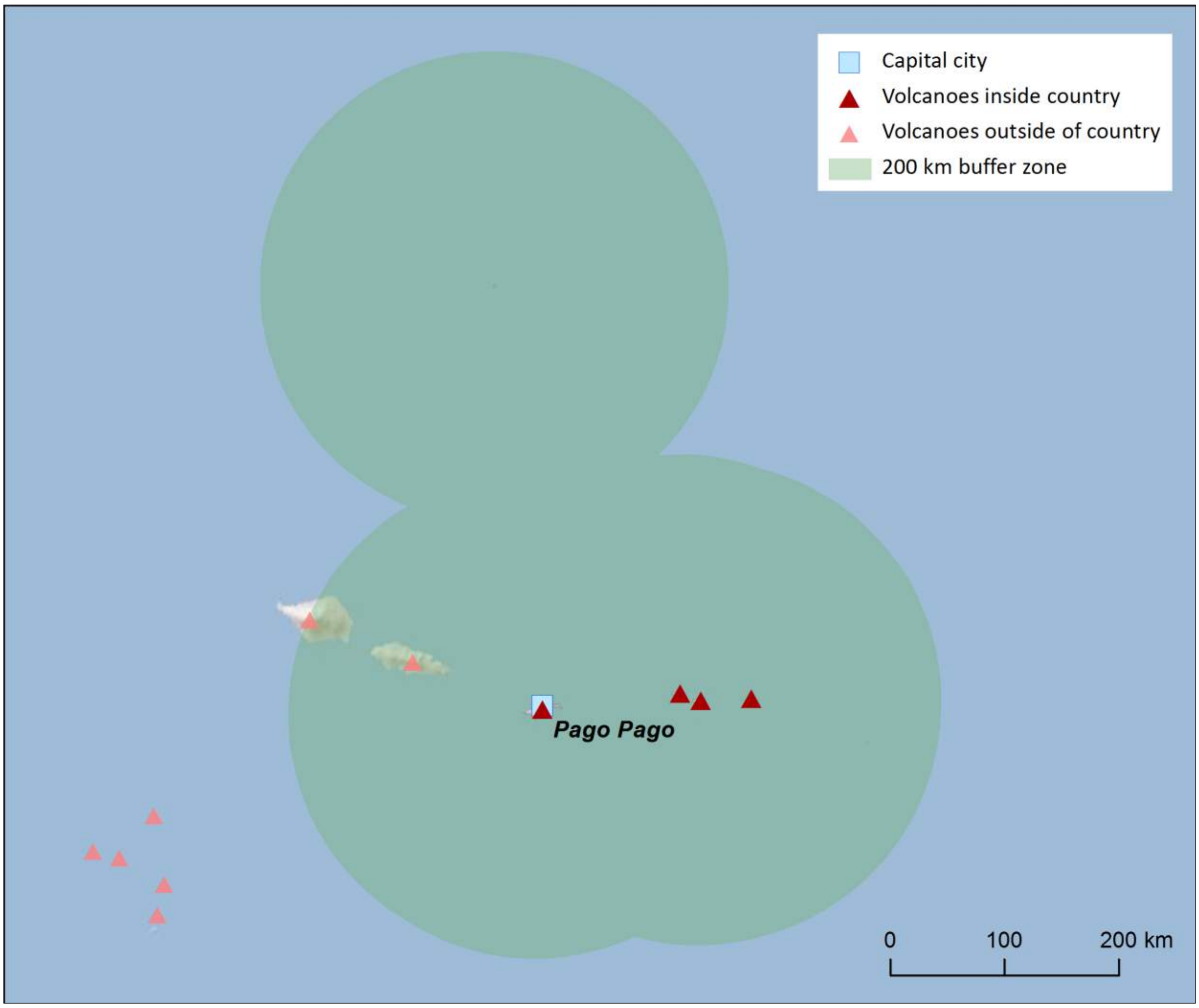


Figure 4.16 Location of American Samoa's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect American Samoa.

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 4.15 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 their population size:

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)	-

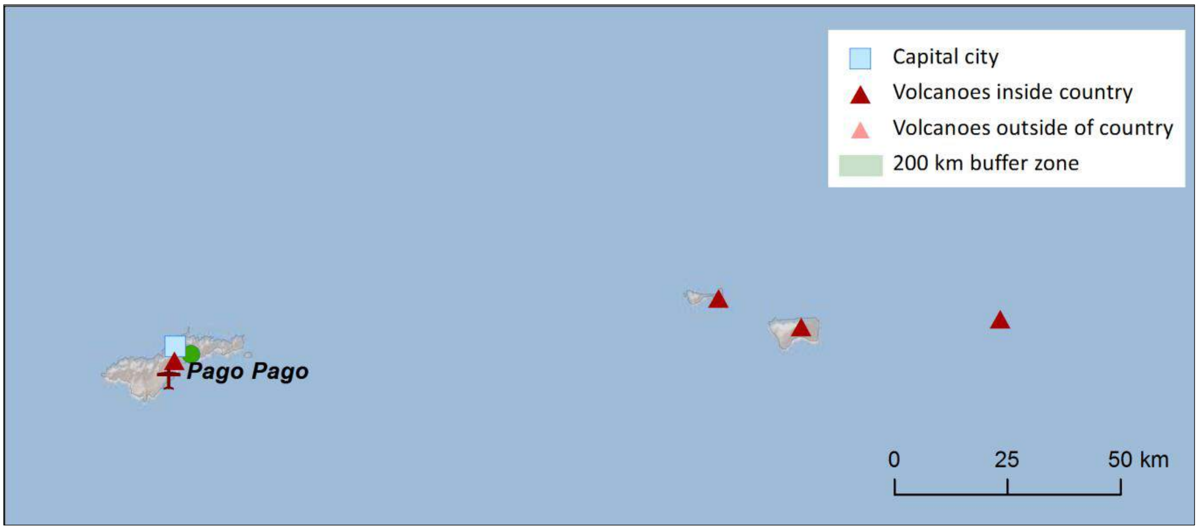


Figure 4.17 The location of American Samoa's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 4.16 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 1900 AD, 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.

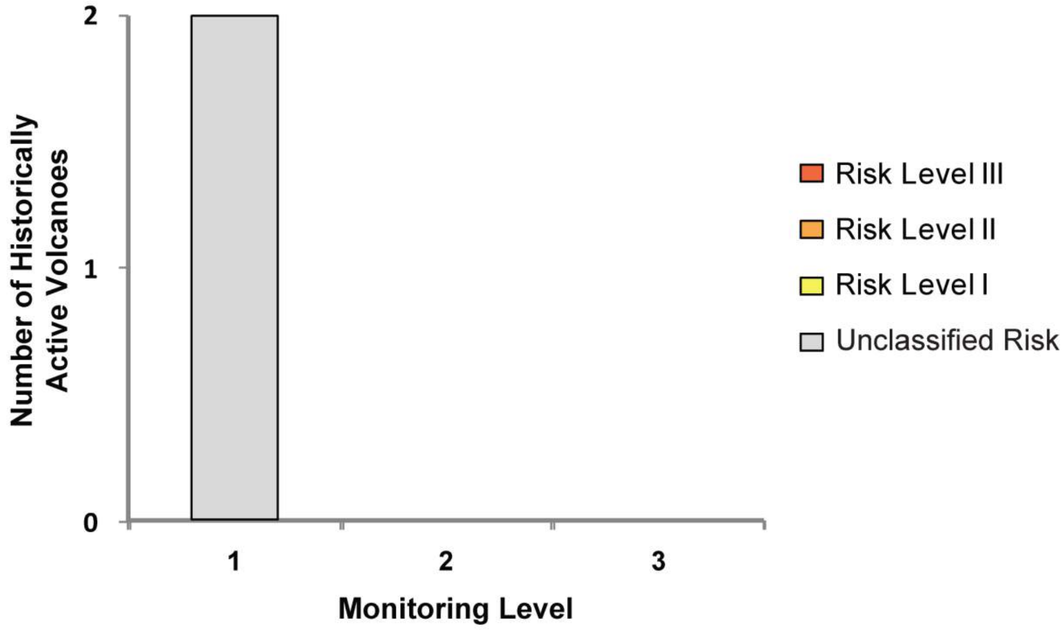


Figure 4.18 The monitoring and risk levels of the historically active volcanoes in American Samoa. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Tonga

Description

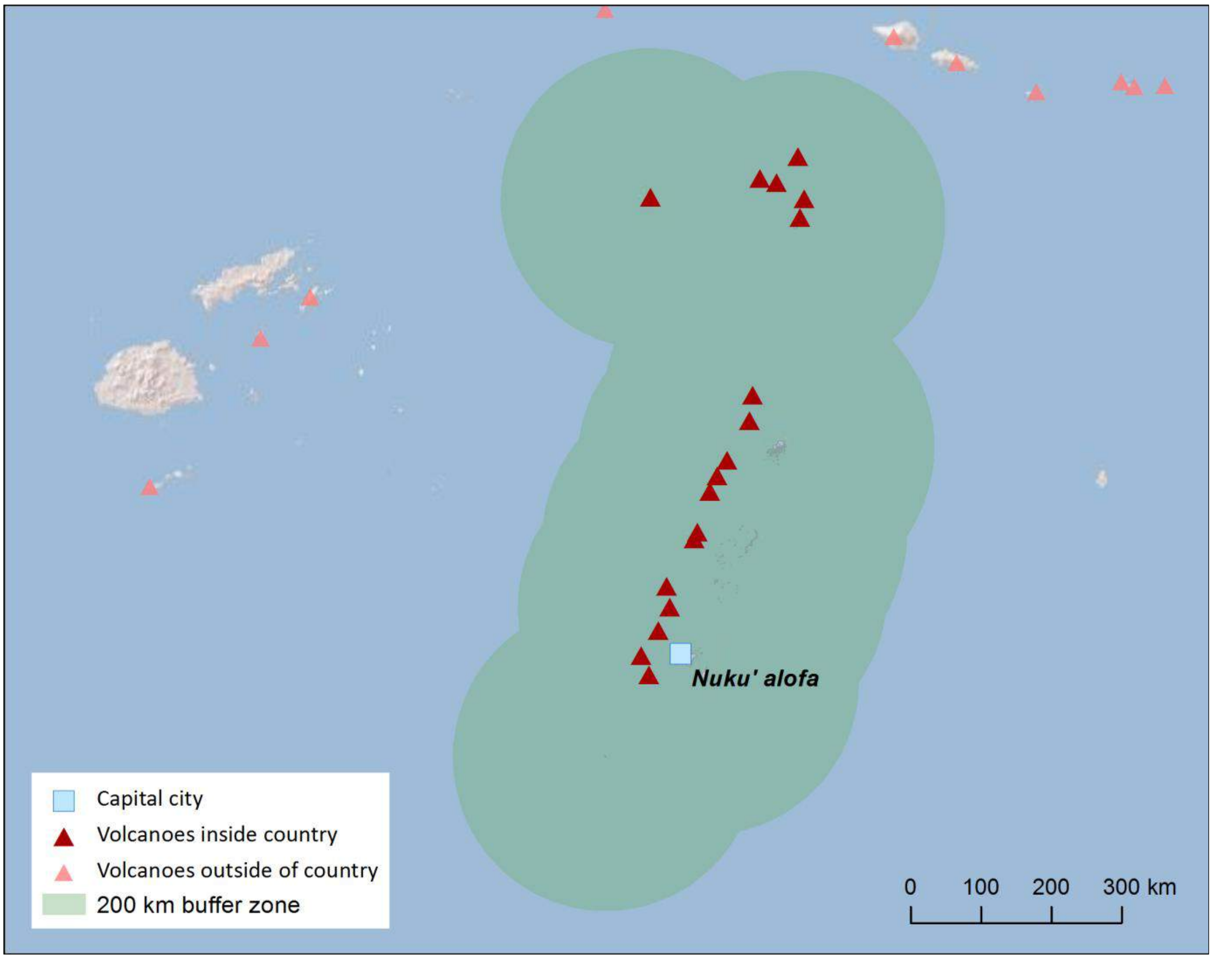


Figure 4.19 Location of Tonga's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Tonga.

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 4.17 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 their population size:

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.

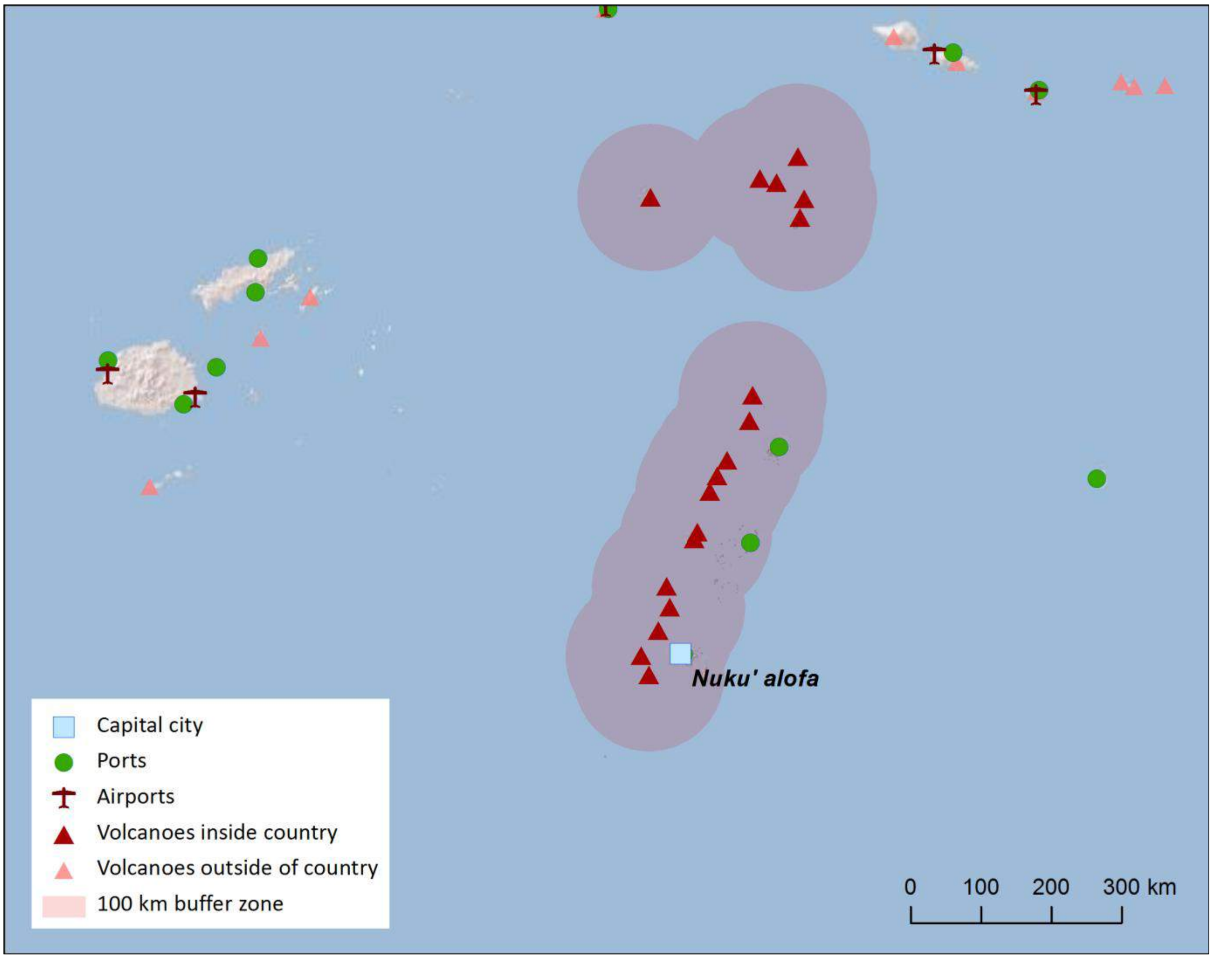


Figure 4.20 The location of Tonga's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 4.18 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 1900 AD, 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 4.19 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.

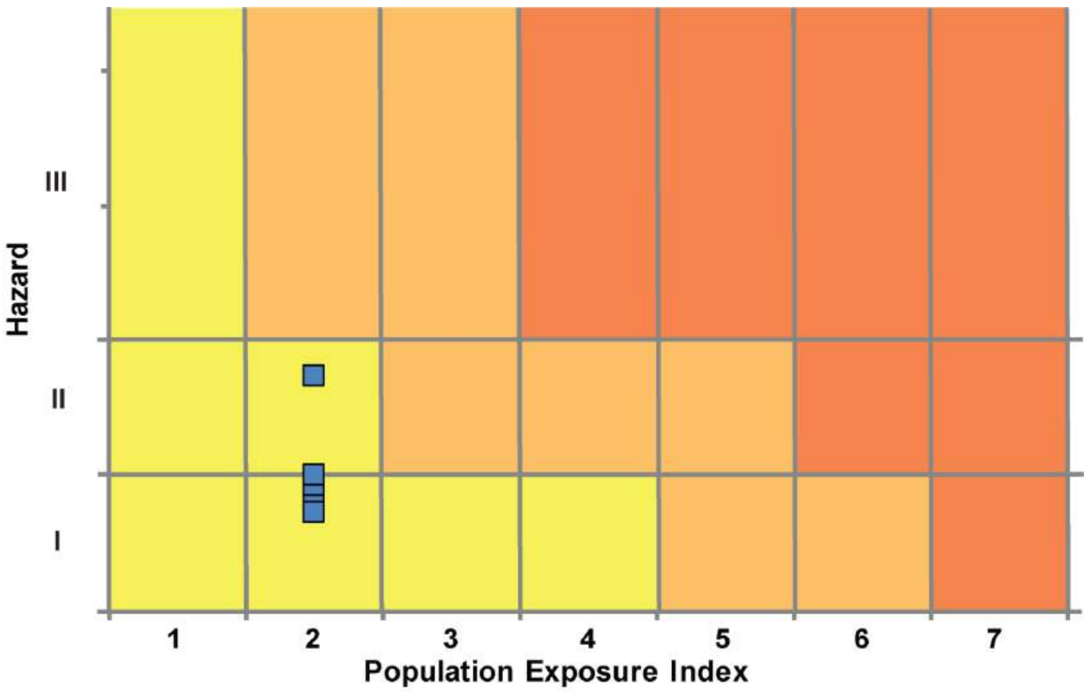


Figure 4.21 Distribution of Tonga's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

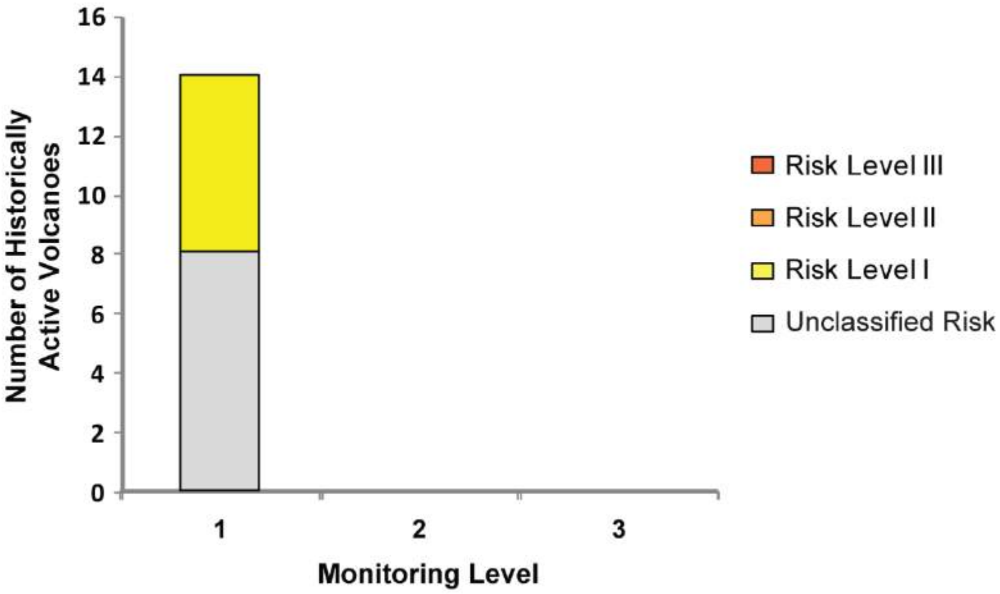


Figure 4.22 The monitoring and risk levels of the historically active volcanoes in Tonga. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 5: Melanesia and Australia

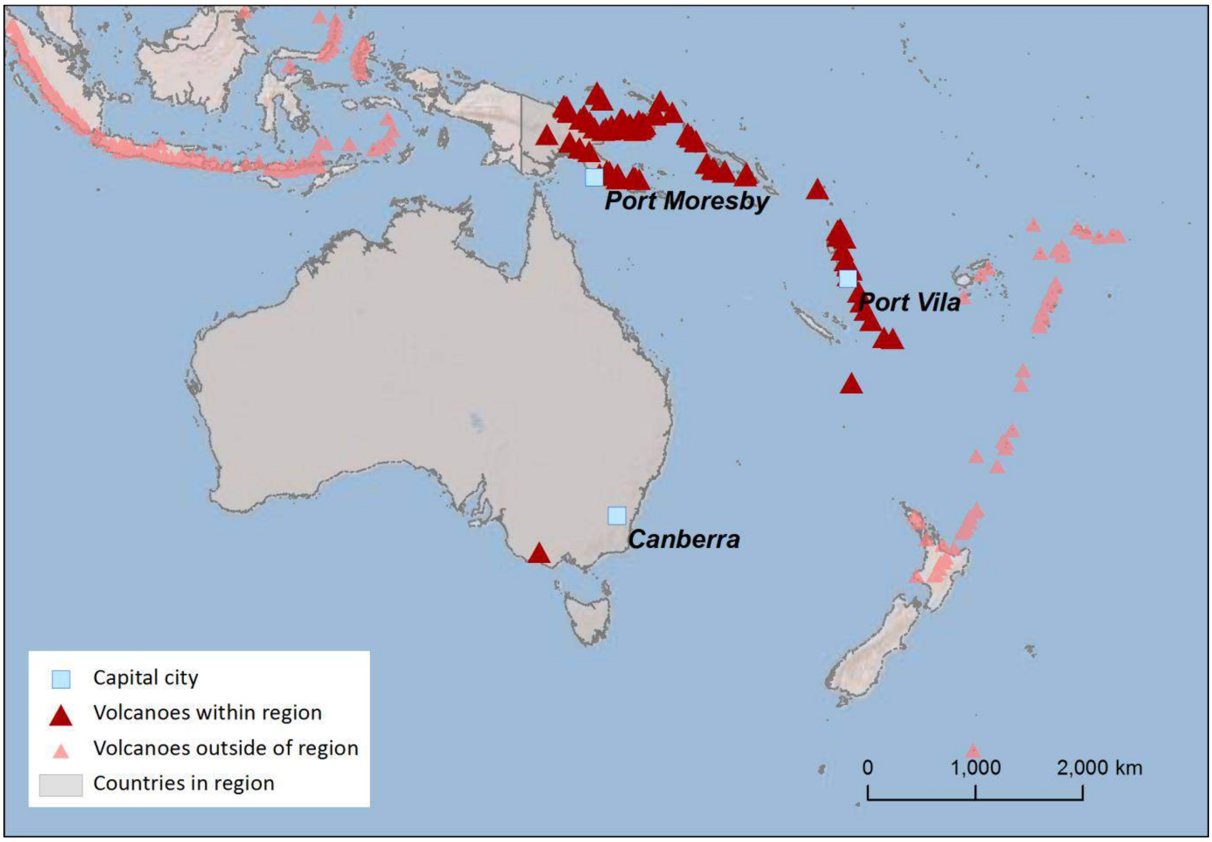


Figure 5.1 The distribution of Holocene volcanoes through the Melanesia and Australia region. The capital cities of the constituent countries are shown.

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 5.1 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.

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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 5.2 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 5.3 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.

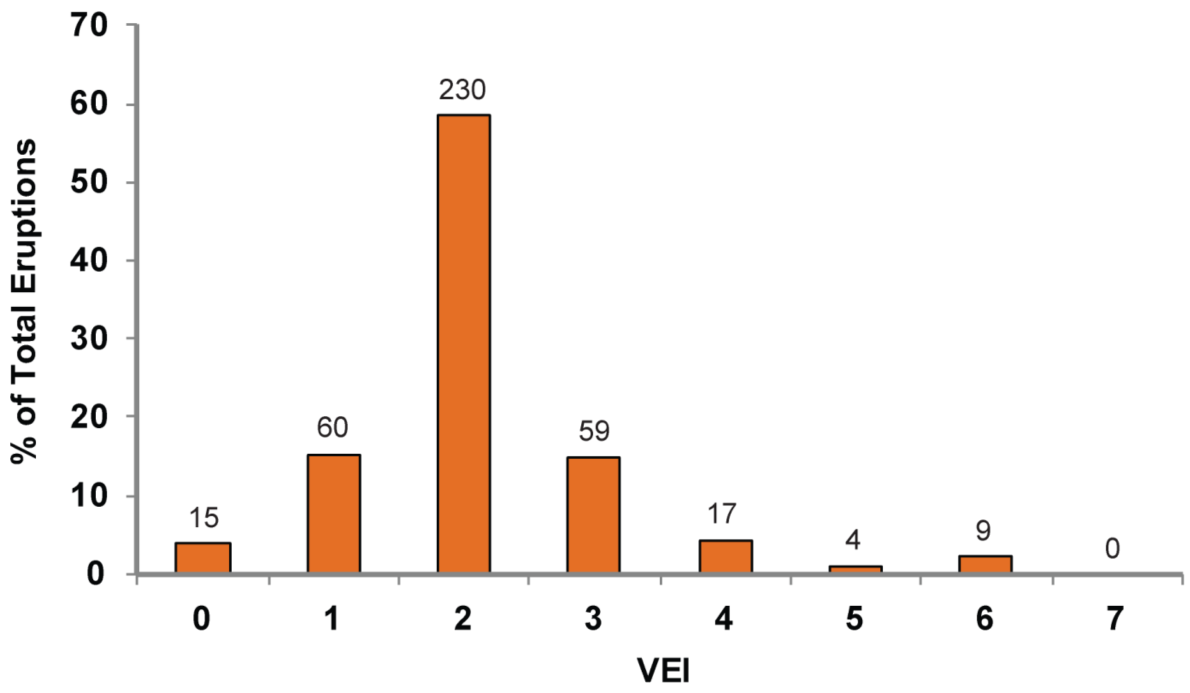

Figure 5.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 55 eruptions were recorded with unknown VEI.

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 5.4 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 1900 AD, 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 5.5 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 5.6 The number of volcanoes in the Melanesia and Australia region classified at each Risk Level.

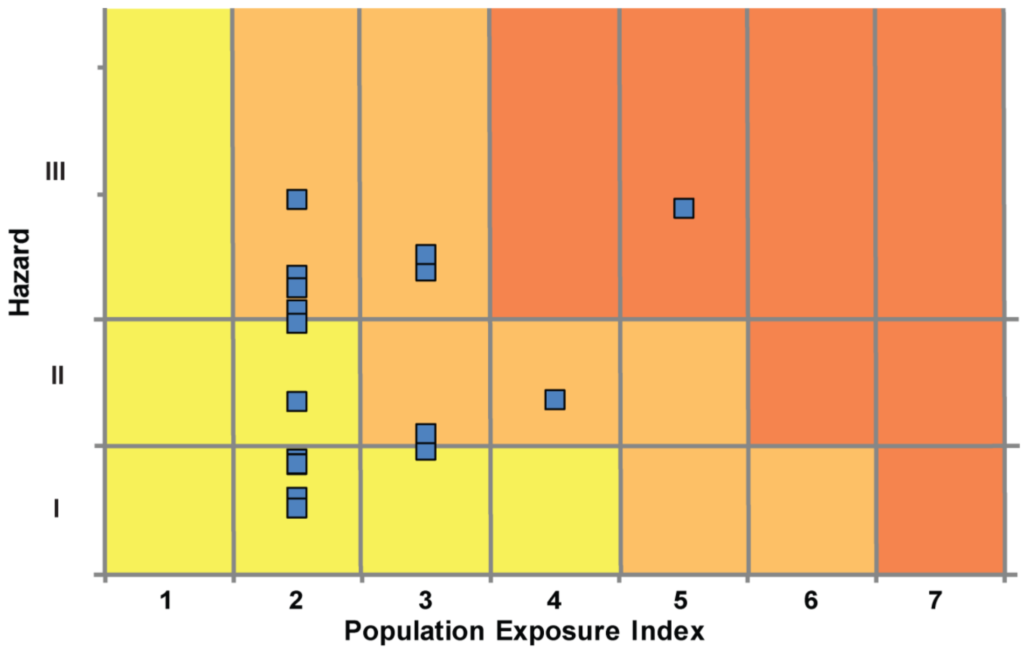

Figure 5.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional Monitoring Capacity

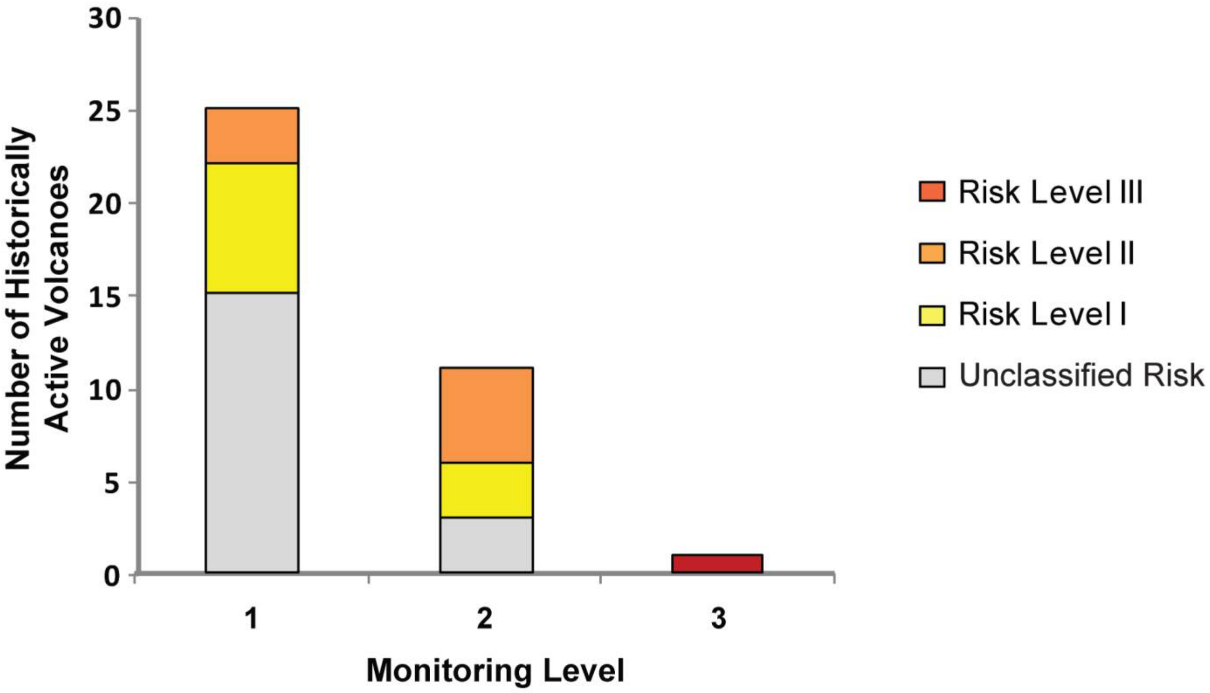

Figure 5.4 The monitoring and risk levels of the historically active Australian volcanoes of the Heard and McDonald Islands. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic 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

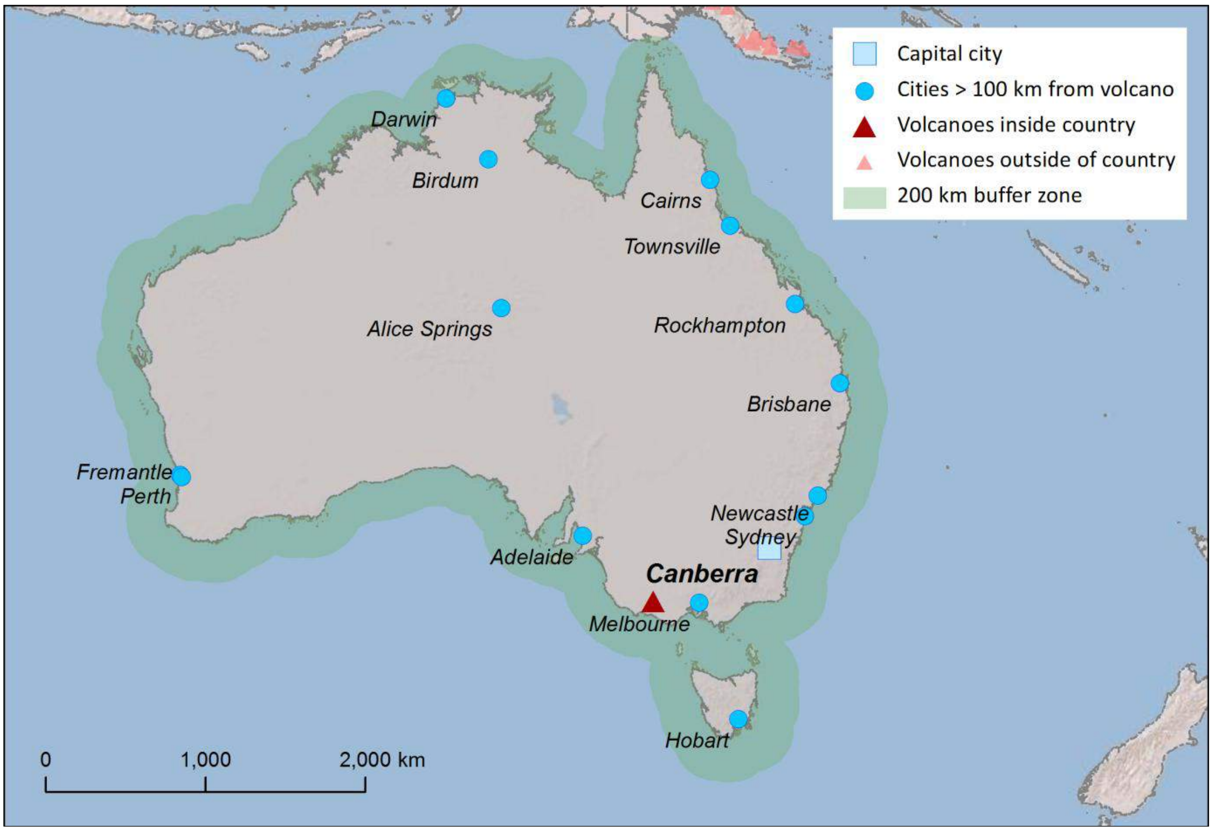

Figure 5.5 Location of Australia’s volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Australia.

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 5.7 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 their population size:

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

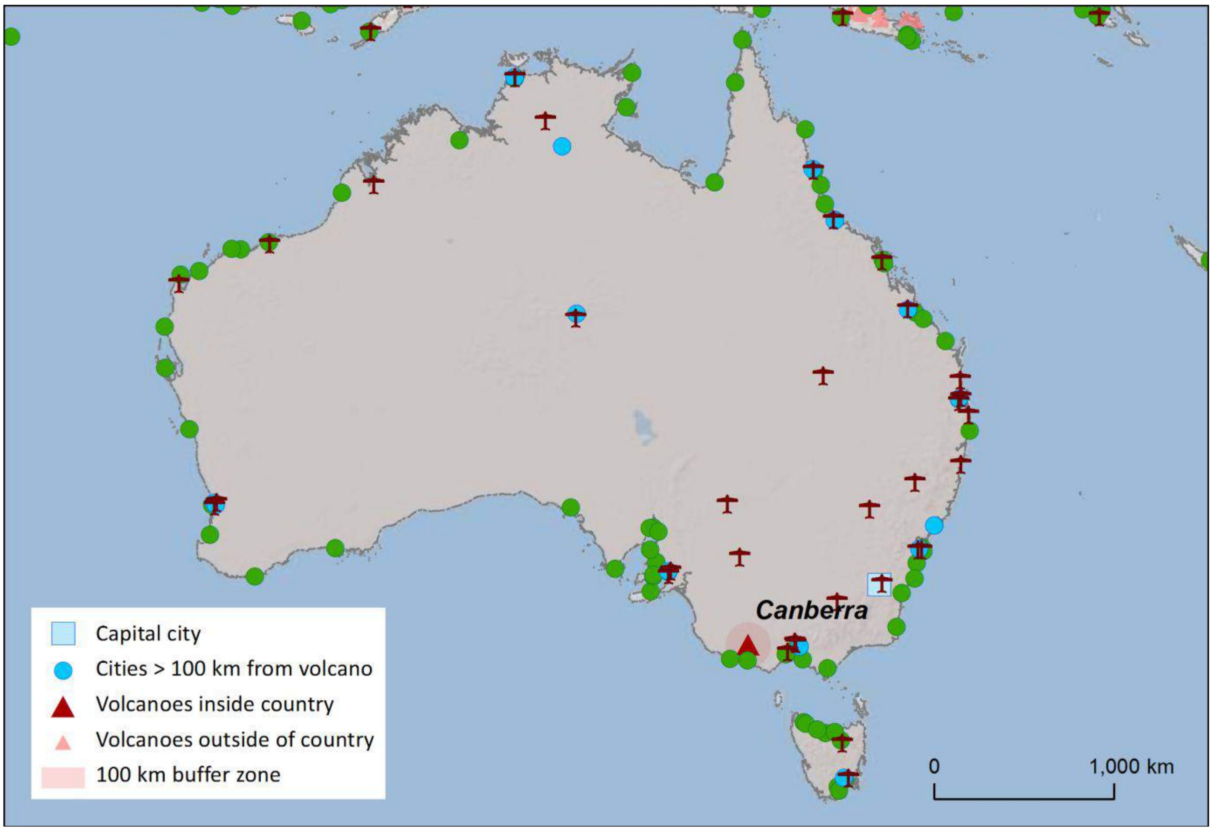

Figure 5.6 The location of Australia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 5.8 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 1900 AD, 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 5.9 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.

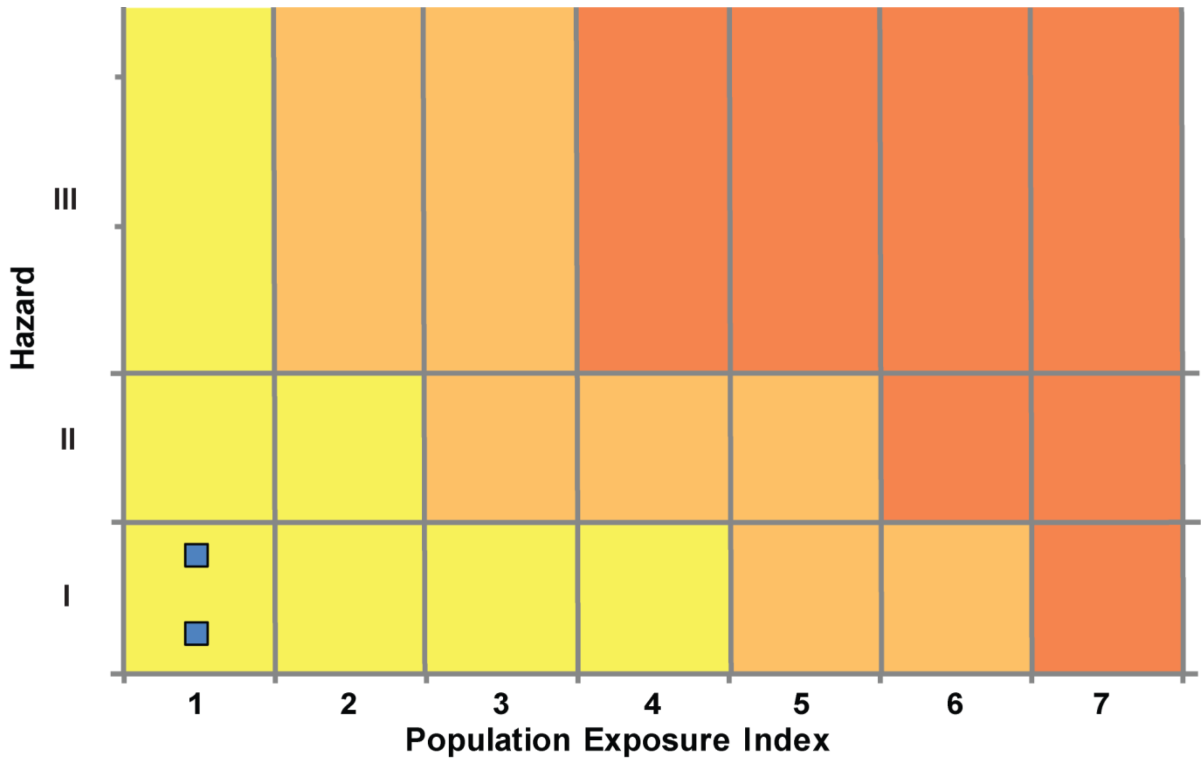

Figure 5.7 Distribution of Australia's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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

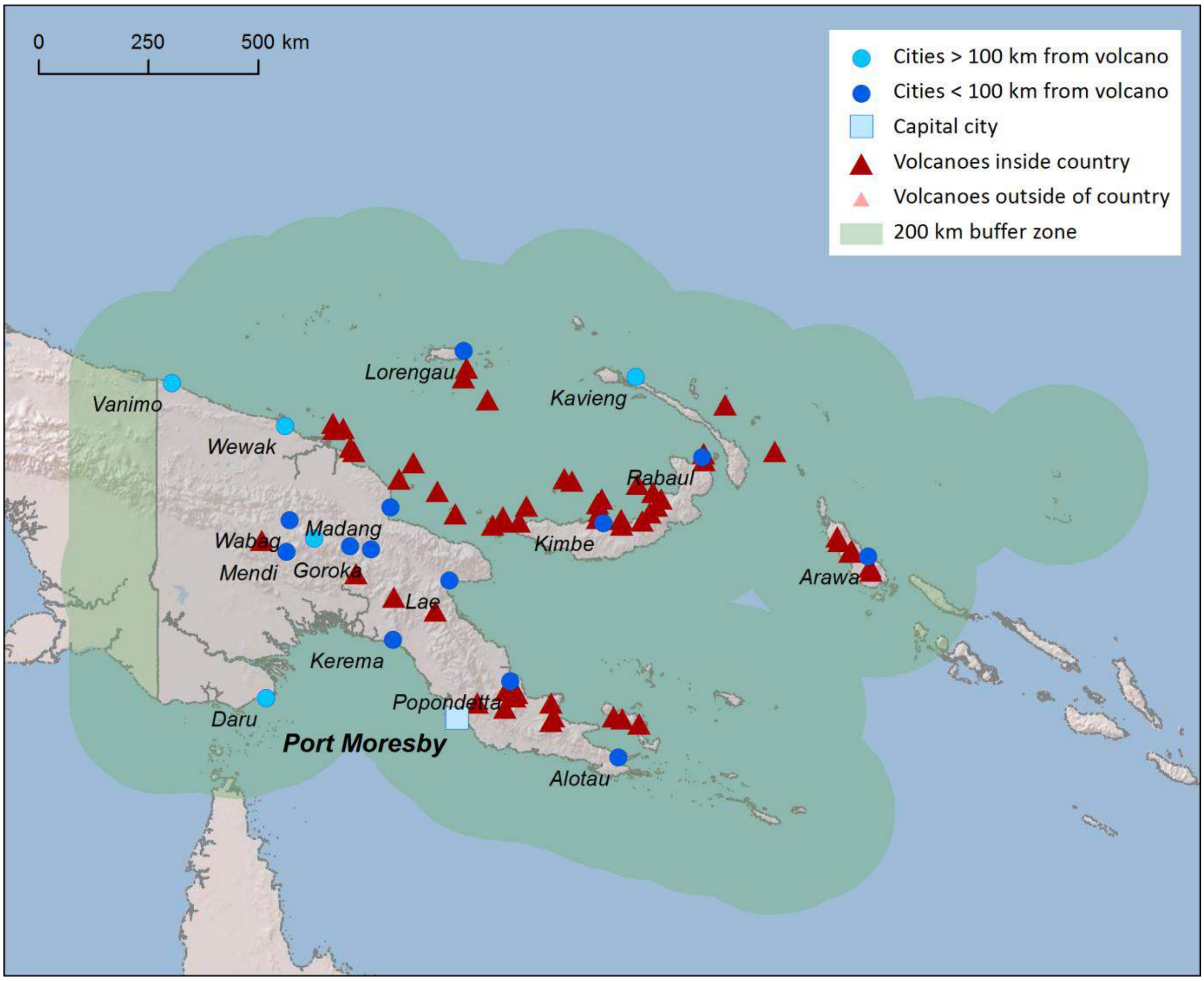

Figure 5.8 Location of Papua New Guinea's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Papua New Guinea.

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 programme 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 programme 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 5.10 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 their population size:

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.

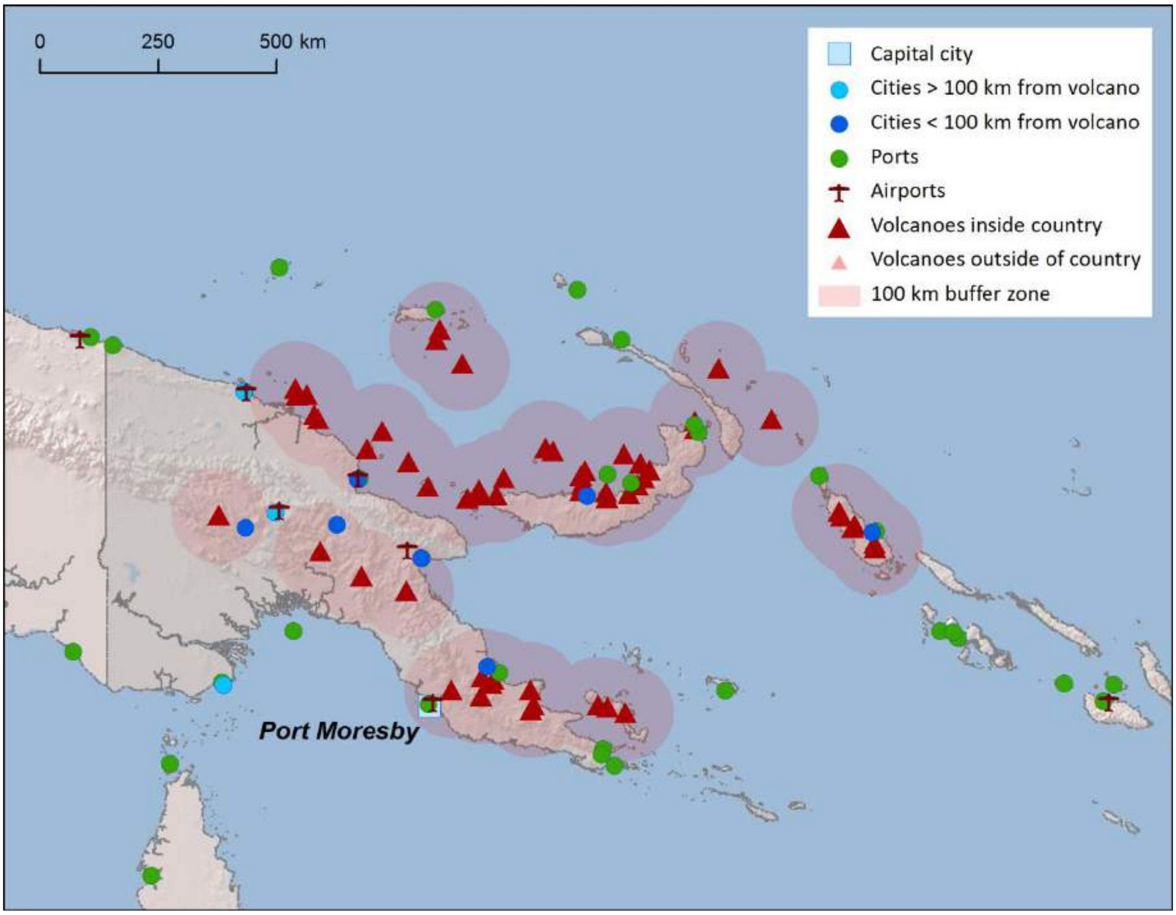

Figure 5.9 The location of Papua New Guinea's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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**; Ambitle		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 5.11 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 1900 AD, 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 5.12 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.

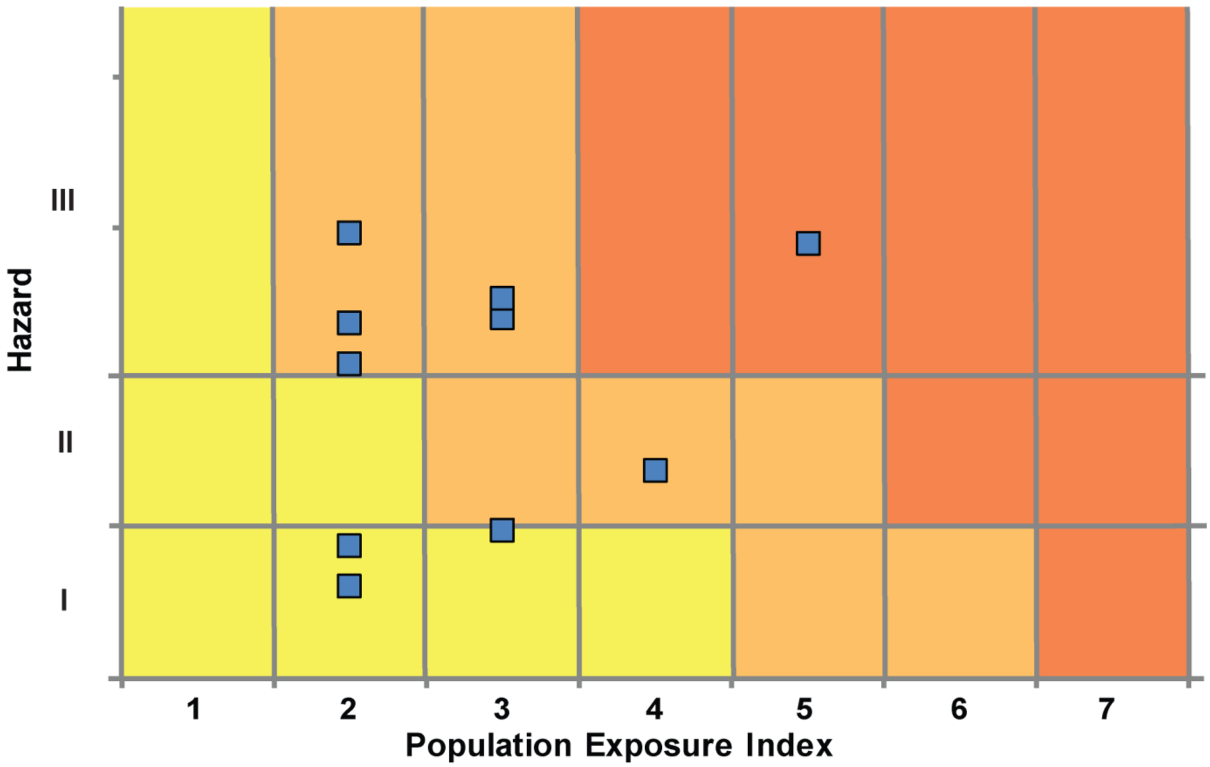

Figure 5.10 Distribution of Papua New Guinea's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

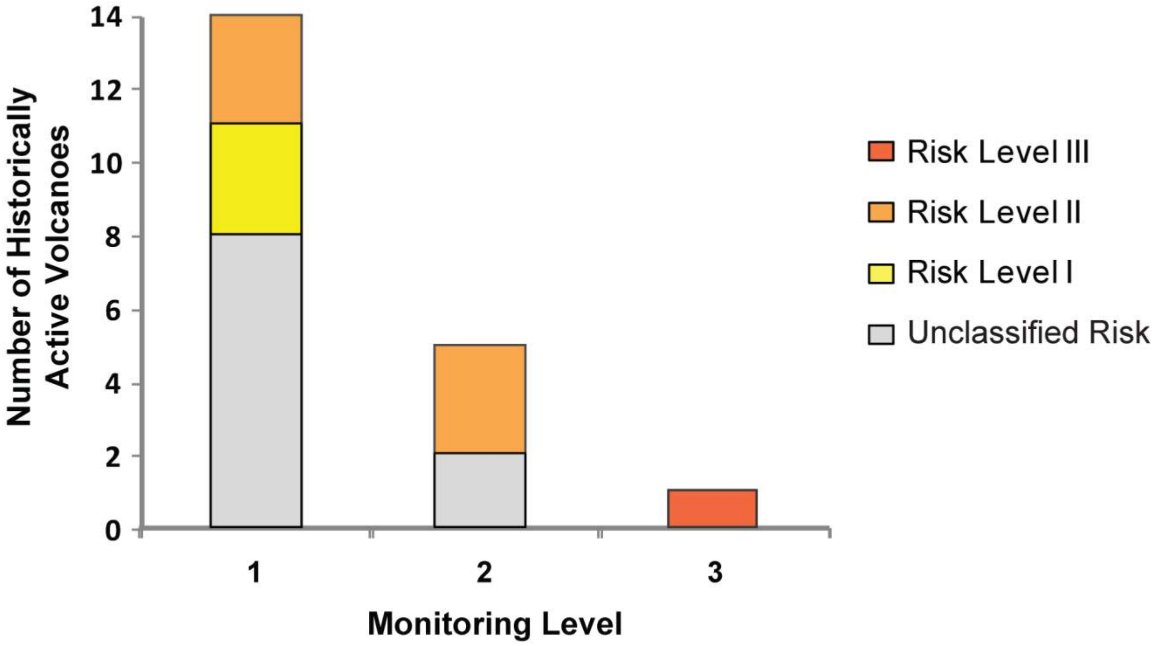

Figure 5.11 The monitoring and risk levels of the historically active volcanoes in Papua New Guinea. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Solomon Islands

Description

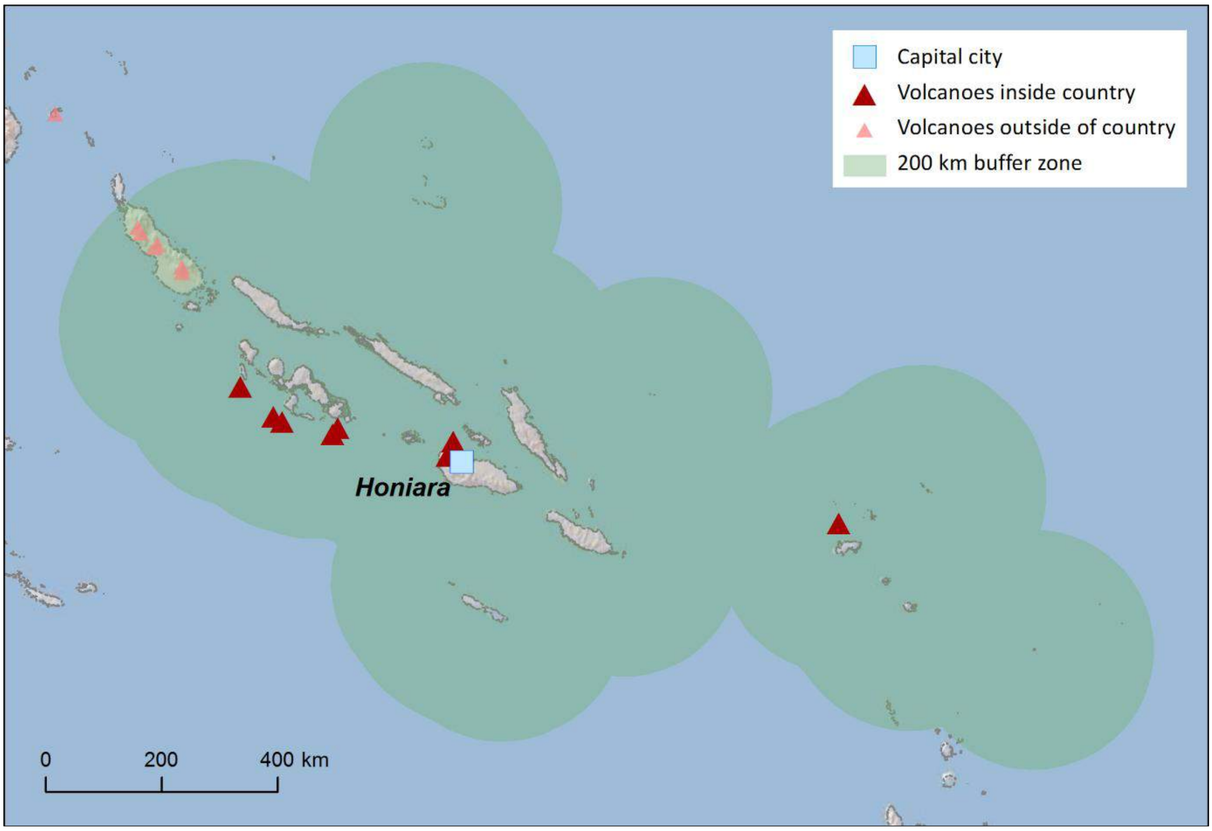

Figure 5.12 Location of Solomon Islands' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Solomon Islands.

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 5.13 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 their population size:

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.

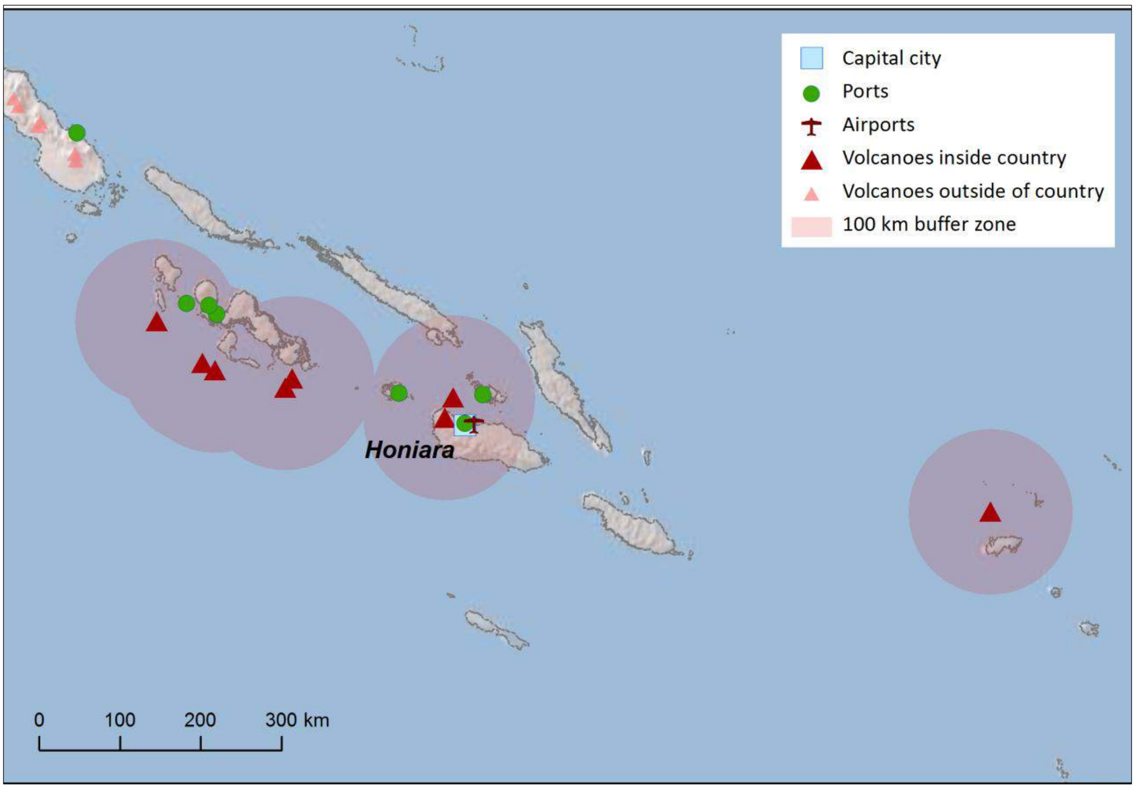

Figure 5.13 The location of the Solomon Islands' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 5.14 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 1900 AD, 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 5.15 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.

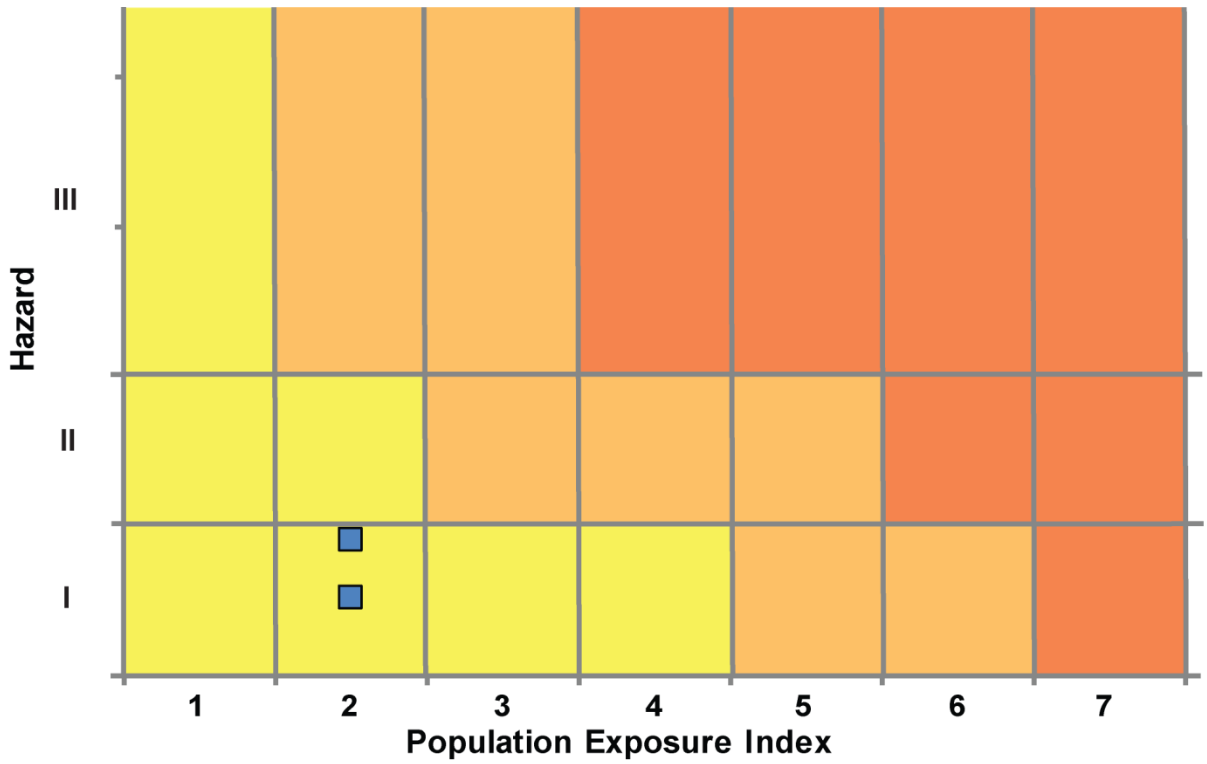

Figure 5.14 Distribution of the Solomon Islands' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

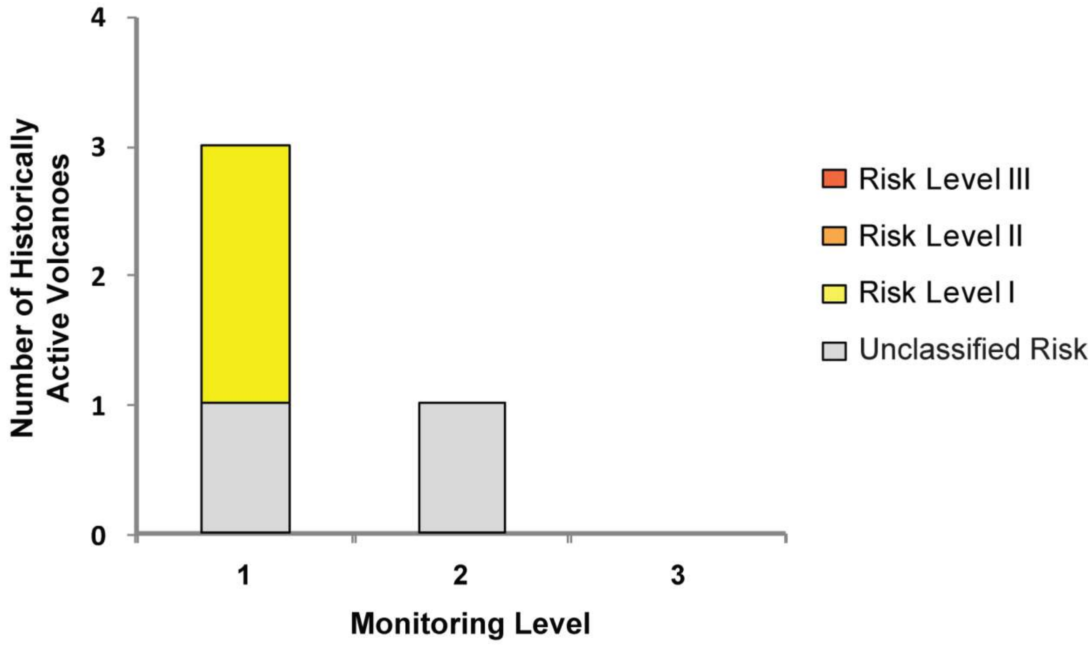

Figure 5.15 The monitoring and risk levels of the historically active volcanoes in the Solomon Islands. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Vanuatu

Description

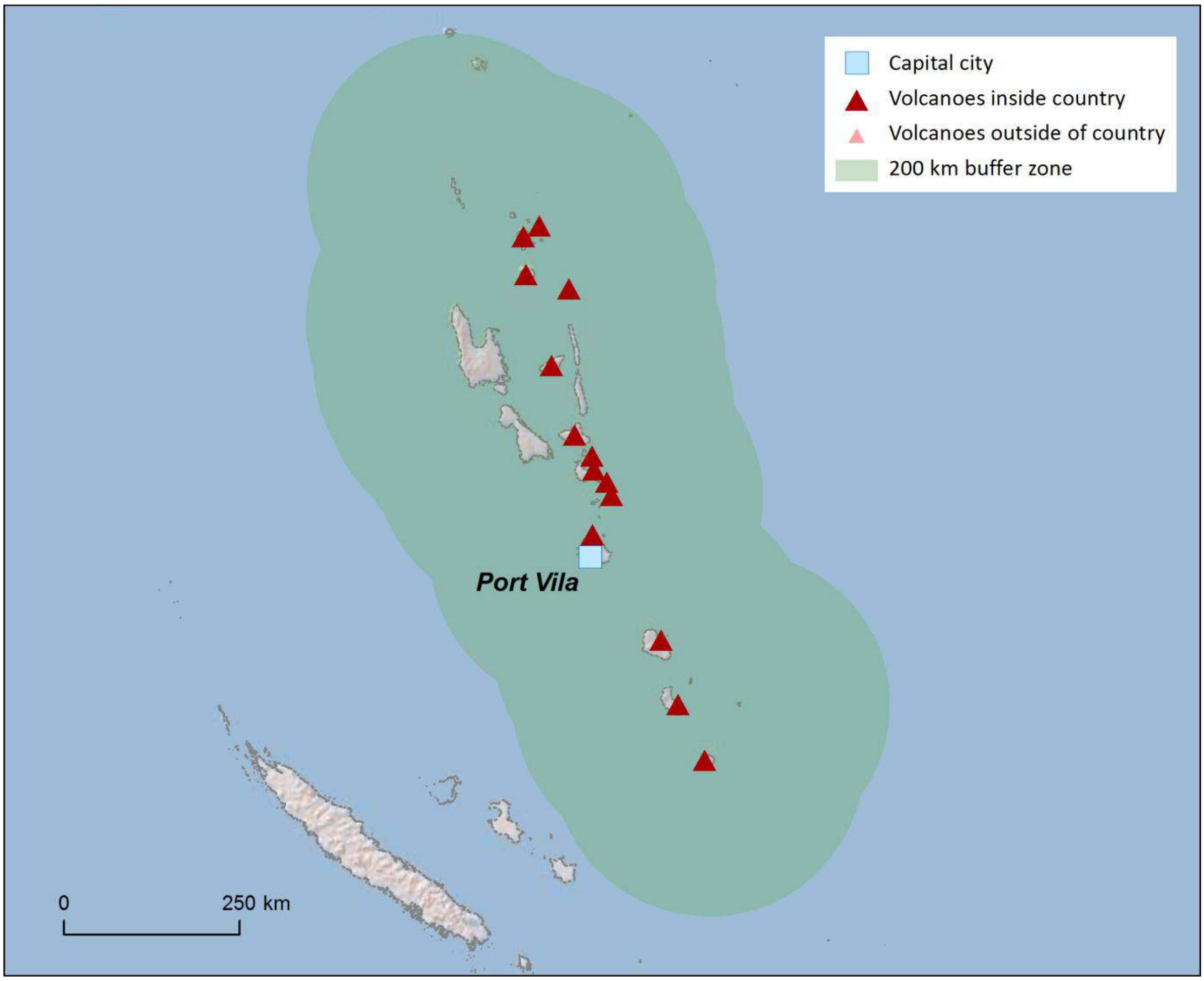

Figure 5.16 Location of Vanuatu's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Vanuatu.

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, 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)

Table 5.16 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 their population size:

Port Vila	35,901

Infrastructure Exposure

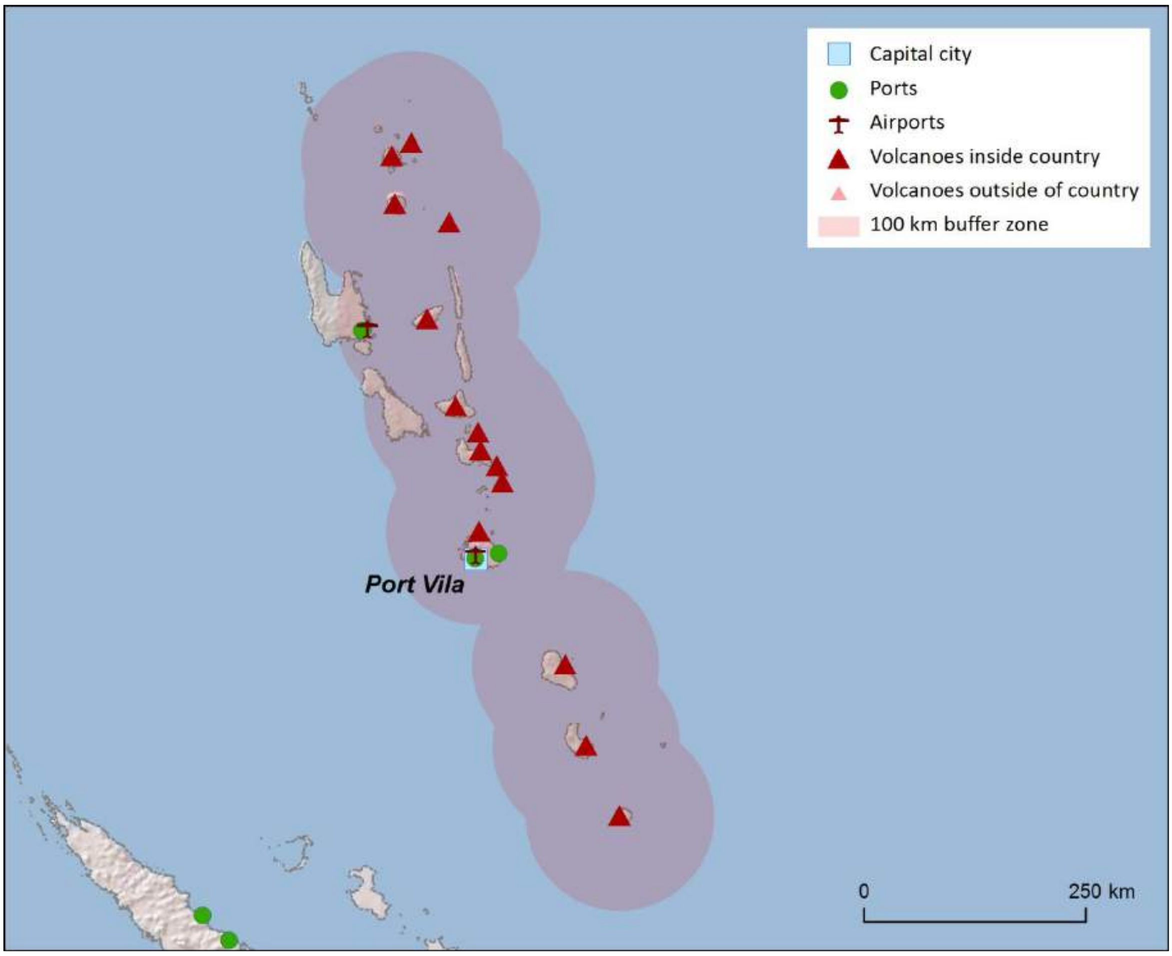

Figure 5.17 The location of Vanuatu's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 5.17 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 1900 AD, 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 5.18 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.

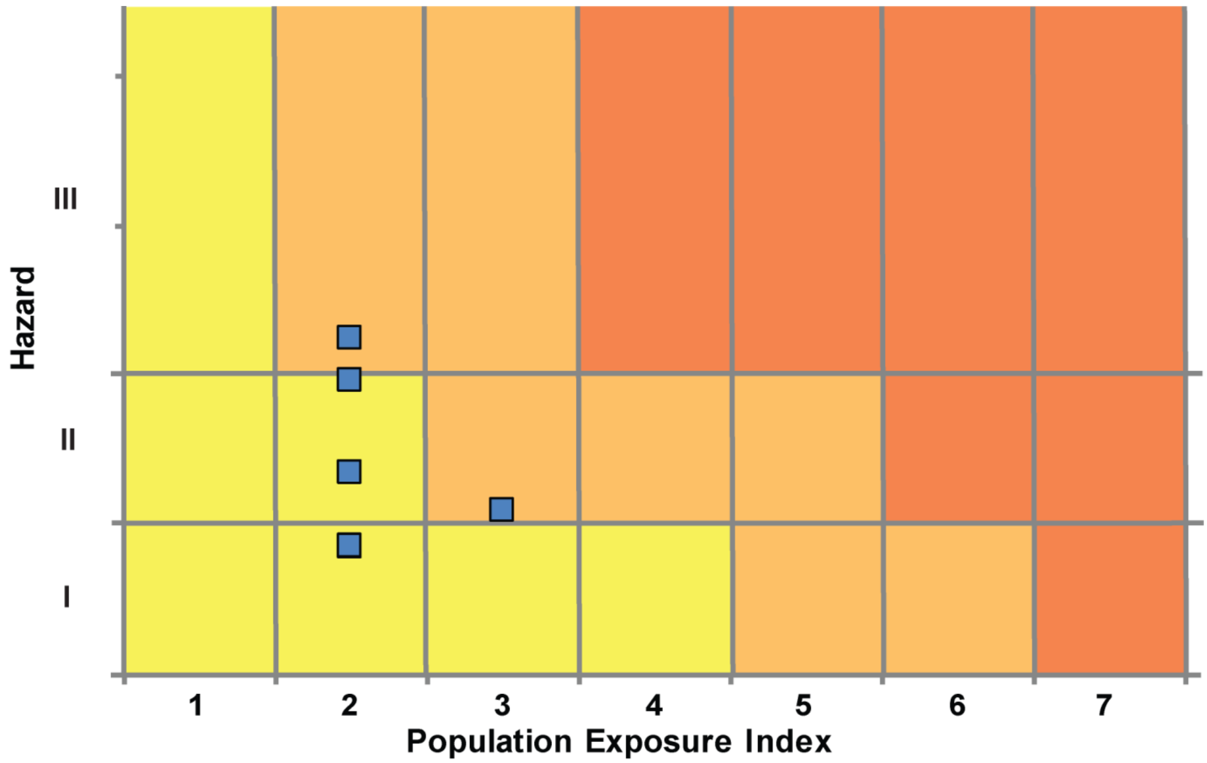

Figure 5.18 Distribution of Vanuatu's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

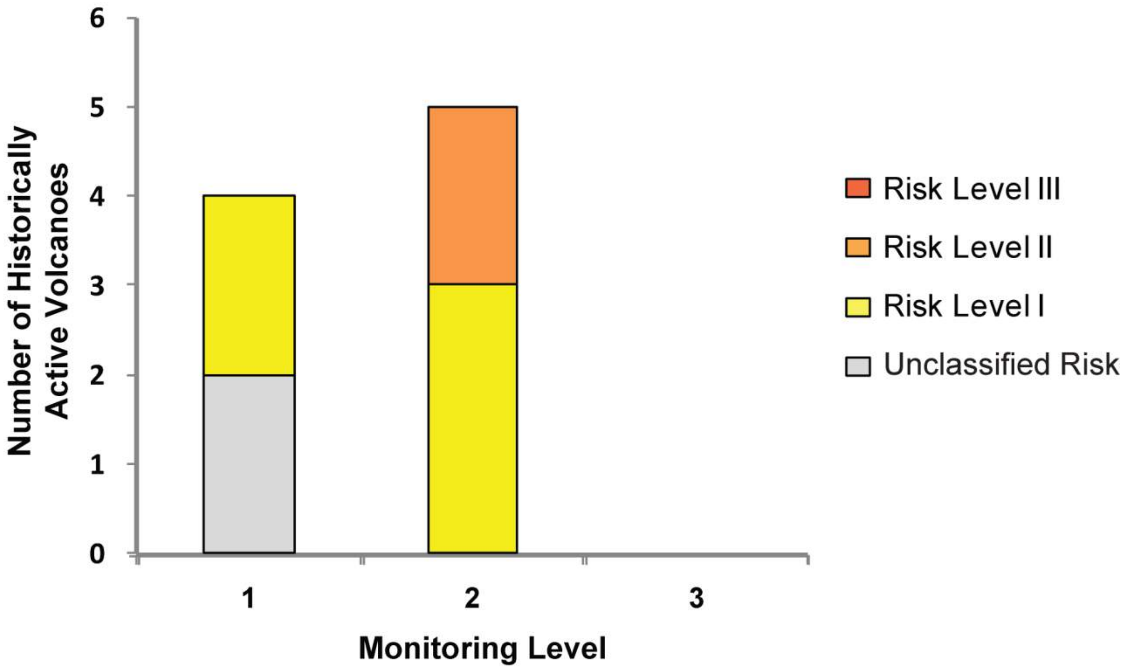

Figure 5.19 The monitoring and risk levels of the historically active volcanoes in Vanuatu. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Region 6: Indonesia

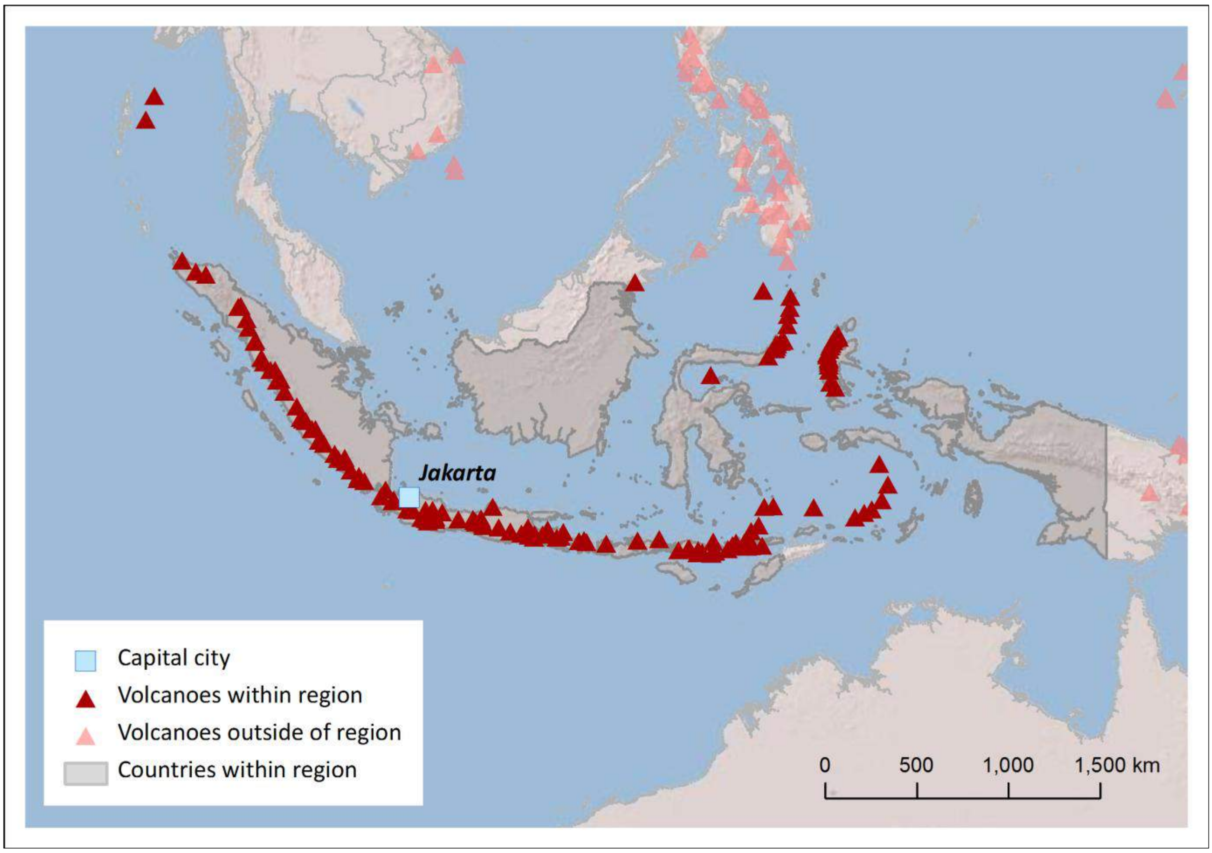

Figure 6.1 The distribution of Holocene volcanoes through the Melanesia and Australia region. The capital cities of the constituent countries are shown.

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 6.1 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. About 31% of classified volcanoes (18) 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 6.2 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 6.3 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.

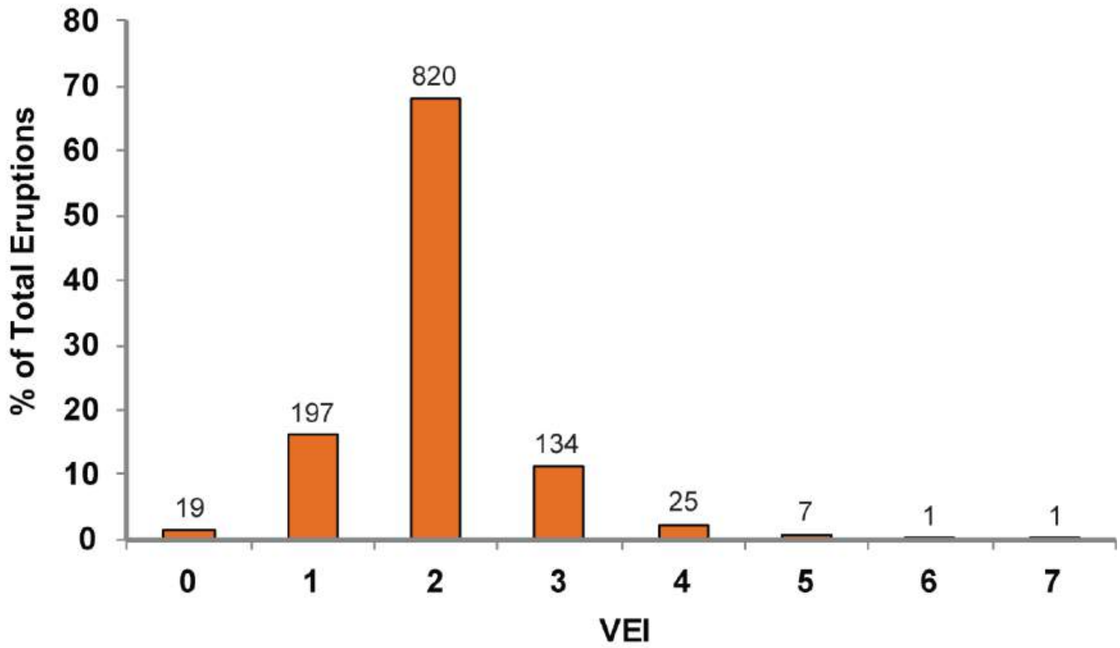

Figure 6.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 73 eruptions were recorded with unknown VEI.

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, Ilibolang, 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 6.4 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 1900 AD, 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 6.5 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 6.6 The number of volcanoes in the Indonesia region classified at each Risk Level.

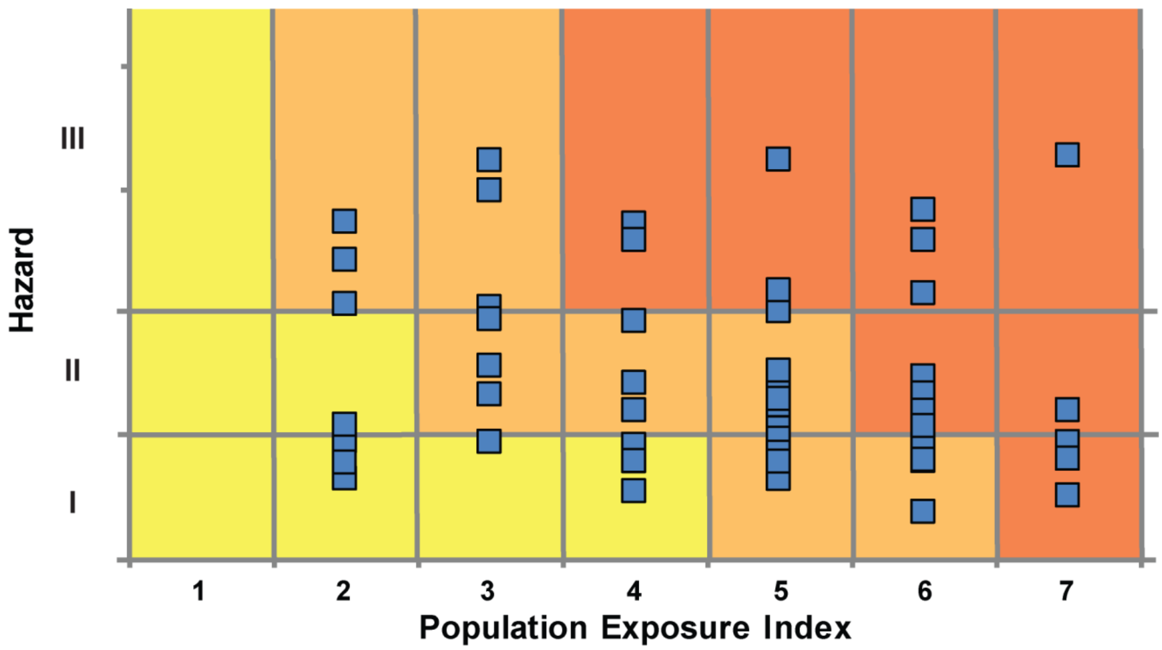

Figure 6.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III..

Regional Monitoring Capacity

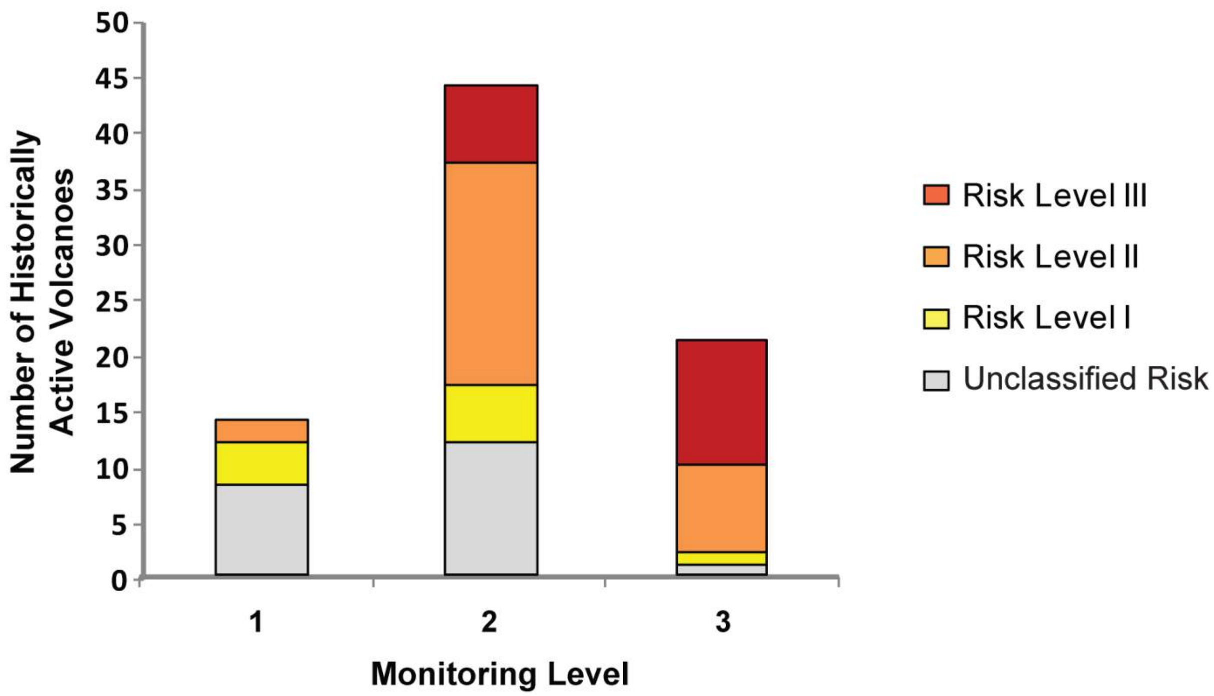

Figure 6.4 The monitoring and risk levels of the historically active volcanoes in the Indonesia region. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring 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 (uncertain presence, see below), which is included in the Region 3 "Middle East and Indian Ocean" description as defined in this region by the Global Volcanism Program.

Description

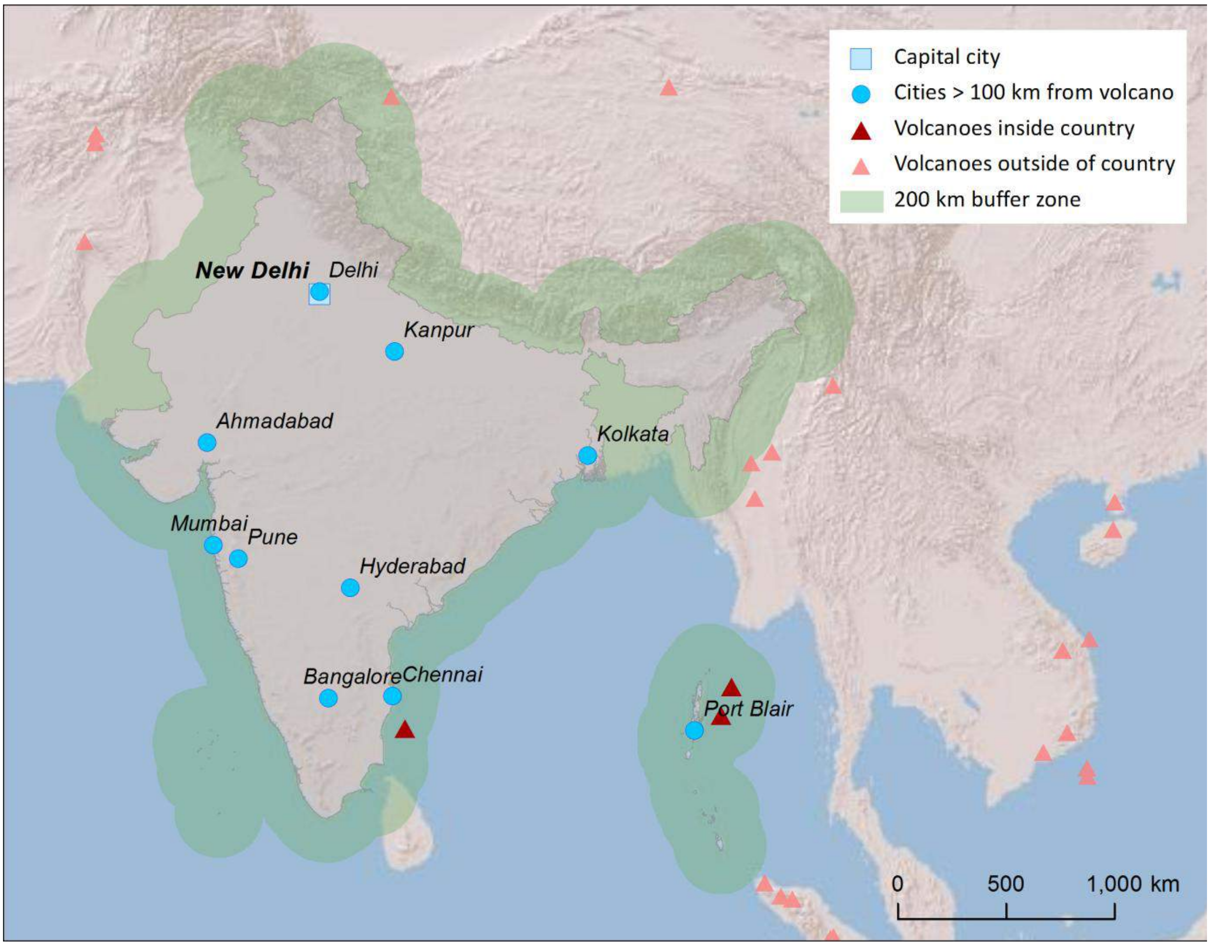

Figure 6.5 Location of India's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect India.

There are three Indian Holocene volcanoes listed in VOTW4.0. Barren Island and Narcondam (Narcondum) are stratovolcanoes located in the Andaman Islands in the north of the volcanic arc stretching through Sumatra. These two volcanoes are broadly related to the subduction of the Indian Plate under the Eurasian Plate. An unnamed submarine volcano is recorded off the south-east coast of India by the Pondicherry coast, however the existence of this volcano is uncertain. The presence this volcano is indicated by a report from 1757 of phenomena suggestive of submarine volcanism, however this is unconfirmed.

Of the three volcanoes, only Barren Island has confirmed activity recorded in the Holocene. The unnamed volcano and Narcondam are suspected to have had Holocene activity. 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 Narcundam 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 Narcondam 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).

One GPS monitoring system and seismograph has been installed on Barren Island by the National Geophysical Research Institute, though no other dedicated ground-based monitoring is in operation at any other Holocene volcano in India. 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:
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 6.7 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 their population size:

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 Narcondam 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

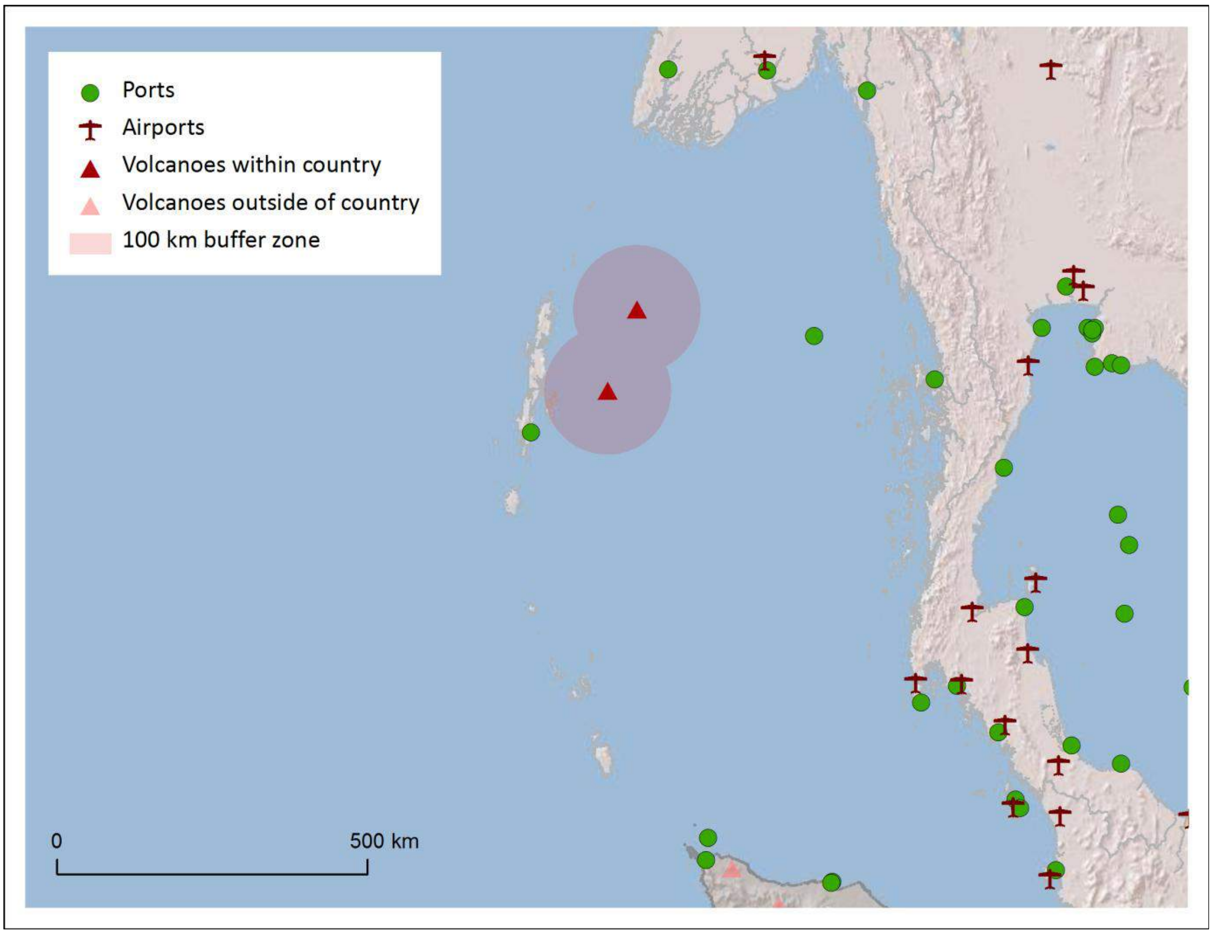

Figure 6.6 The location of India's volcanoes in the Andaman Islands and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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.

Narcondam 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. Narcondam has no permanent population living within this distance however there is a police outpost with 10 to 20 personnel at any given time. The low PEI of Narcondam suggests low risk. Barren Island is classified at Risk Level I.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I		Barren Island					
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR	Narcondam	Unnamed (235010)					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 6.8 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 1900 AD, 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 6.9 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.

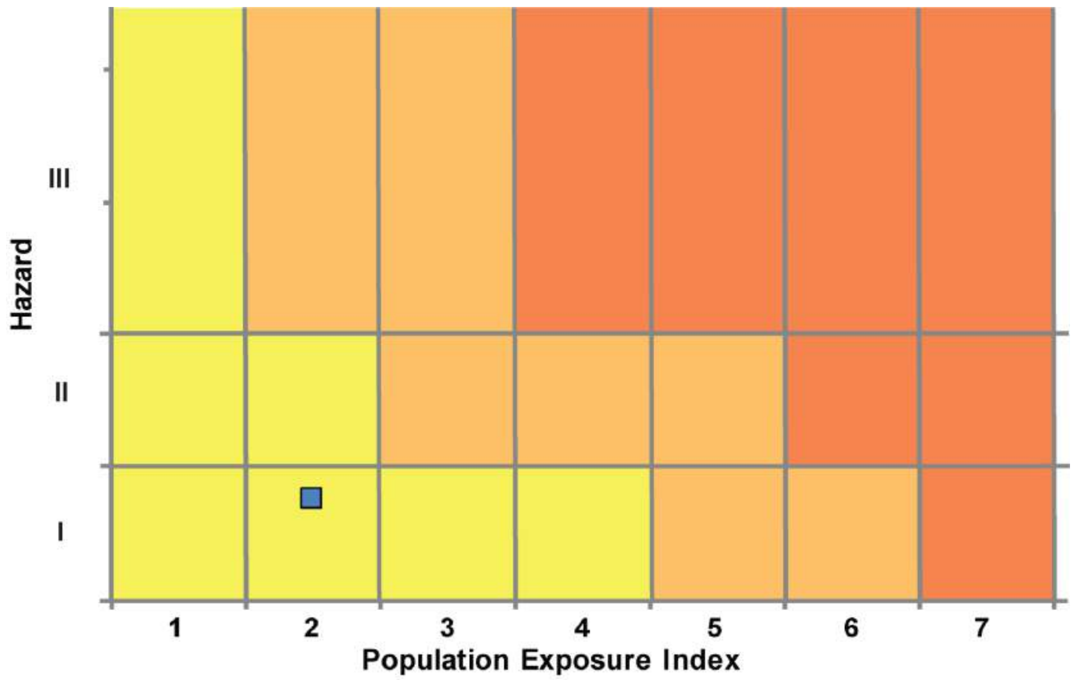

Figure 6.7 Distribution of India's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

One GPS station and a seismograph have been installed on Barren Island, but with no real-time data transmission. These have been installed and are operated by the National Geophysical Research Institute.

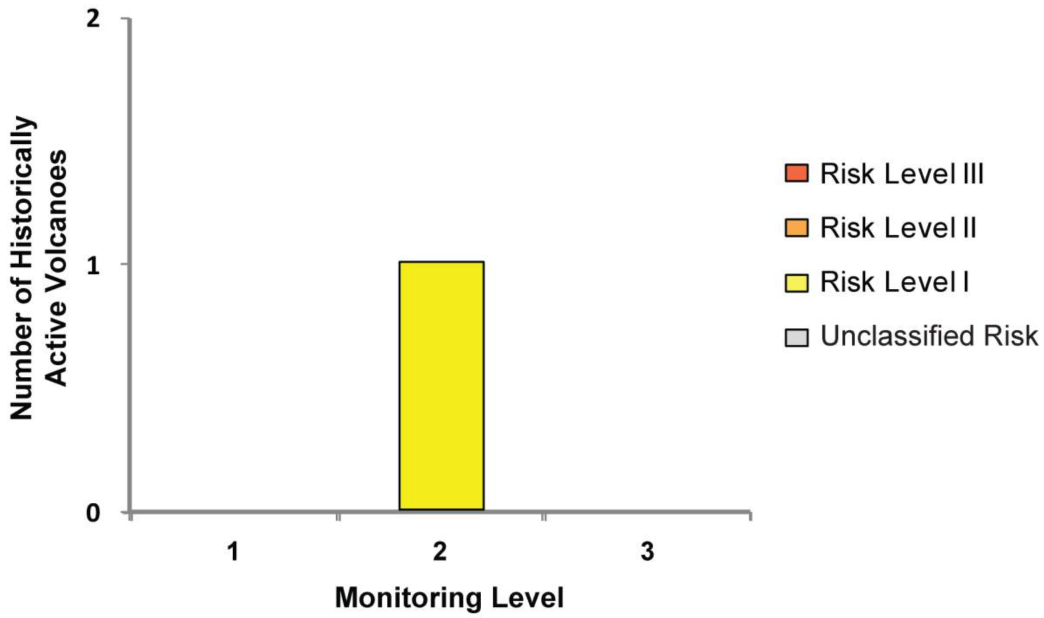

Figure 6.8 The monitoring and risk levels of the historically active volcanoes in India. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Indonesia

Description

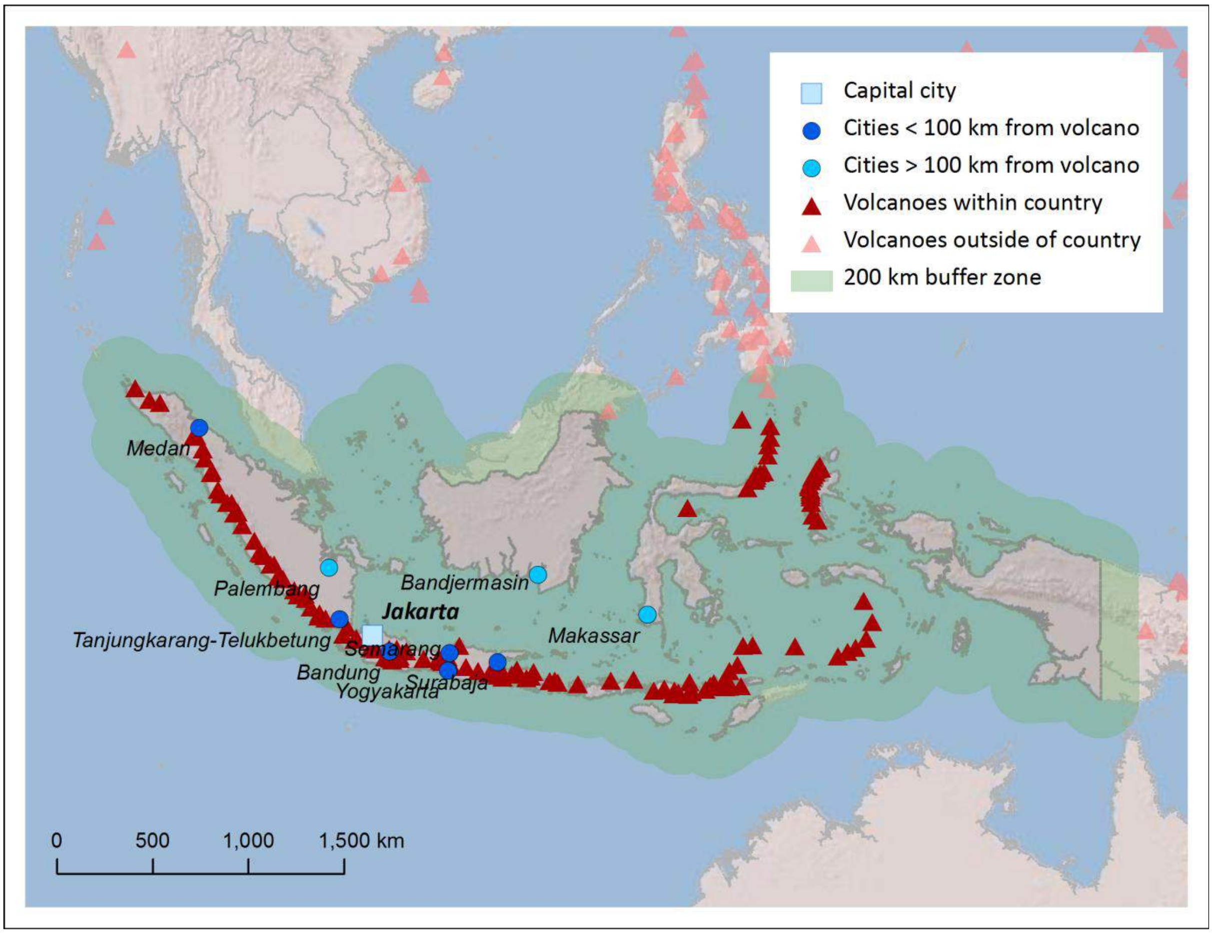

Figure 6.9 Location of Indonesia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Indonesia.

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. Ninety-one 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. Thirty 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: 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 6.10 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 their population size:

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.

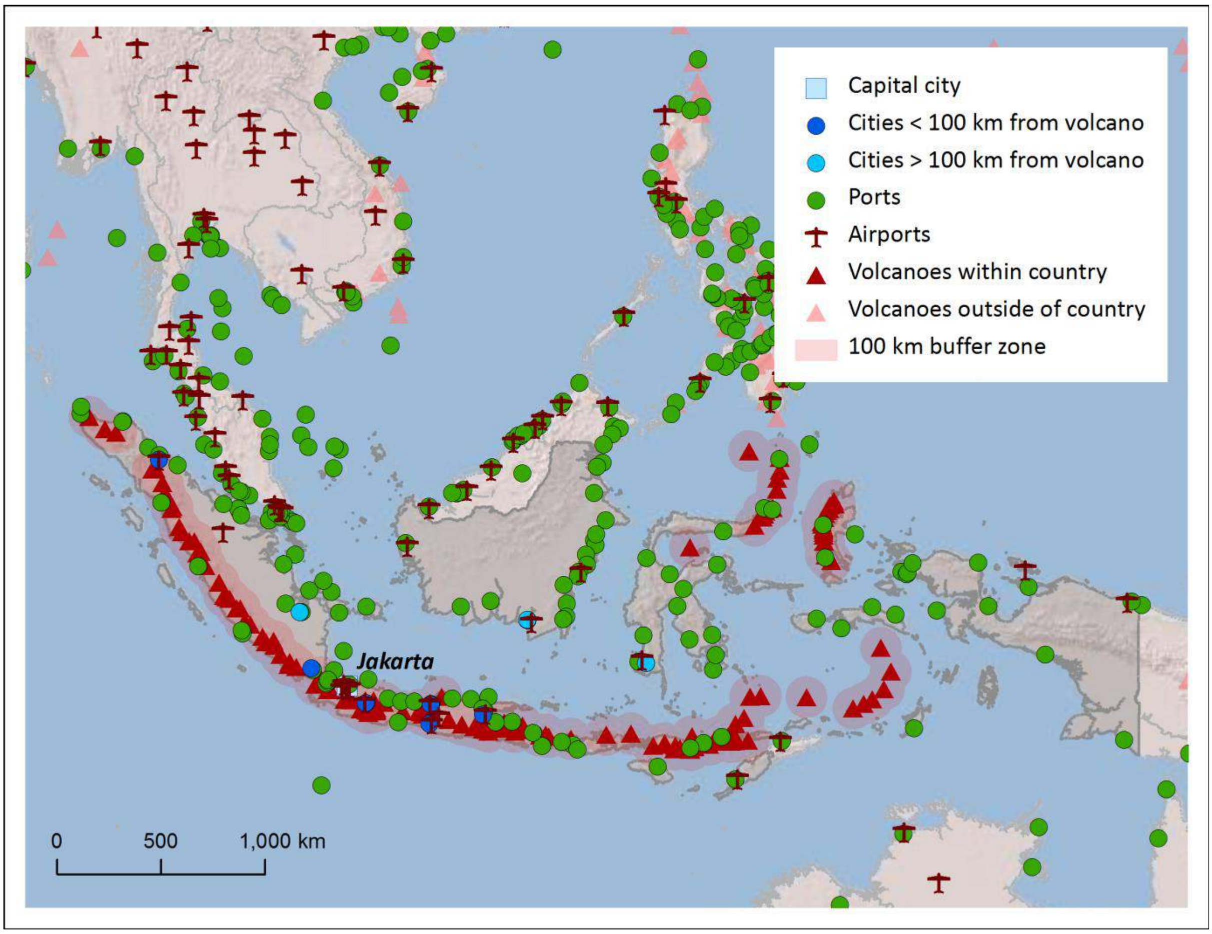

Figure 6.10 The location of Indonesia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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. Of these classified volcanoes 54 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. Thirty-six 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 6.11 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 1900 AD, 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 6.12 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.

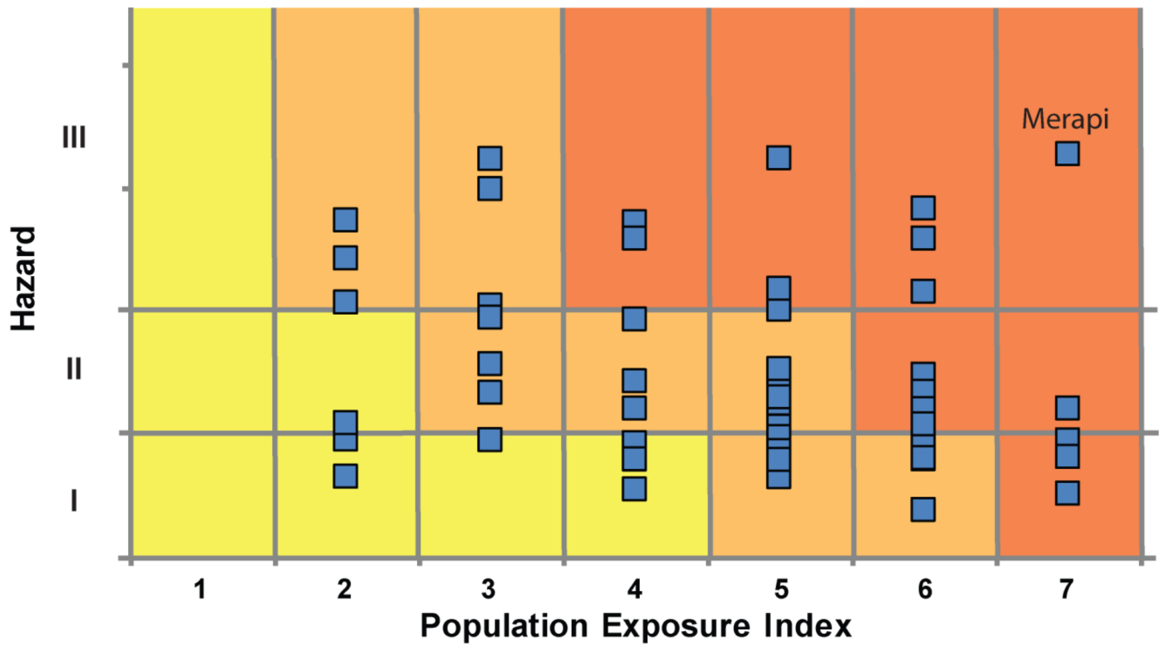

Figure 6.11 Distribution of Indonesia's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

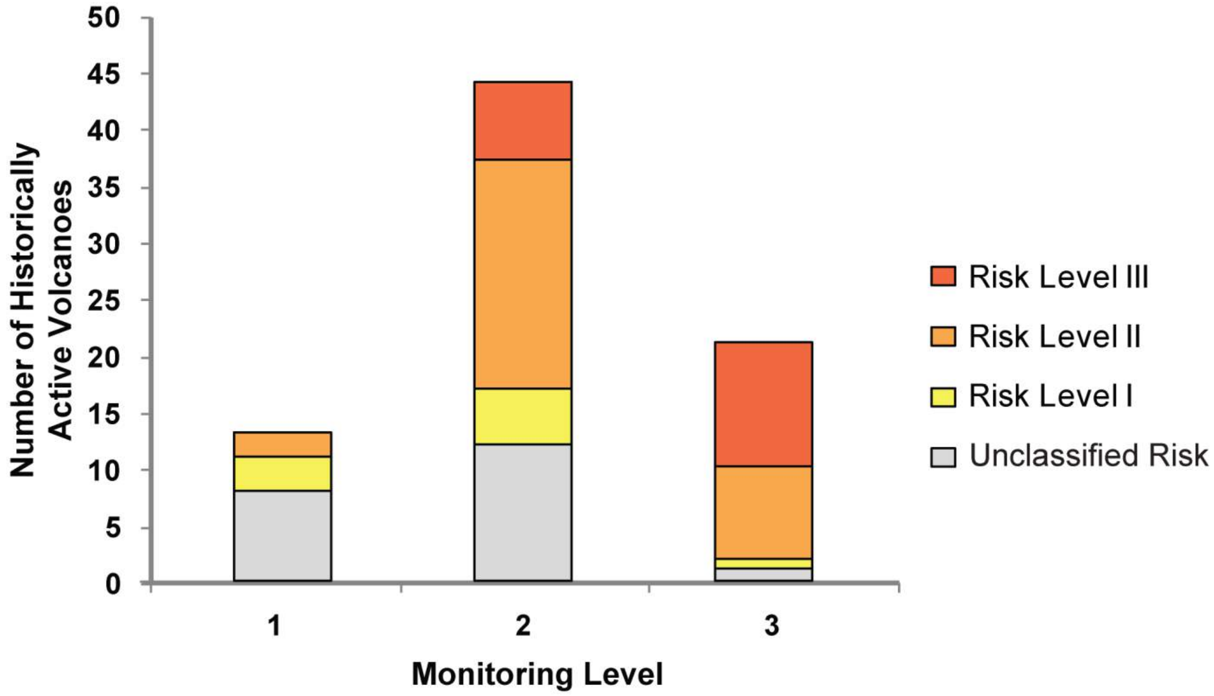

Figure 6.12 The monitoring and risk levels of the historically active volcanoes in Indonesia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Malaysia

Description

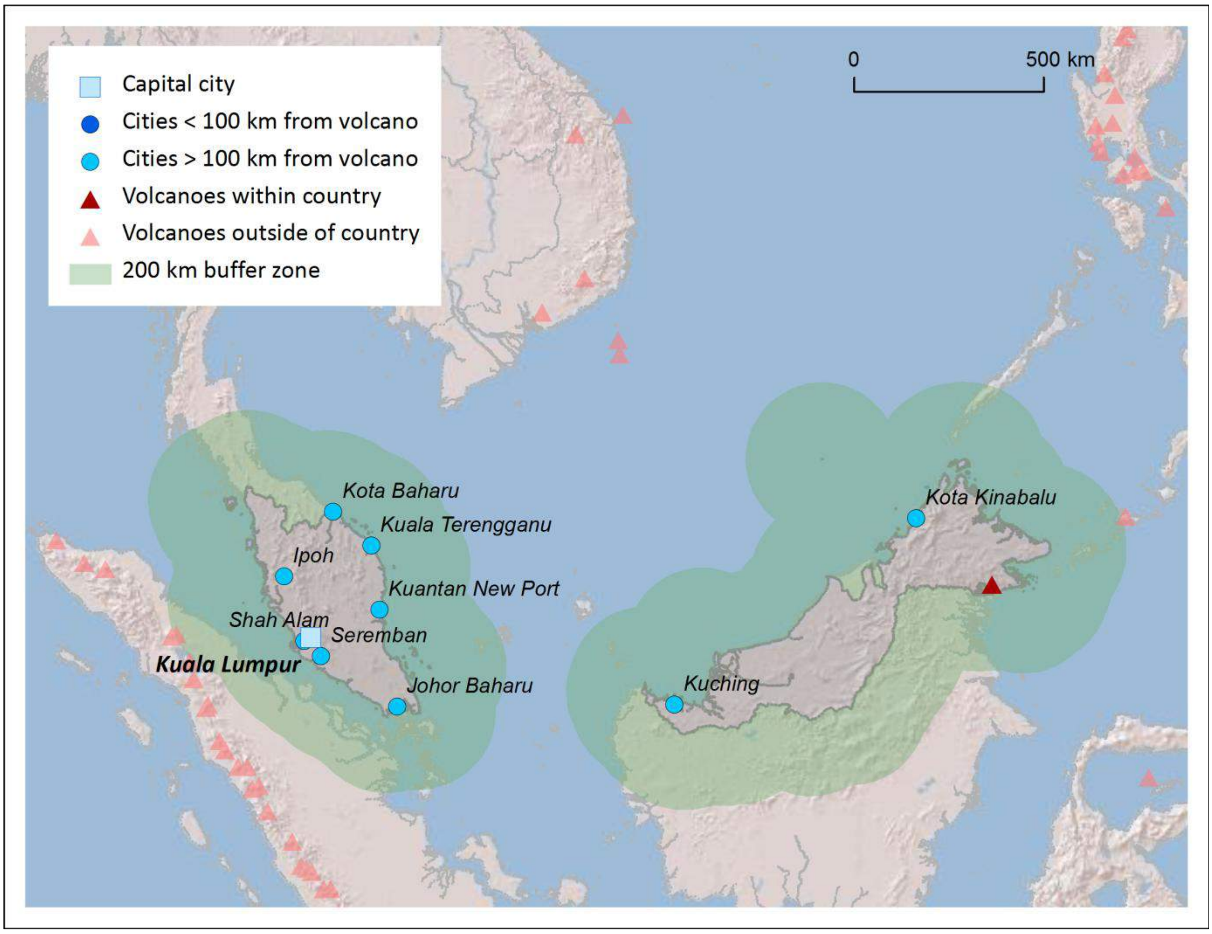

Figure 6.13 Location of Malaysia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Malaysia.

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:
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 6.13 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 their population size:

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.

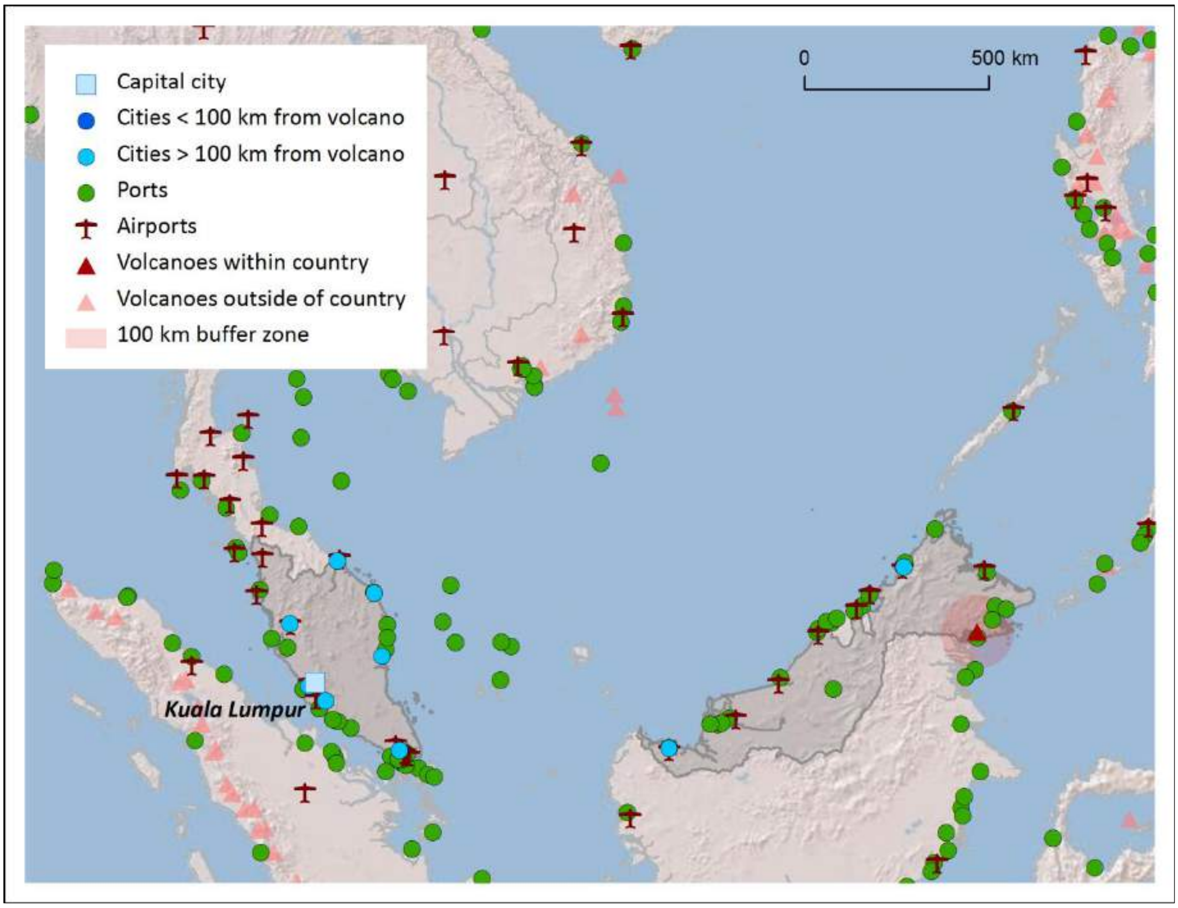

Figure 6.14 The location of Malaysia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 6.14 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 1900 AD, 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 (Table 7.1). 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 7.1 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.

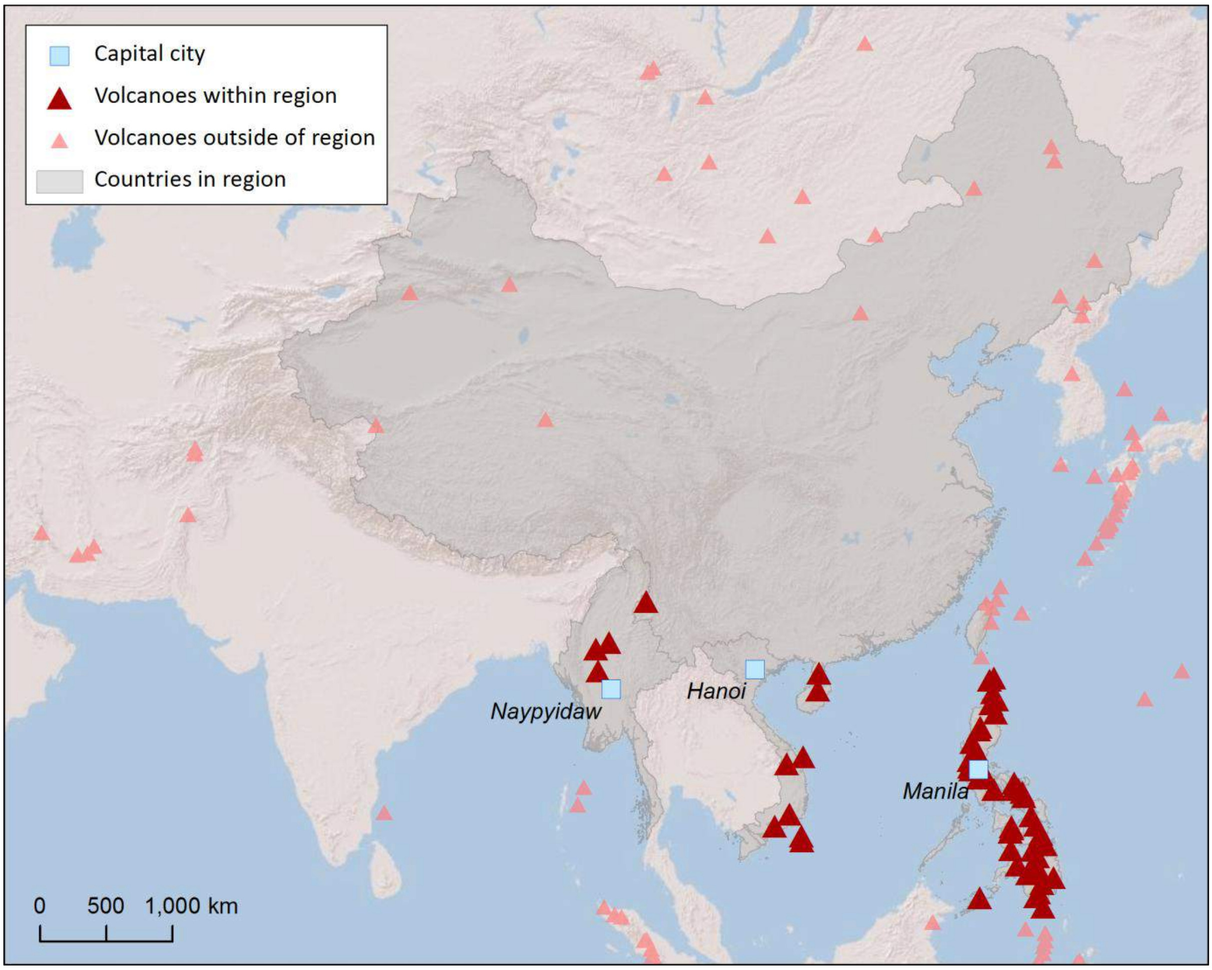

Figure 7.1 The distribution of Holocene volcanoes through the Philippines and SE Asia region. The capital cities of the constituent countries are shown.

This profile and the data therein should not be used in place of focussed assessments and information provided by local monitoring and research institutions.

Published online by Cambridge University Press

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 7.2 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 7.3 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 (Figure 7.2). 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.

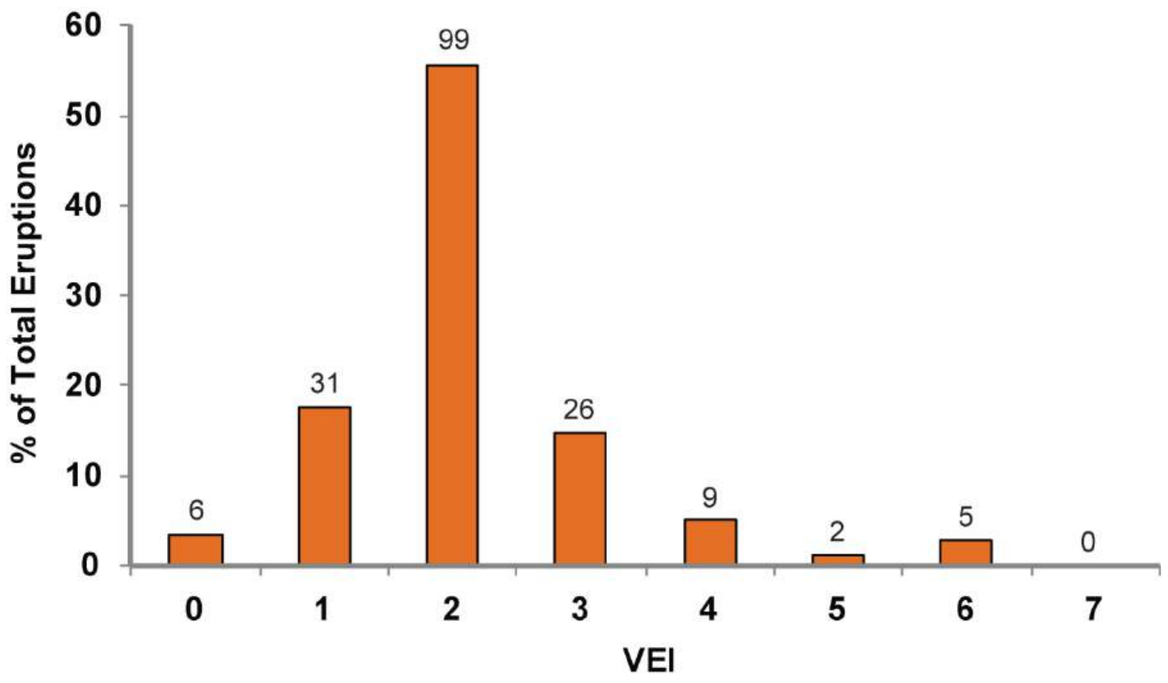

Figure 7.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 25 eruptions were recorded with unknown VEI.

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 7.4 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 1900 AD, 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 7.5 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 7.6 The number of volcanoes in the Philippines and SE Asia region classified at each Risk Level.

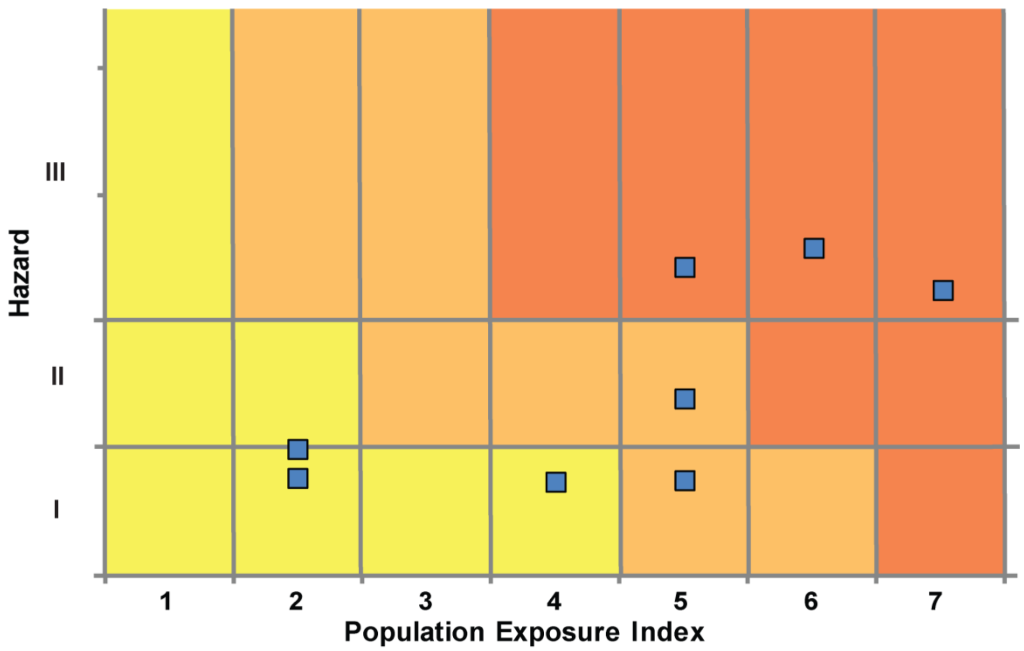

Figure 7.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional Monitoring Capacity

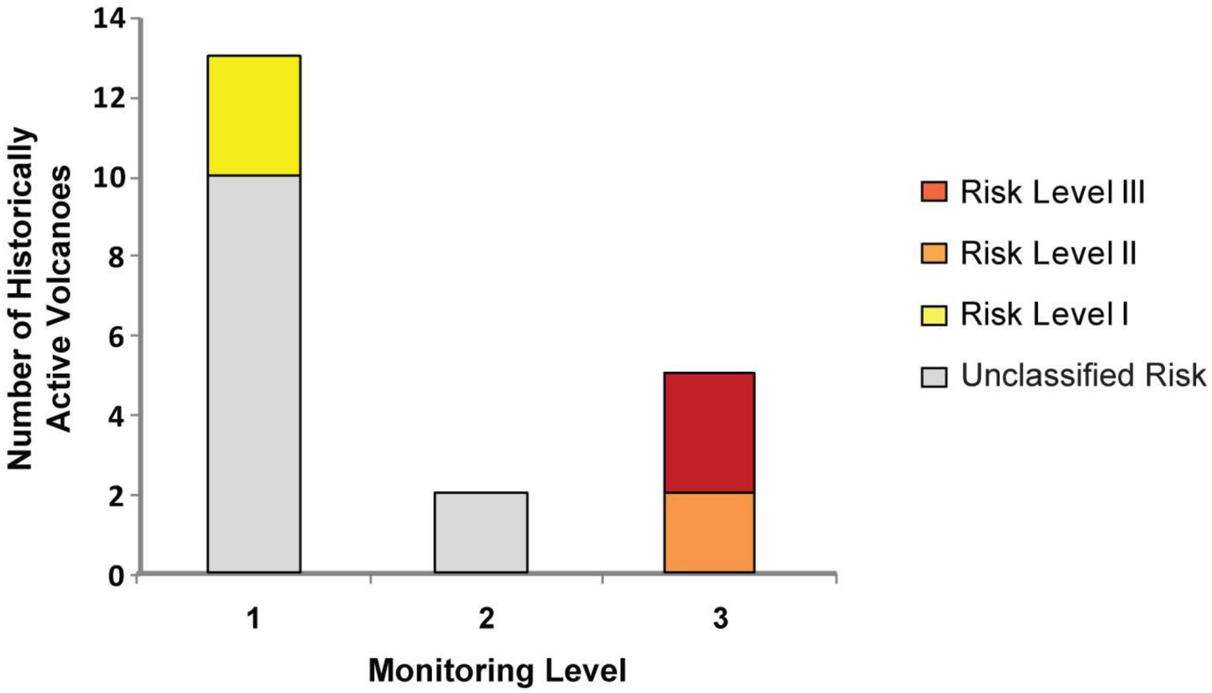

Figure 7.4 The monitoring and risk levels of the historically active volcanoes in the Philippines and SE Asia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Myanmar

Description

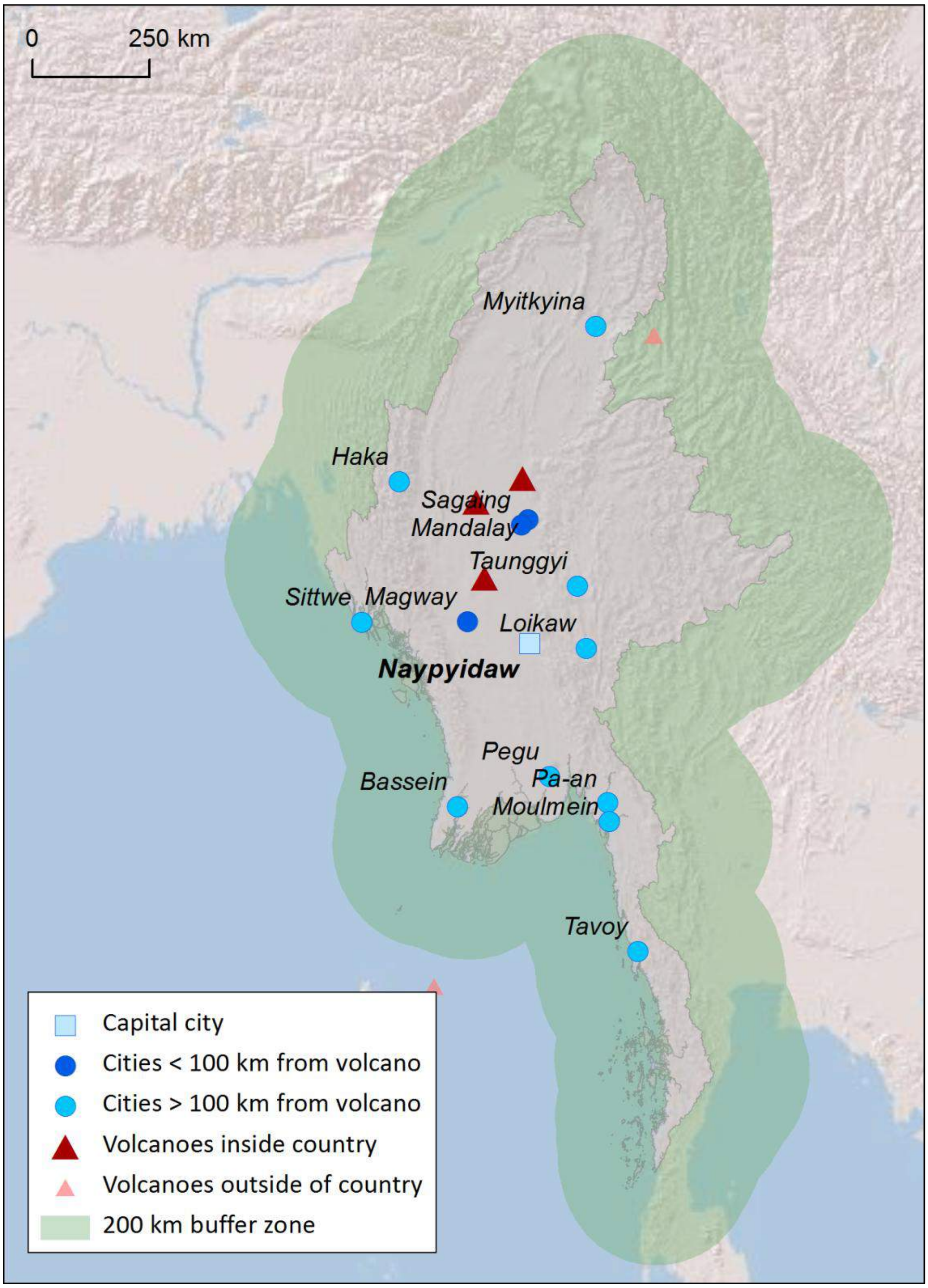

Figure 7.5 Location of Myanmar's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Myanmar.

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:
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 7.7 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 their population size:

Rangoon (Yangon)	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

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.

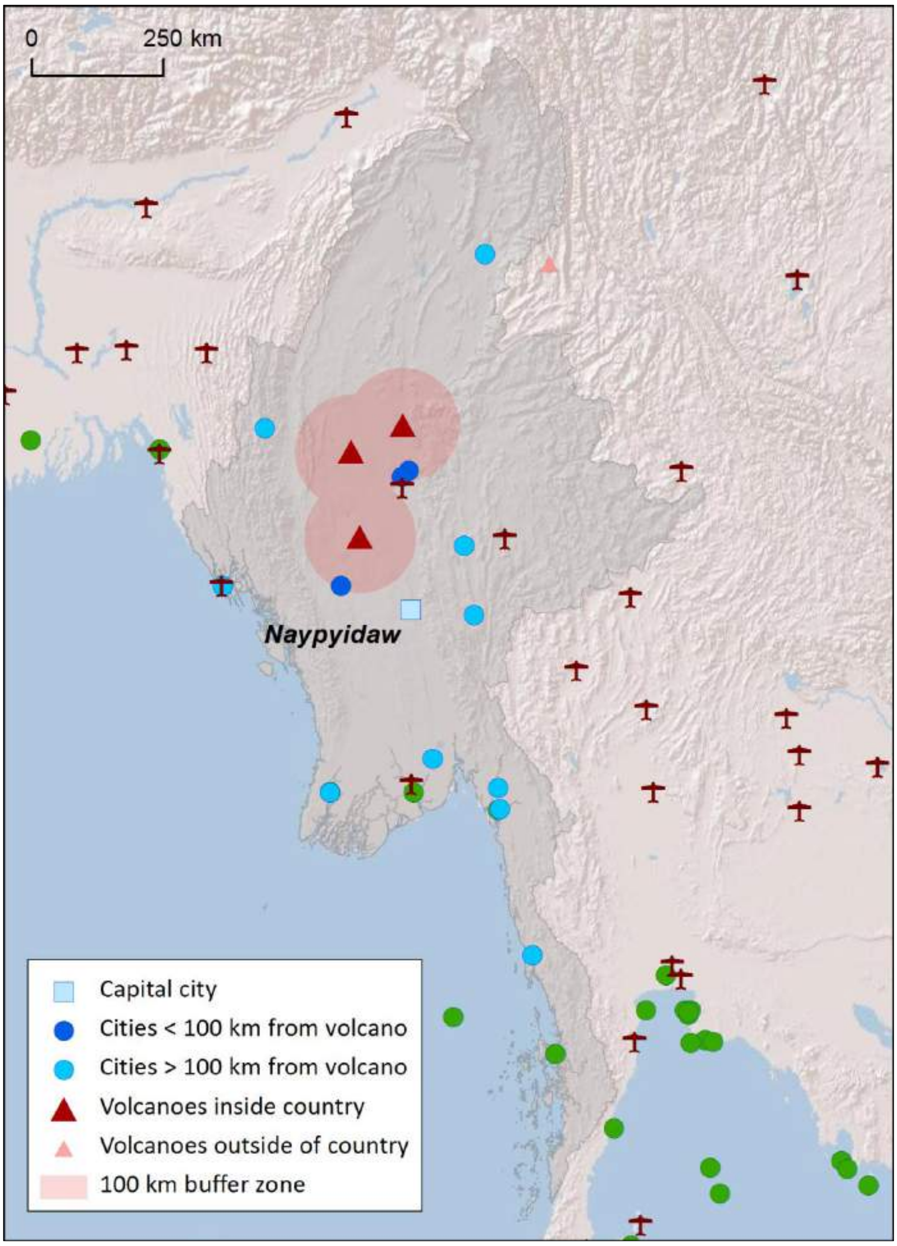

Figure 7.6 The location of Myanmar's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 7.8 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 1900 AD, 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

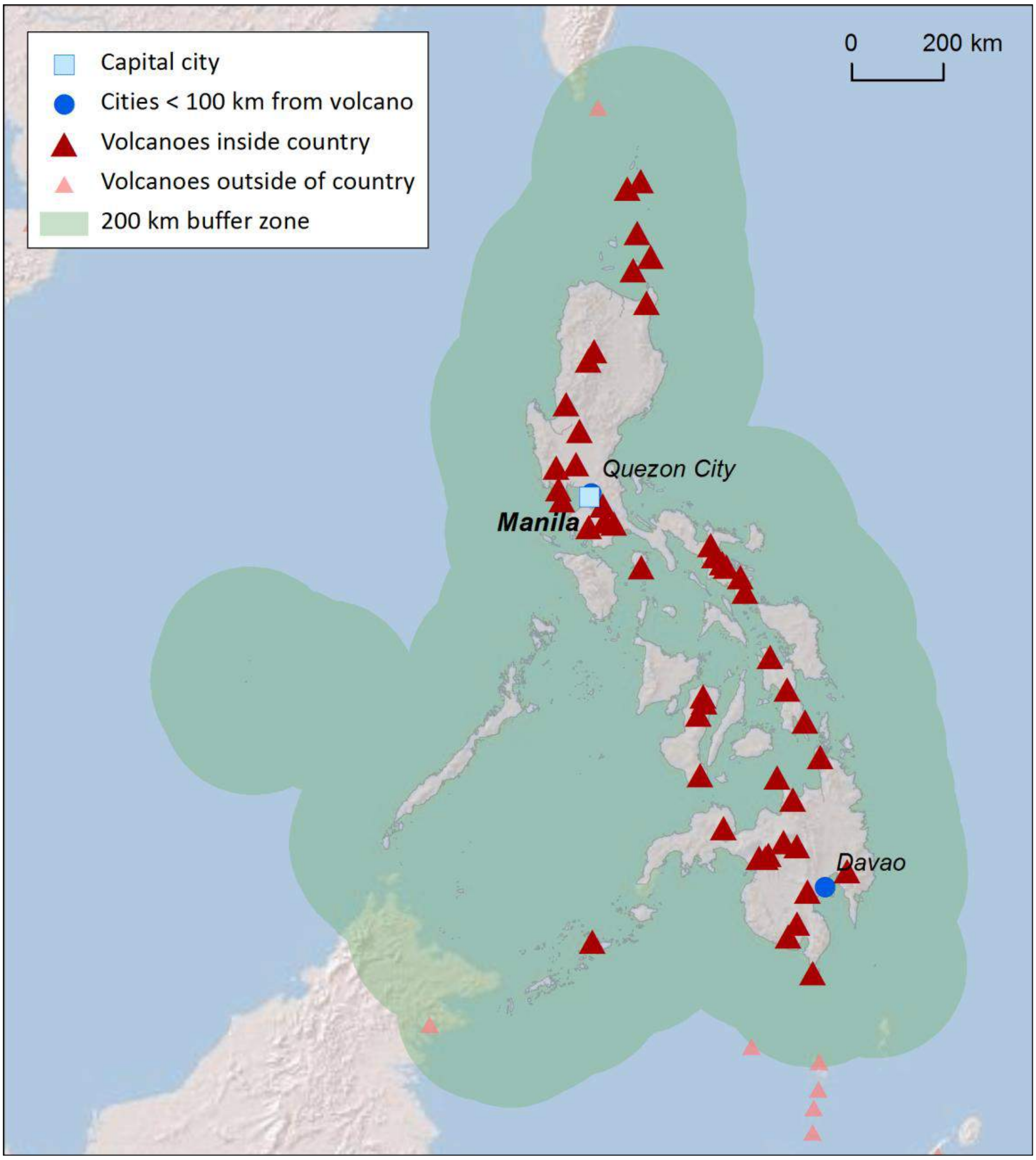

Figure 7.7 Location of the Philippines' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Philippines.

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.

VOTW4.22 lists 175 historical eruptions 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. Between 1640 and 2013 AD 33 eruptions from Parker, Camiguin, Kanlaon, Bulusan, Mayon, Taal, Pinatubo, Didicas, Ragang and Ambalatungan Group resulted in fatalities. Fatalities are recorded in 18% of historical eruptions. 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. A high local population is present at 37 volcanoes, 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: 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 7.9 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 their population size:

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. An extensive road and rail network lies within 100 km of the volcanoes, as do 60 ports and 7 airports.

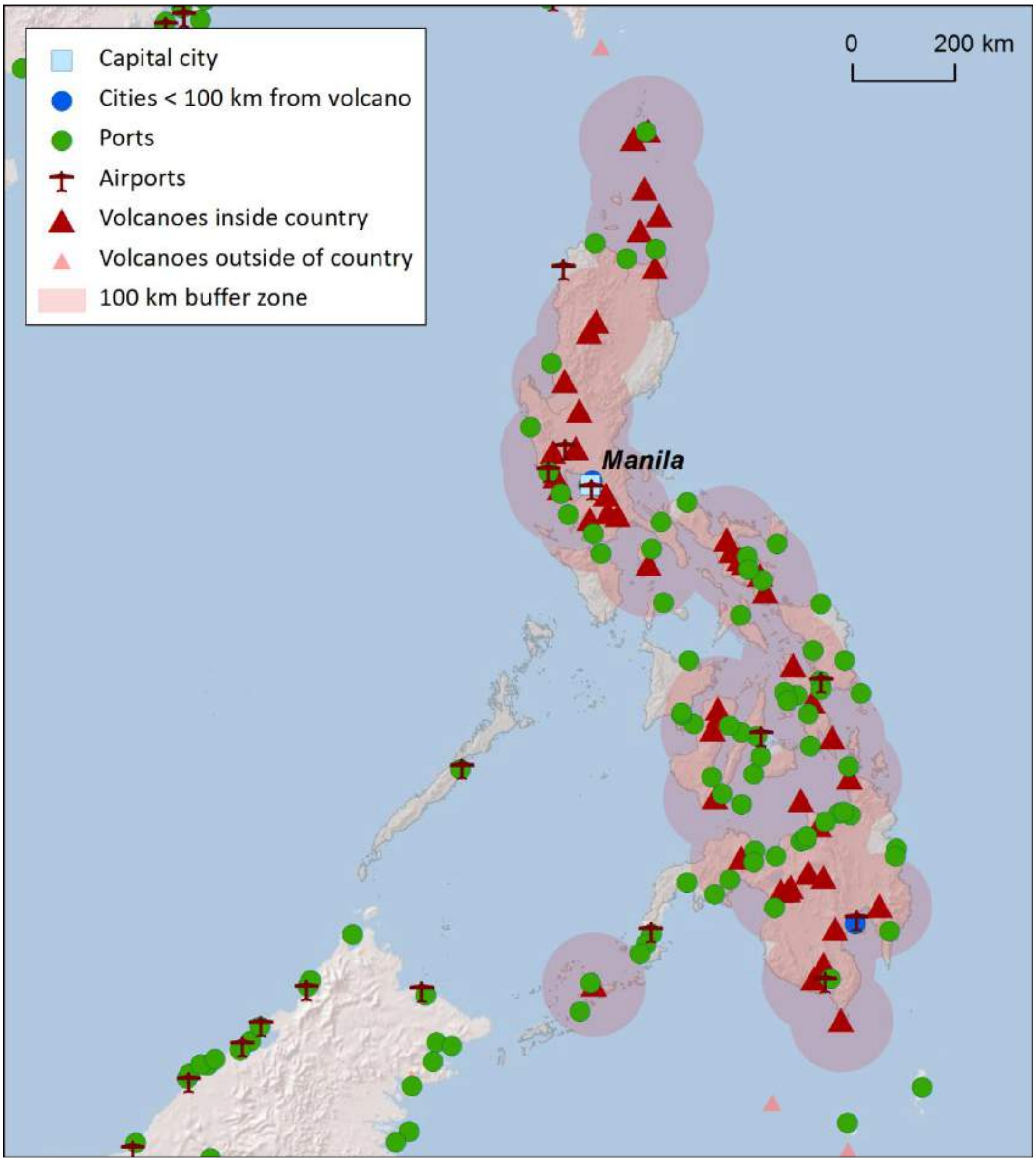

Figure 7.8 The location of the Philippines' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 7.10 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 1900 AD, 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 7.11 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.

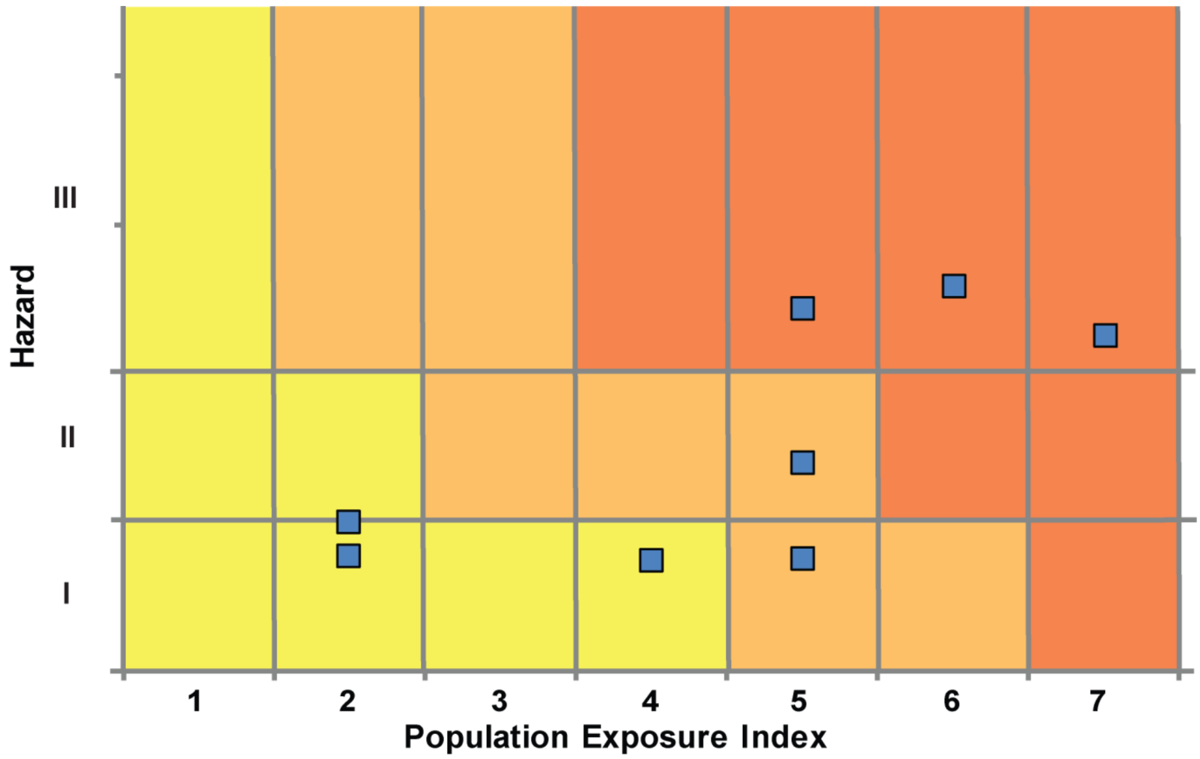

Figure 7.9 Distribution of the Philippines' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The Philippine Institute of Volcanology and Seismology (PHIVOLCS) is responsible for the volcanoes in the Philippines, 18 of which 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.

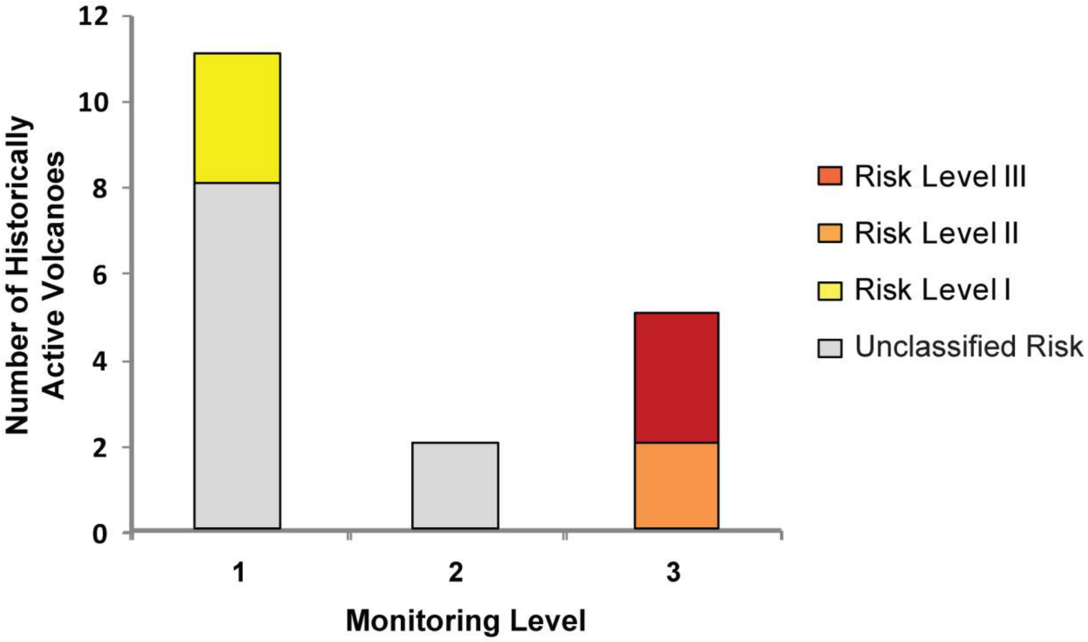

Figure 7.10 The monitoring and risk levels of the historically active volcanoes in the Philippines. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Vietnam

Description

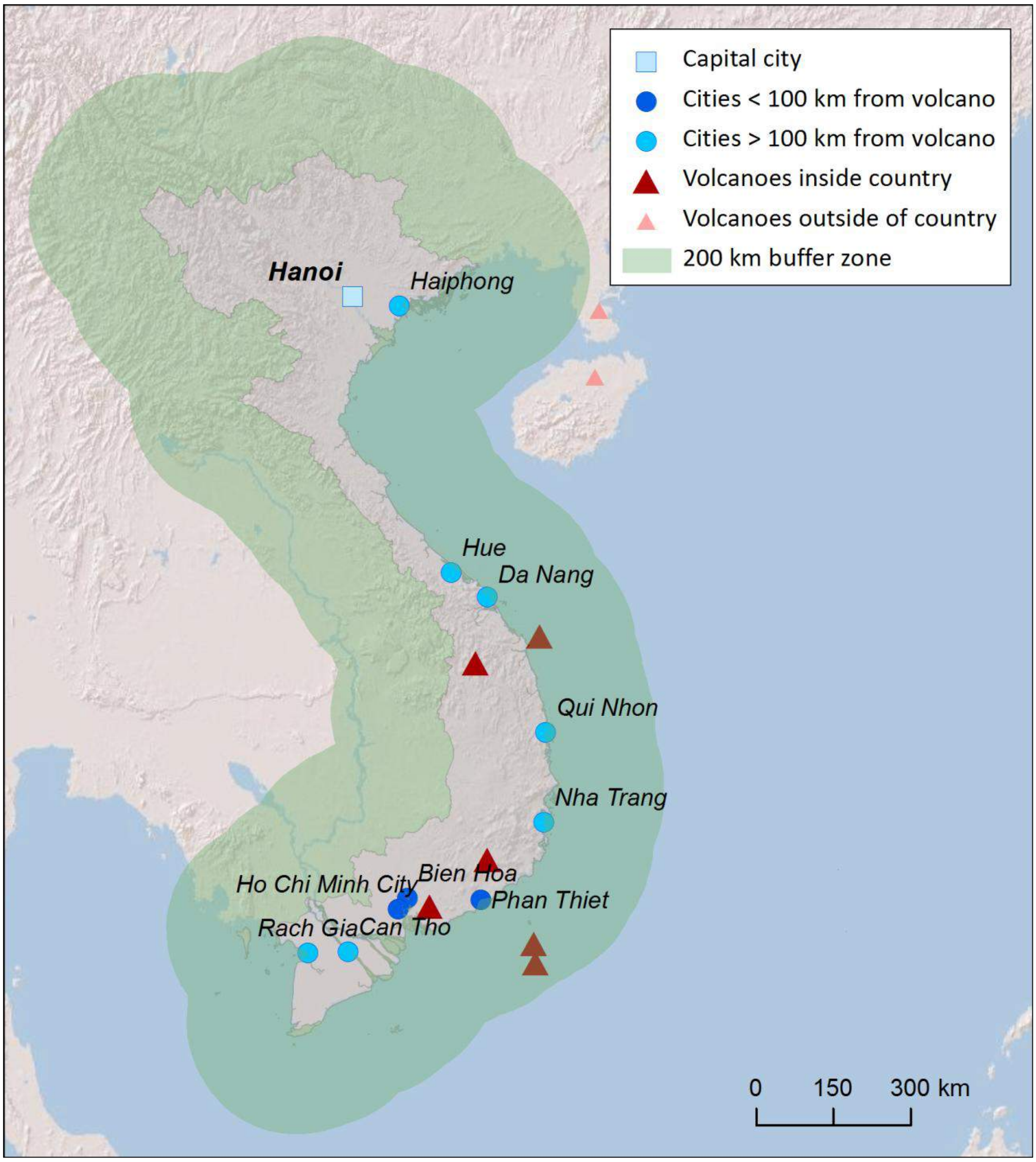

Figure 7.11 Location of Vietnam's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Vietnam.

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: 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 7.12 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 their population size:

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

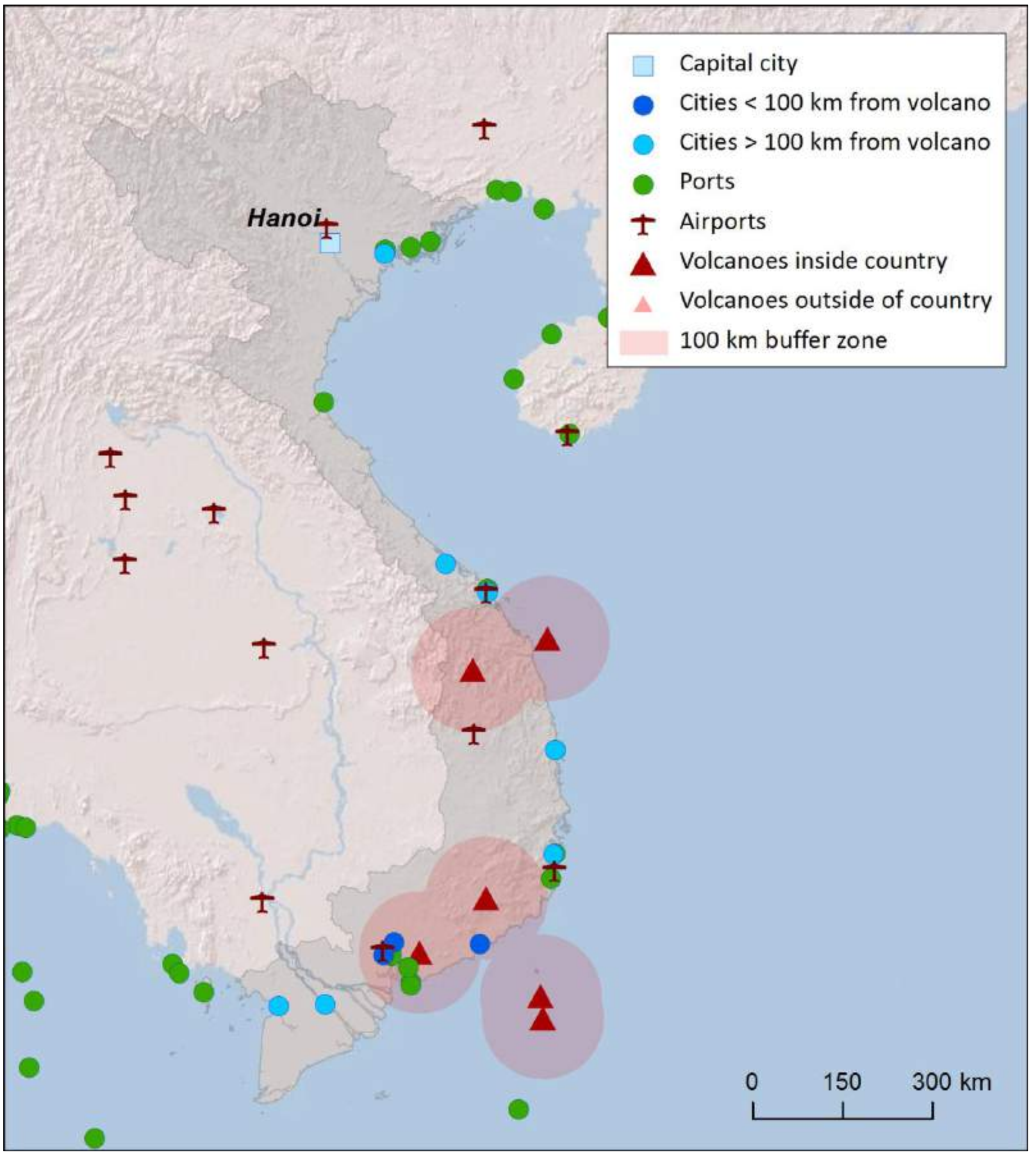

Figure 7.12 The location of Vietnam's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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 7.13 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 1900 AD, 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.

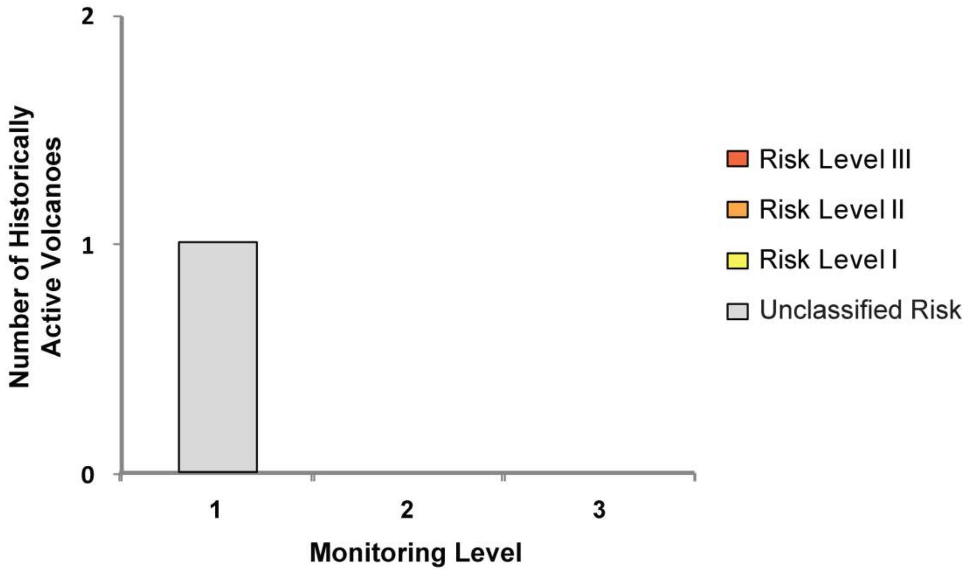

Figure 7.13 The monitoring and risk levels of the historically active volcanoes in Vietnam. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.