Appendix B – Region 4

Country and regional profiles of volcanic hazard and risk:

New Zealand to Fiji

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[1]University of Bristol, UK; [2]British Geological Survey, UK, * Full contributor list available in Appendix B Full Download

This download comprises the profiles for Region 4: New Zealand to Fiji only. For the full report and all regions see Appendix B Full Download. Page numbers reflect position in the full report. The following countries are profiled here:

Brown, S.K., Sparks, R.S.J., Mee, K., Vye-Brown, C., Ilyinskaya, E., Jenkins, S.F., and Loughlin, S.C. (2015) Country and regional profiles of volcanic hazard and risk. In: S.C. Loughlin, R.S.J. Sparks, S.K. Brown, S.F. Jenkins & C. Vye-Brown (eds) *Global Volcanic Hazards and Risk,* Cambridge: Cambridge University Press.

Region 4: New Zealand to Fiji

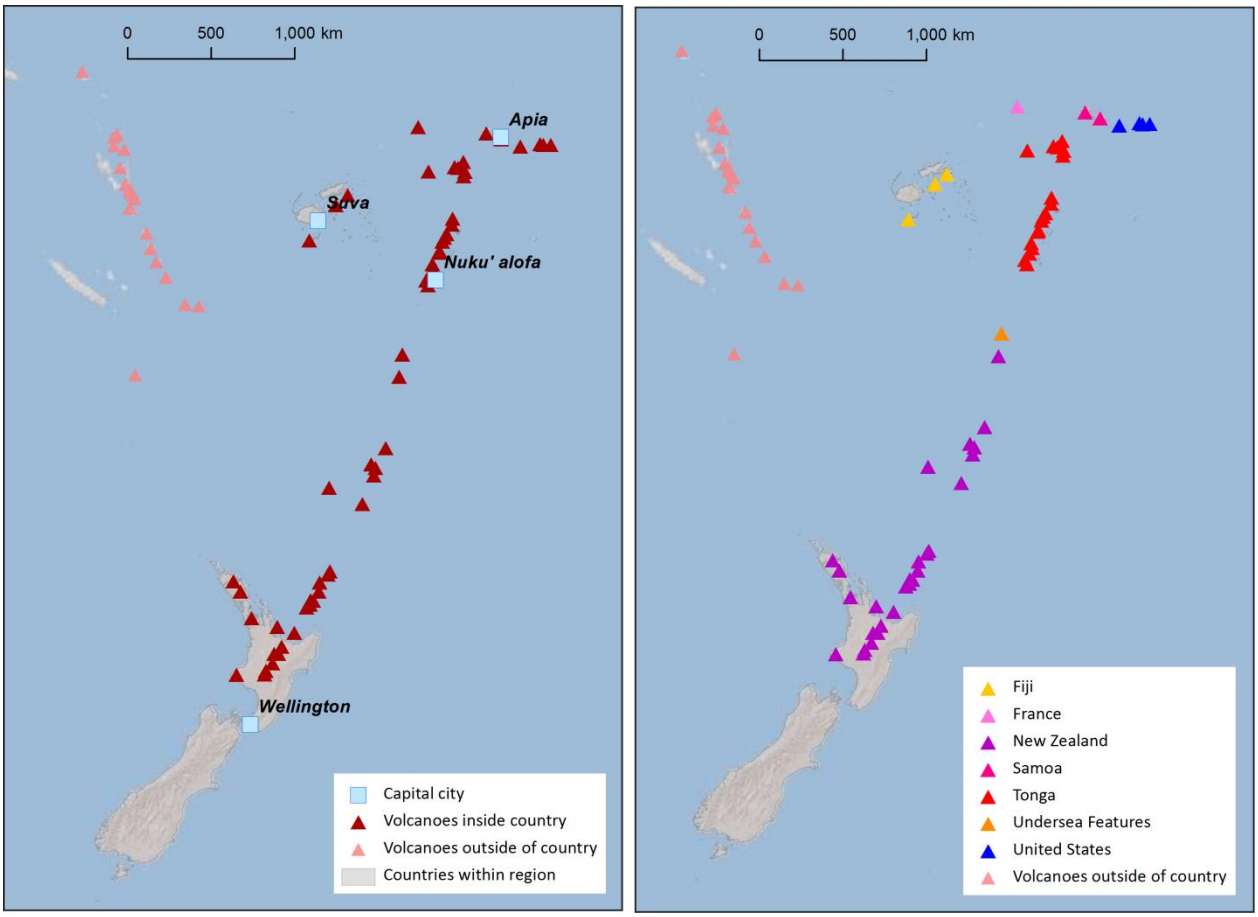

Figure 4.1 The distribution of Holocene volcanoes through the New Zealand to Fiji region. The capital cities of the constituent countries are shown.

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.

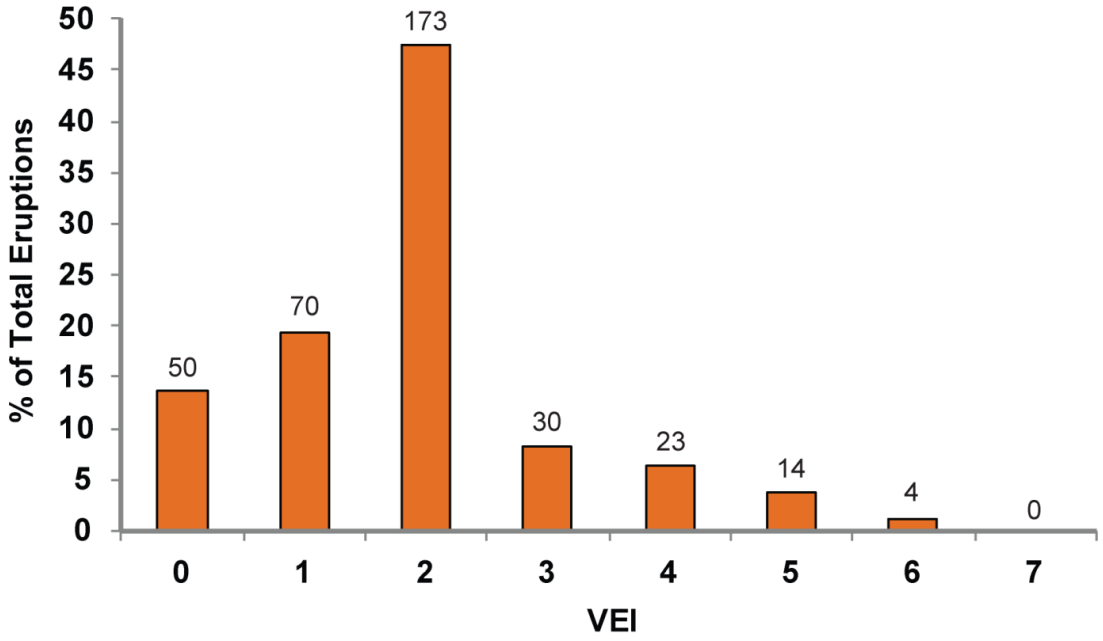

Figure 4.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 73 eruptions were recorded with unknown VEI.

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.

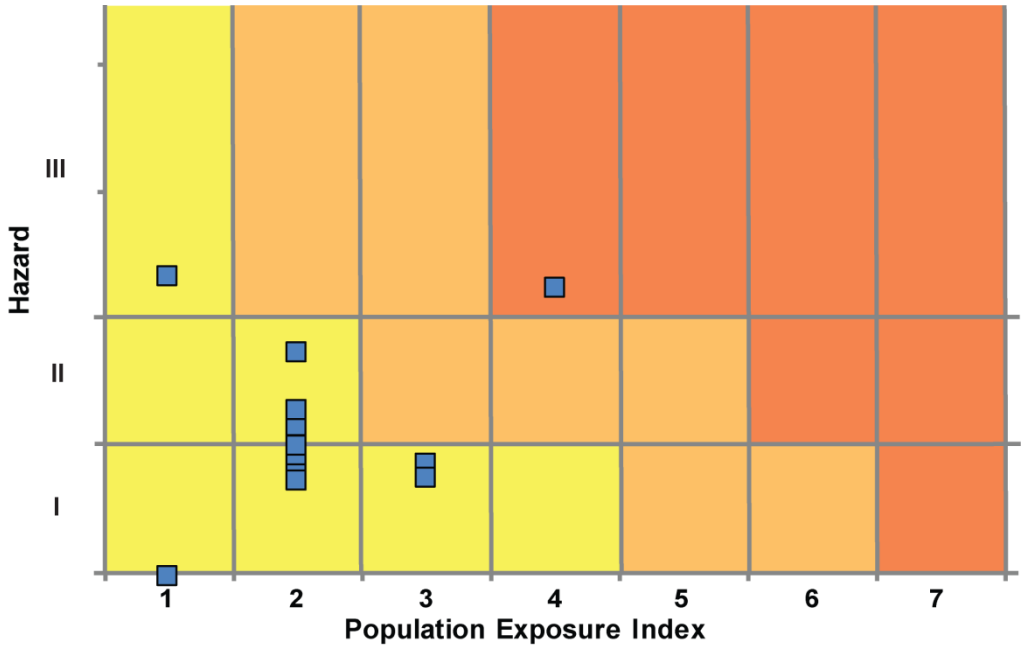

Figure 4.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional Monitoring Capacity

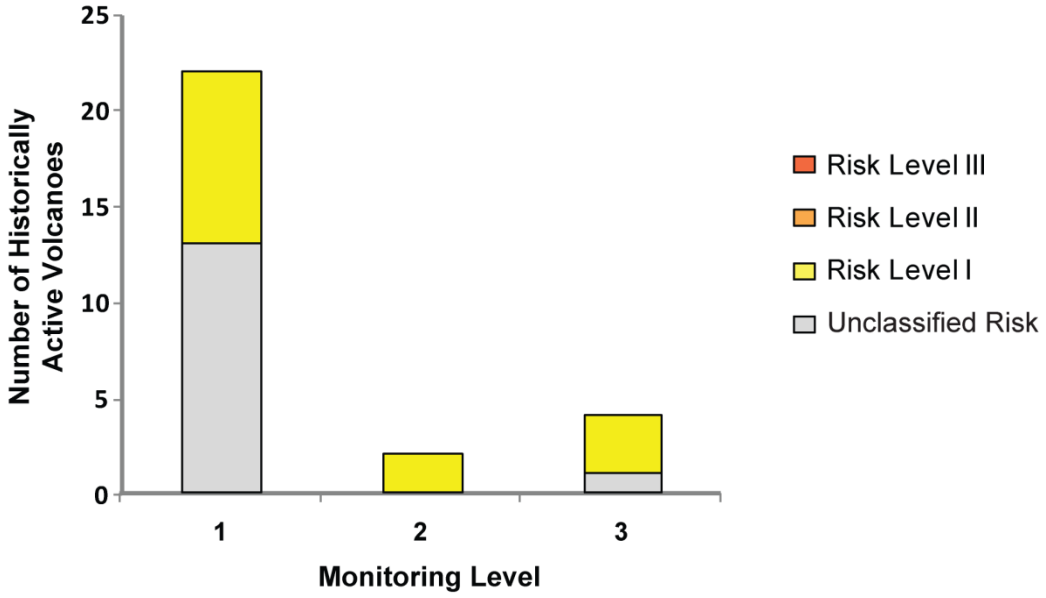

Figure 4.4 The monitoring and risk levels of the historically active volcanoes in New Zealand to Fiji. Monitoring Level 1indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring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

Fiji

Description

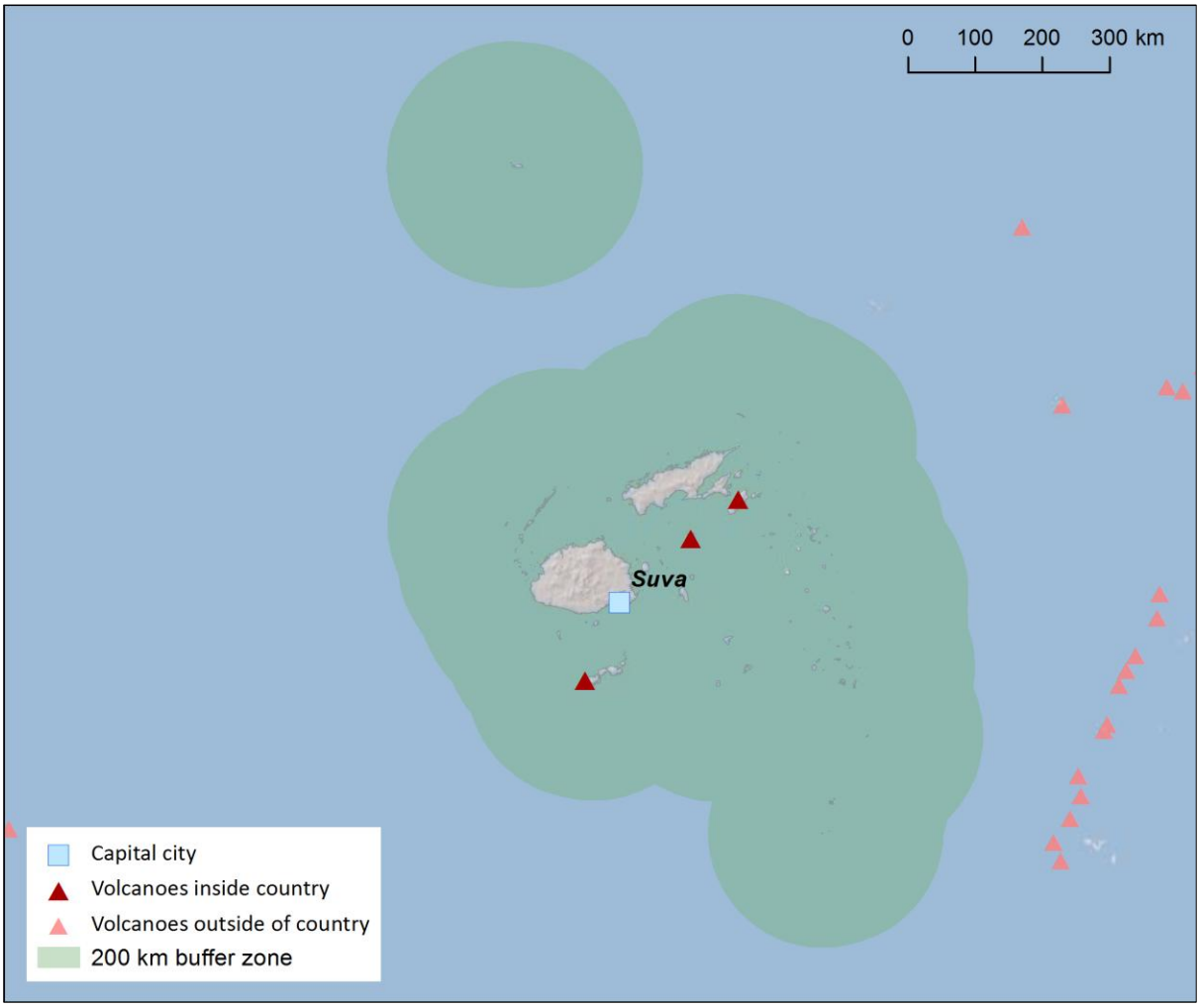

Figure 4.5 Location of Fiji's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Fiji.

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.

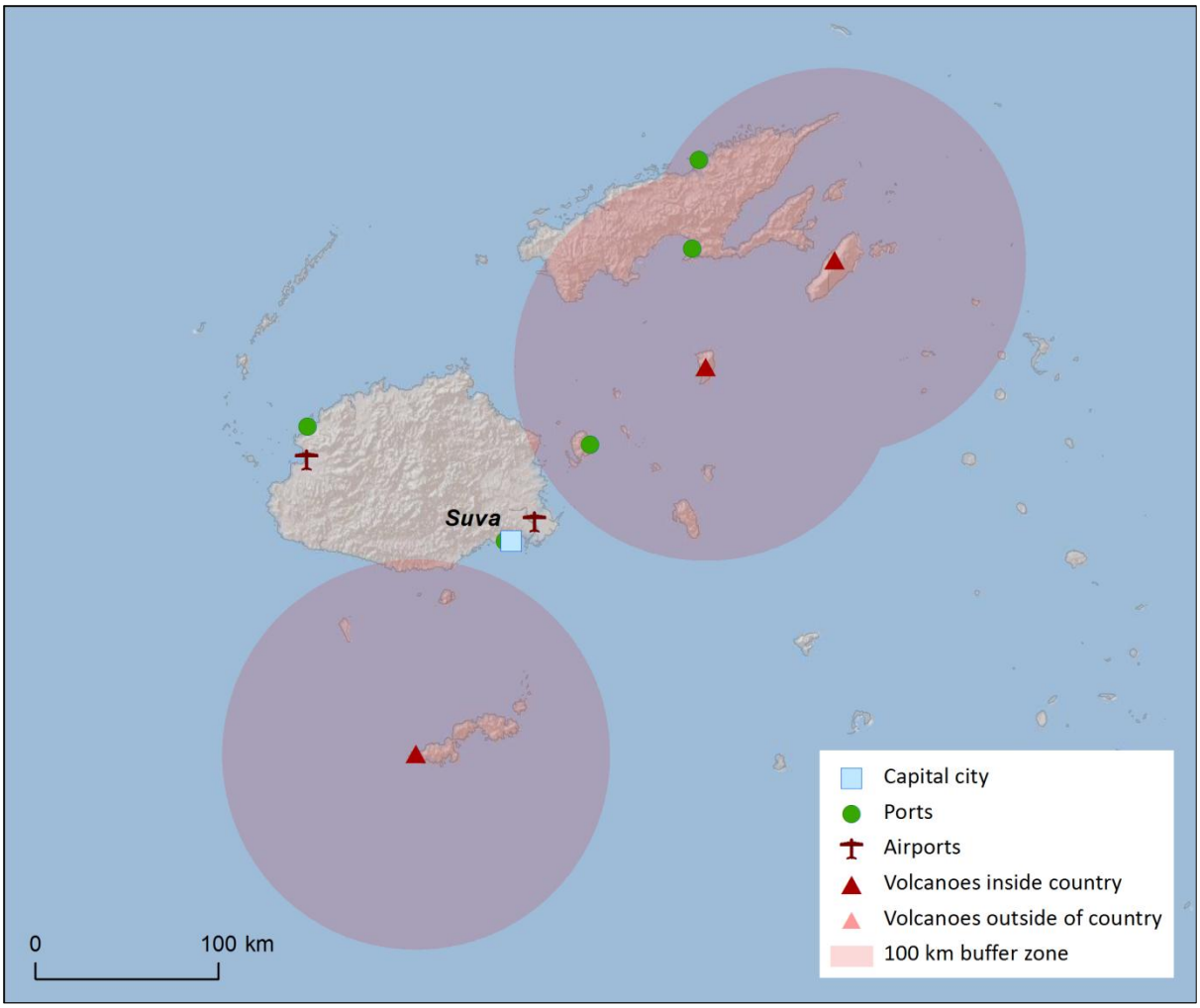

Figure 4.6 The location of Fiji's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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.

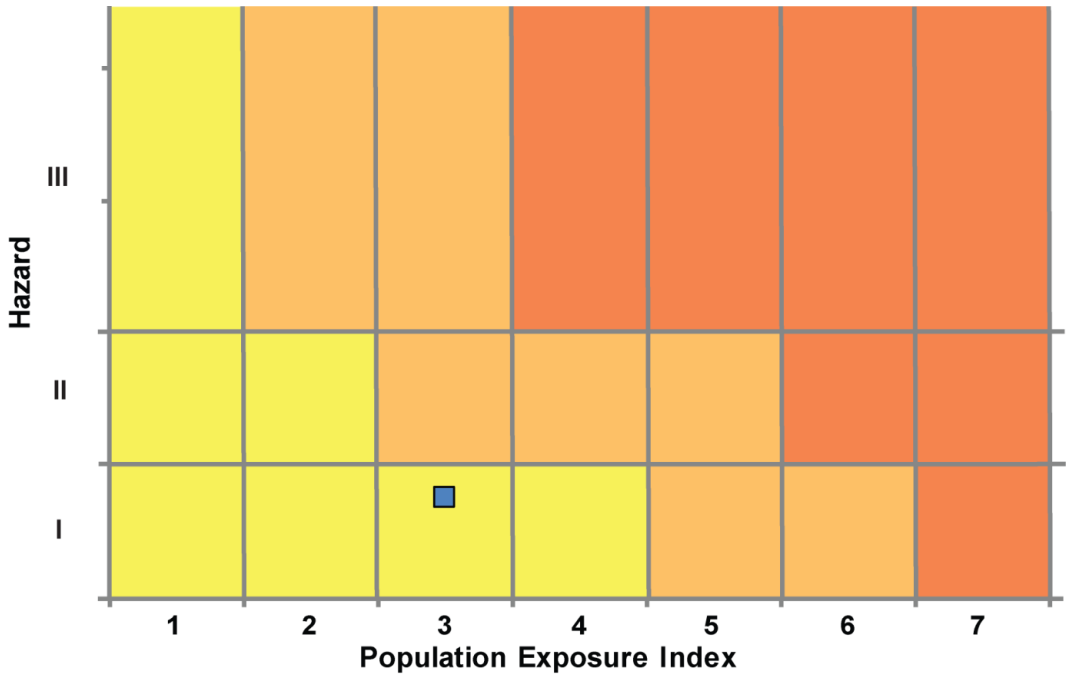

Figure 4.7 Distribution of Fiji's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

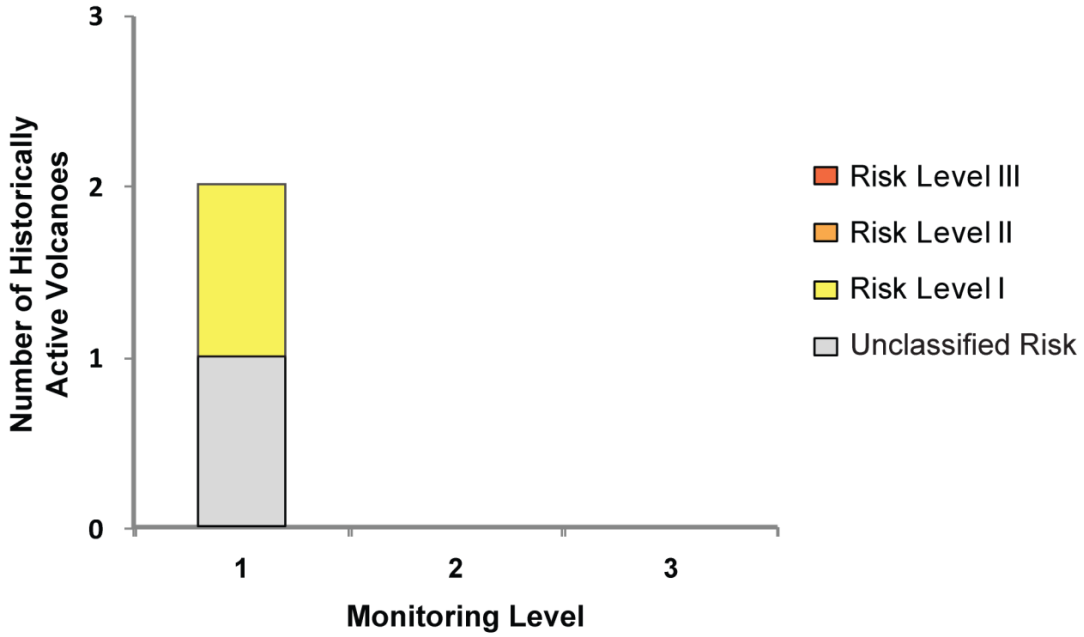

Figure 4.8 The monitoring and risk levels of the historically active volcanoes in Fiji. Monitoring Level 1indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates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

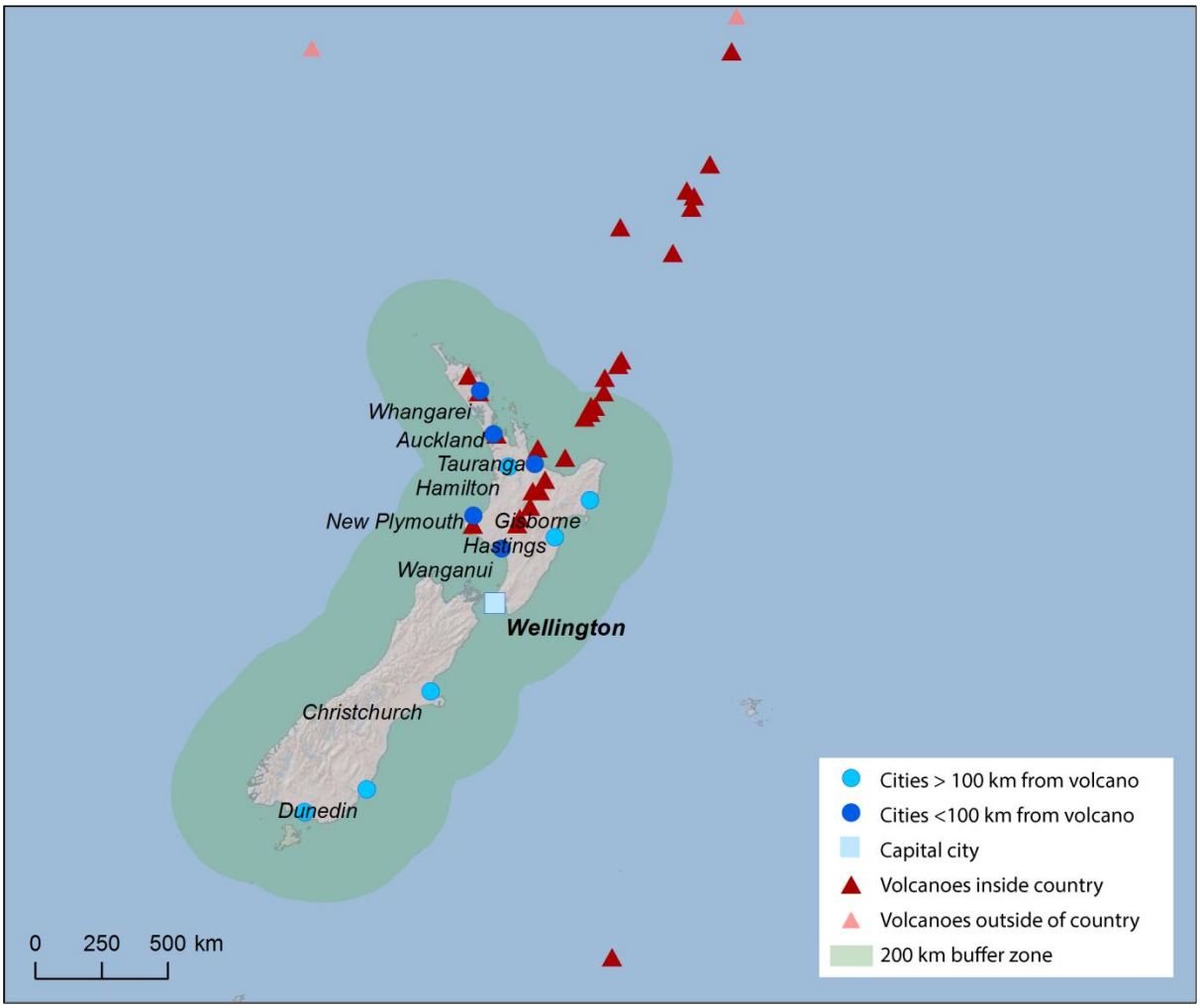

Figure 4.9 Location of New Zealand's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect New Zealand.

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.

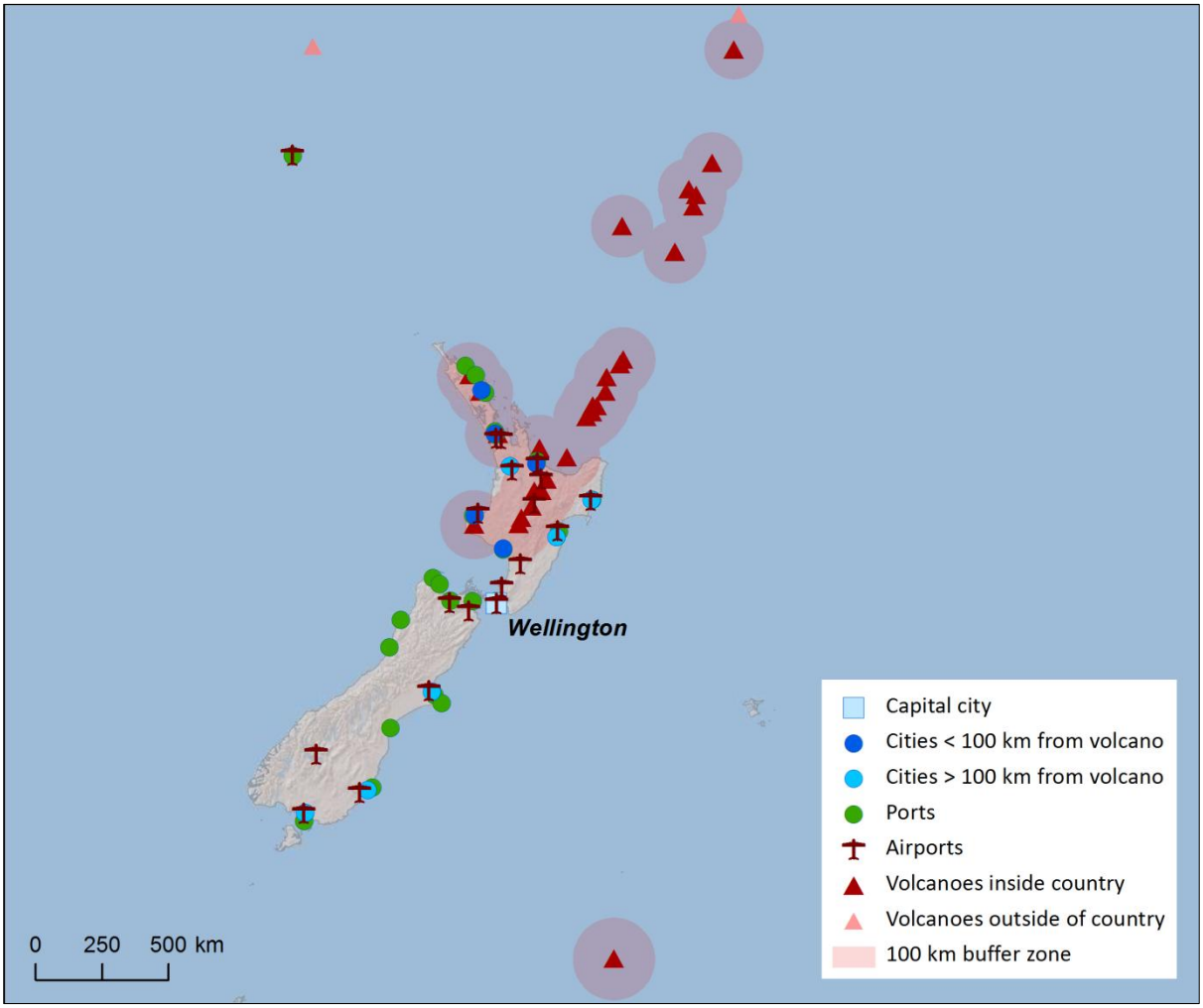

Figure 4.10 The location of New Zealand's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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.

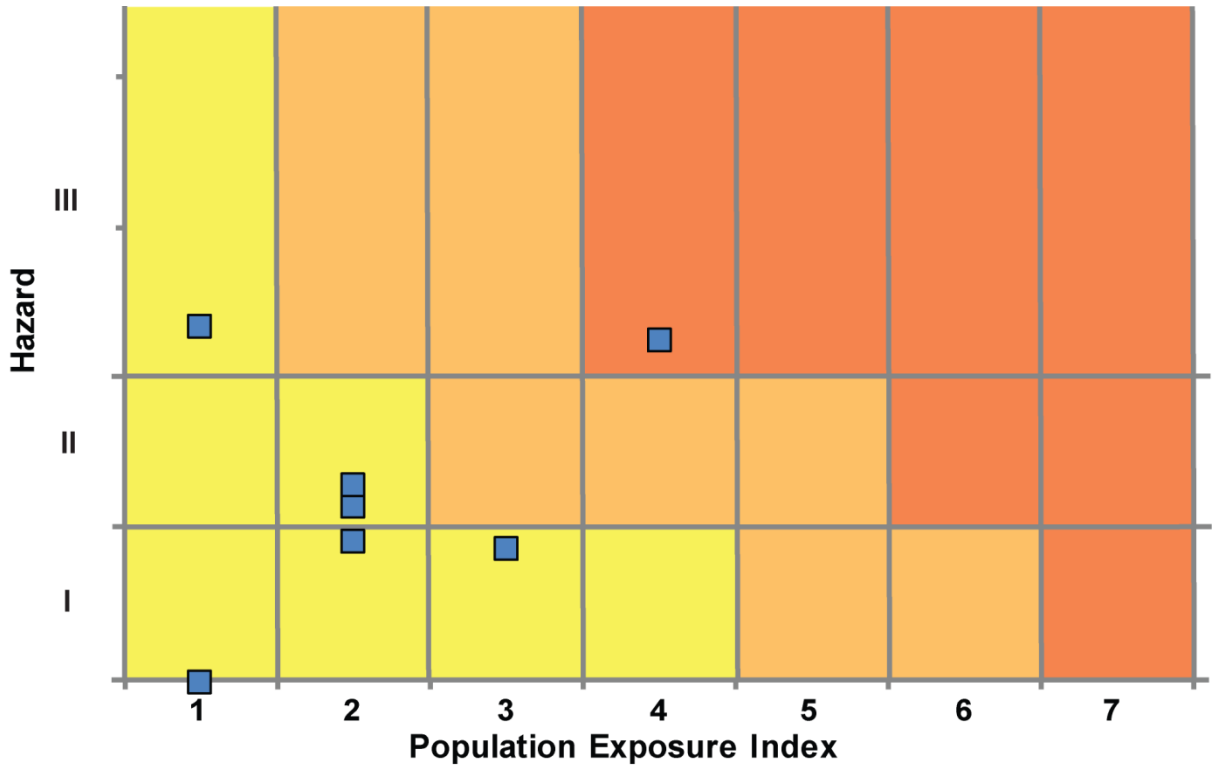

Figure 4.11 Distribution of New Zealand's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

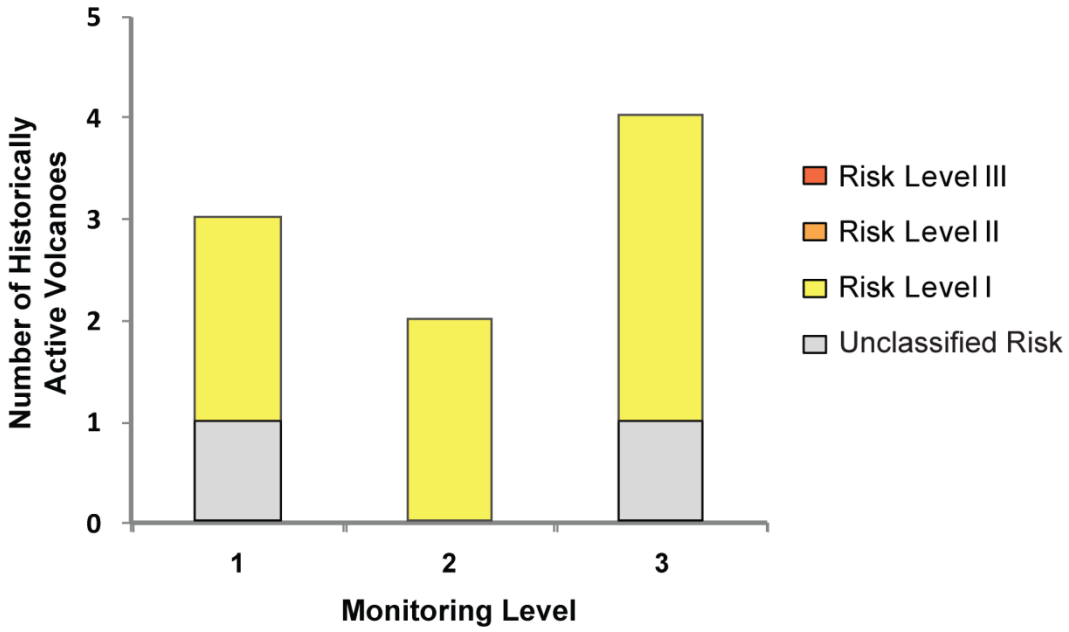

Figure 4.12 The monitoring and risk levels of the historically active volcanoes in New Zealand. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level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

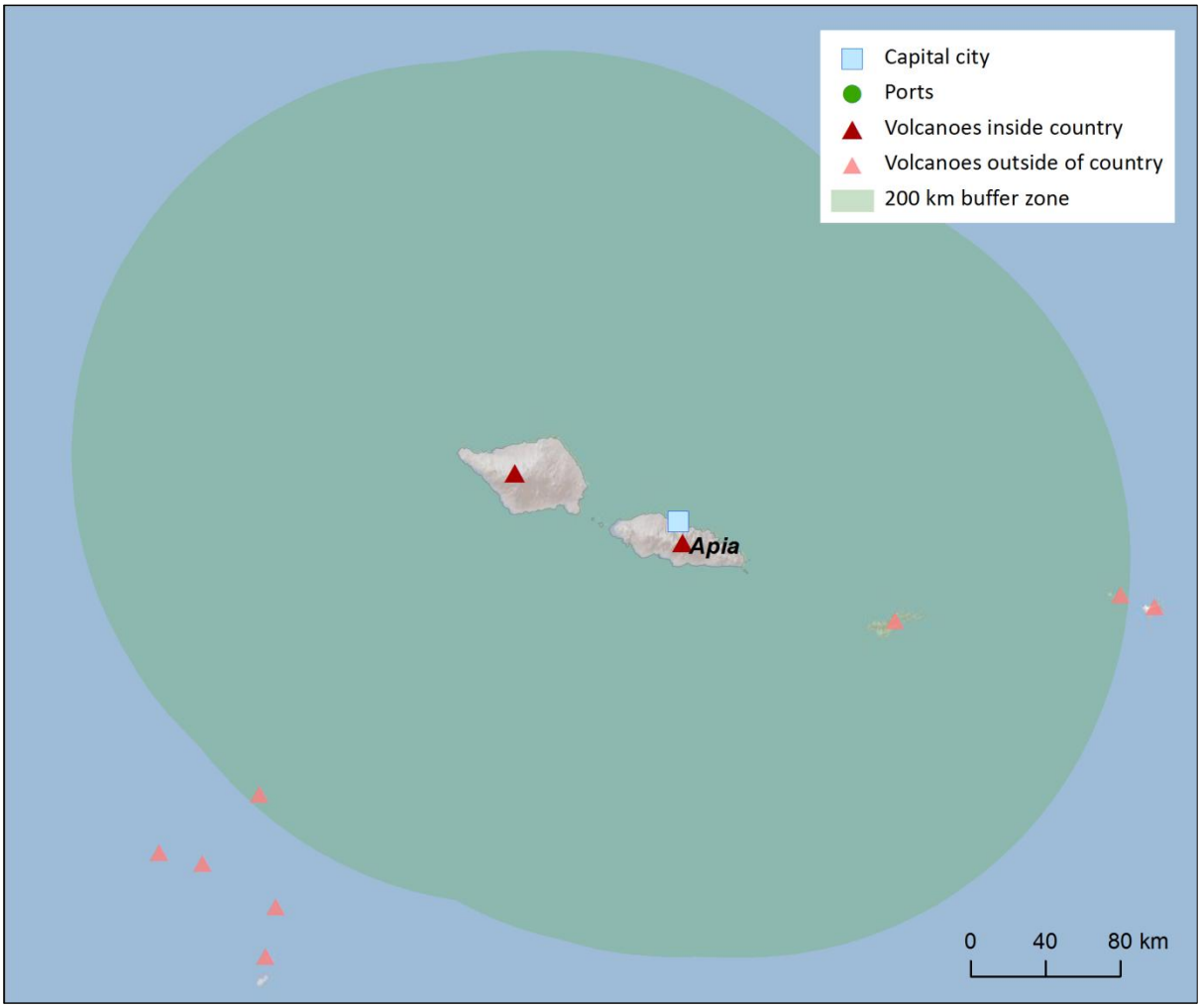

Figure 4.13 Location of Samoa's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Samoa.

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

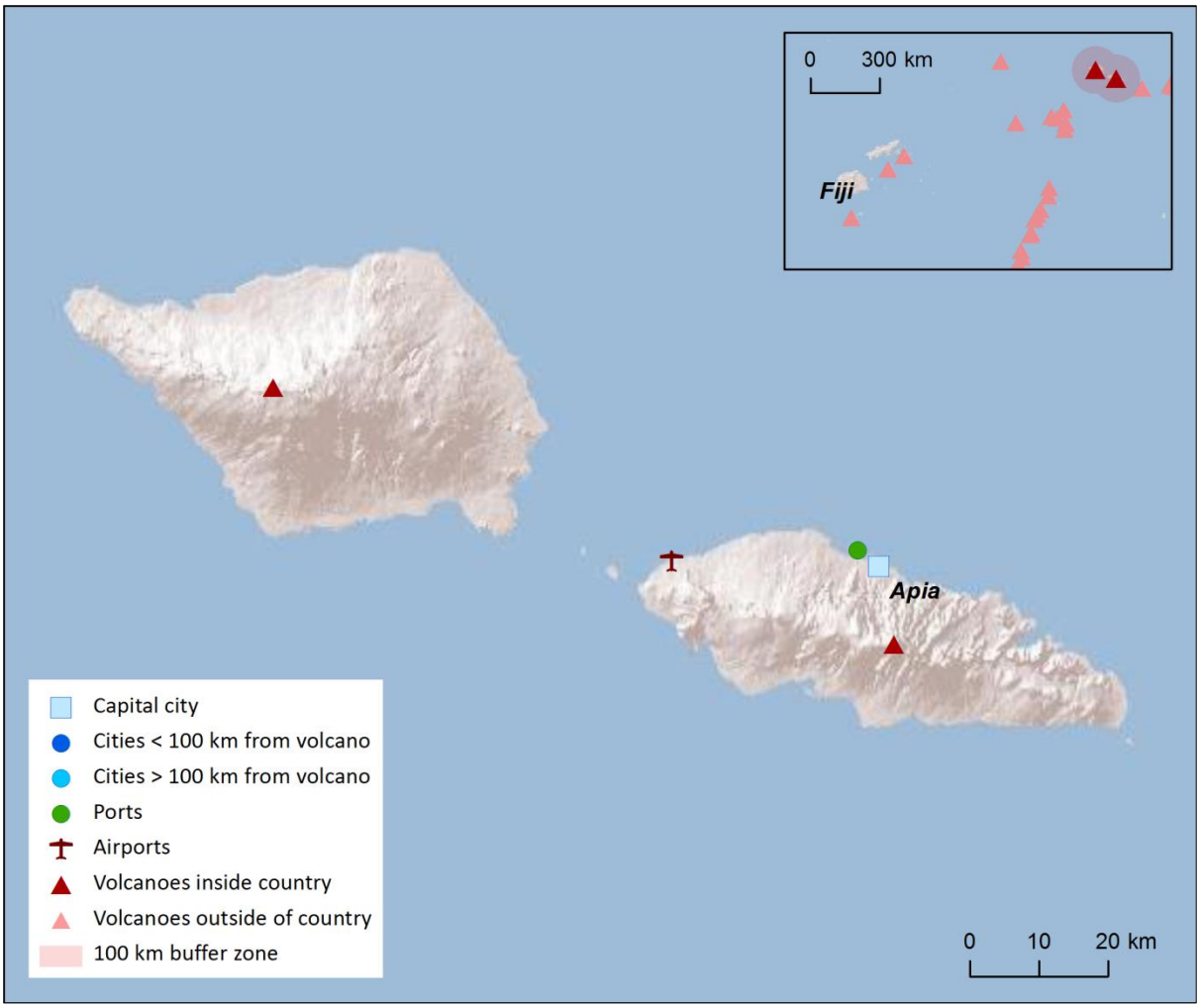

Figure 4.14 The location of Samoa's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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.

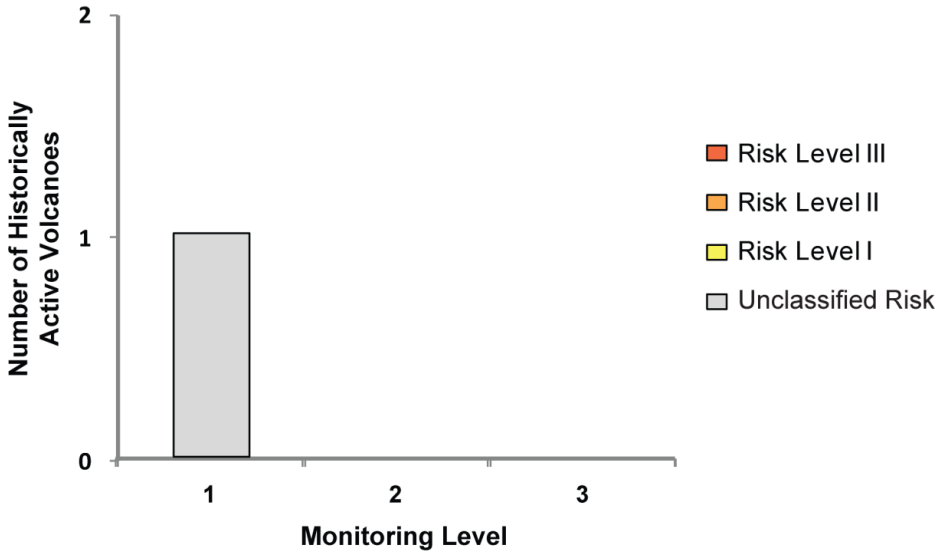

Figure 4.15 The monitoring and risk levels of the historically active volcanoes in Samoa. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates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

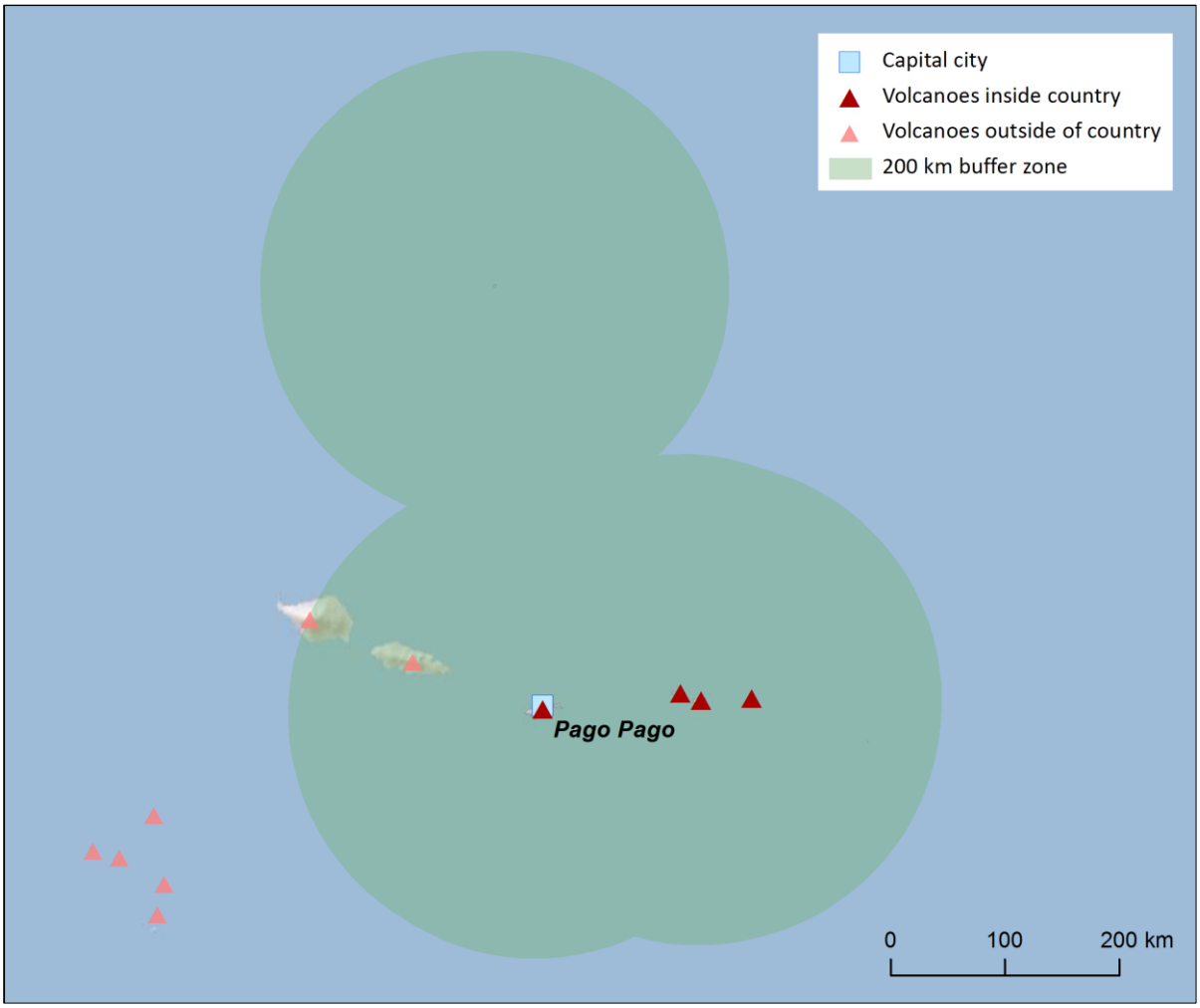

Figure 4.16 Location of American Samoa's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect American Samoa.

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)	-

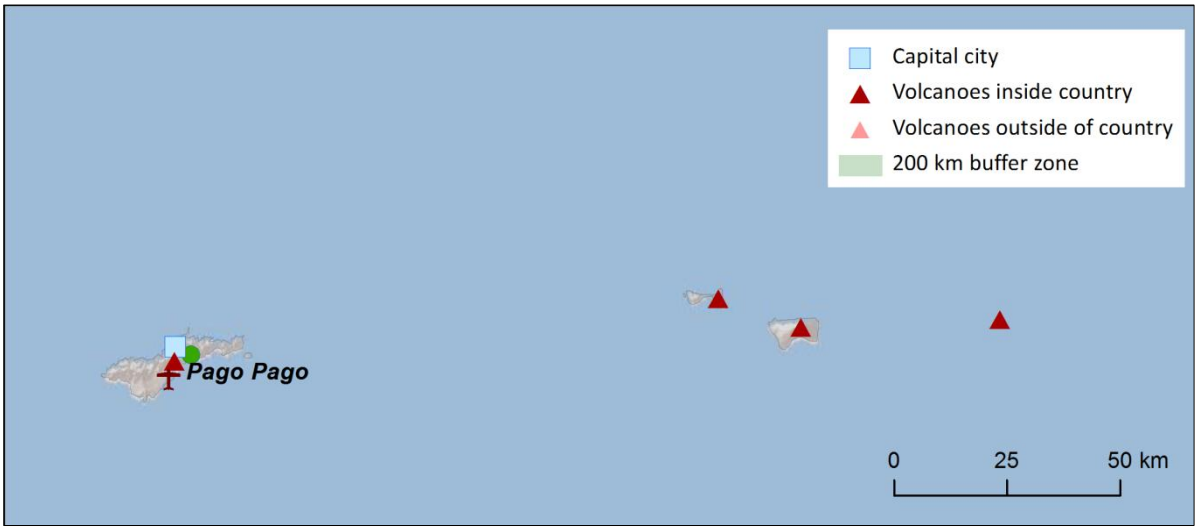

Figure 4.17 The location of American Samoa's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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.

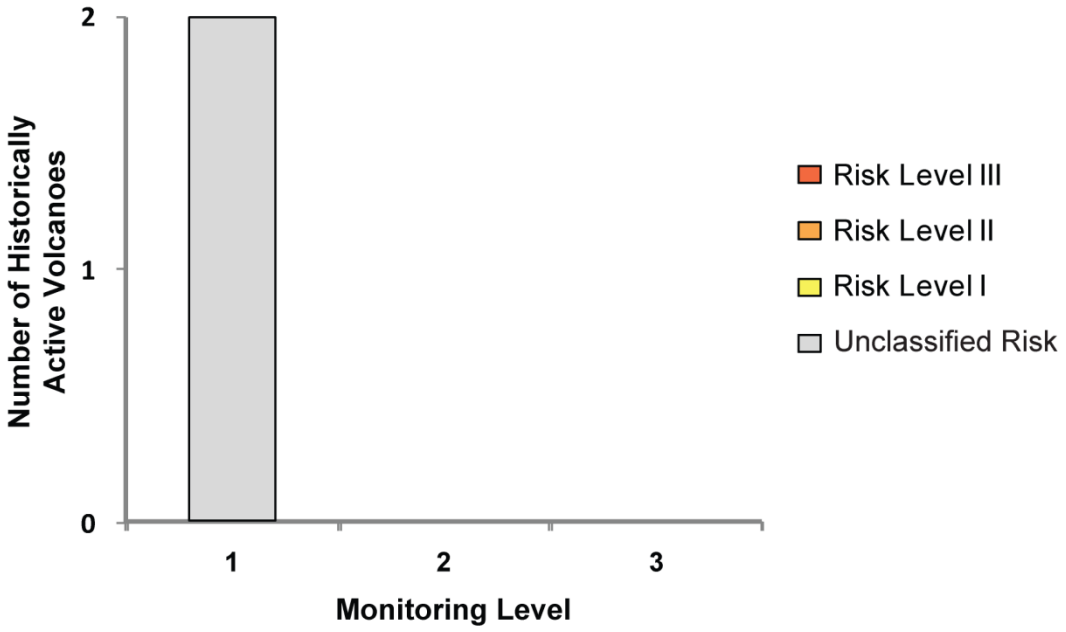

Figure 4.18 The monitoring and risk levels of the historically active volcanoes in American Samoa. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level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

Tonga

Description

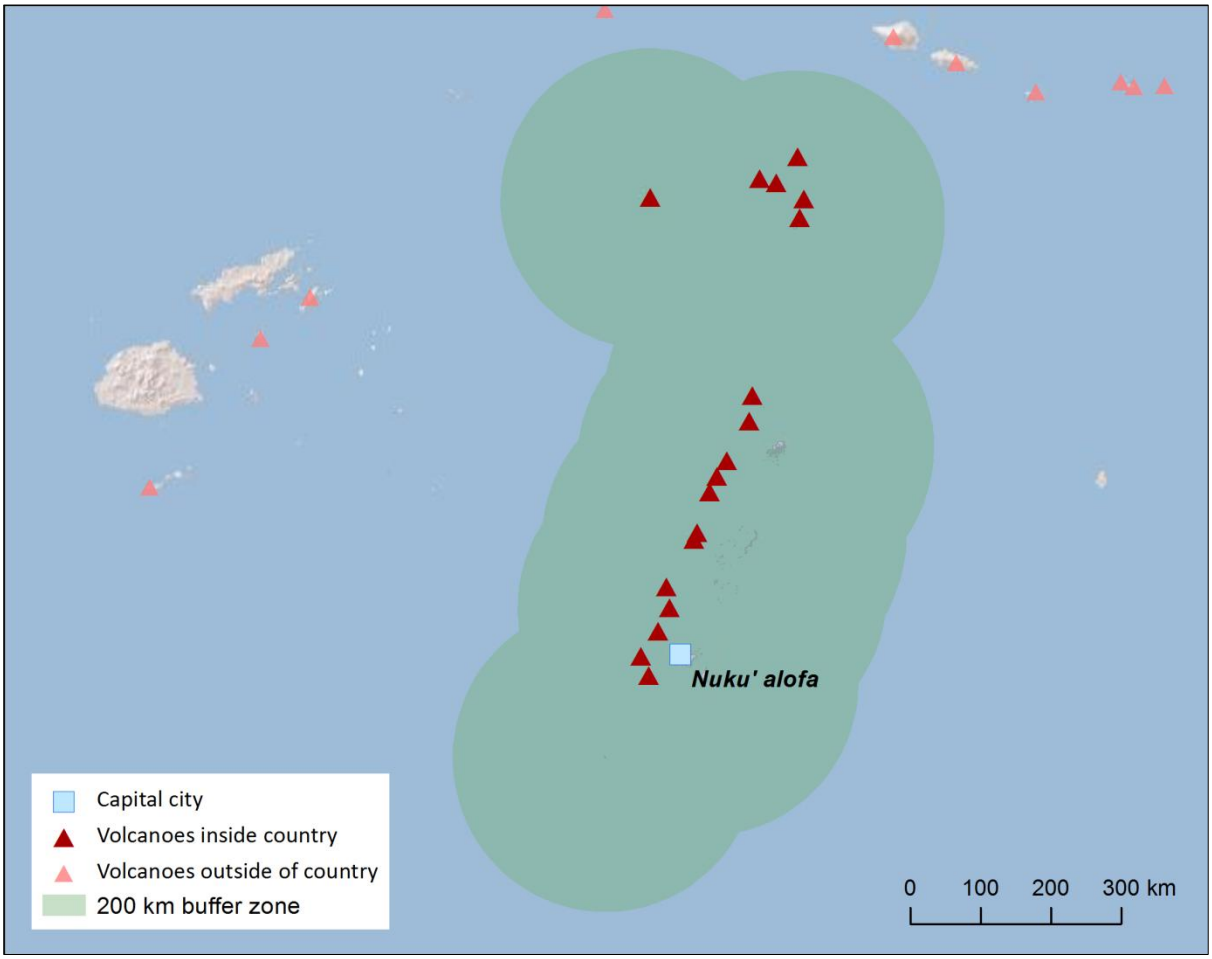

Figure 4.19 Location of Tonga's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Tonga.

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.

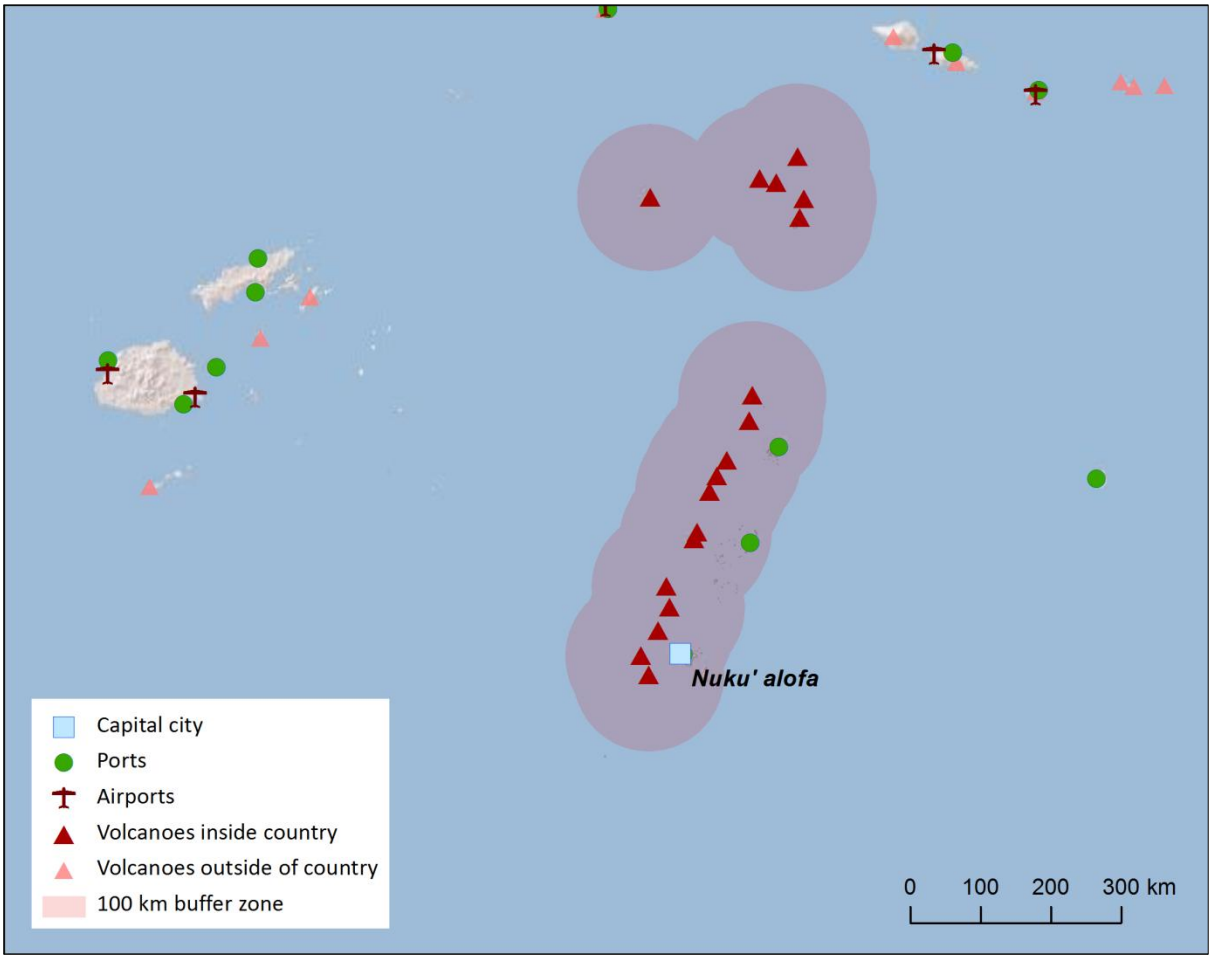

Figure 4.20 The location of Tonga's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

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.

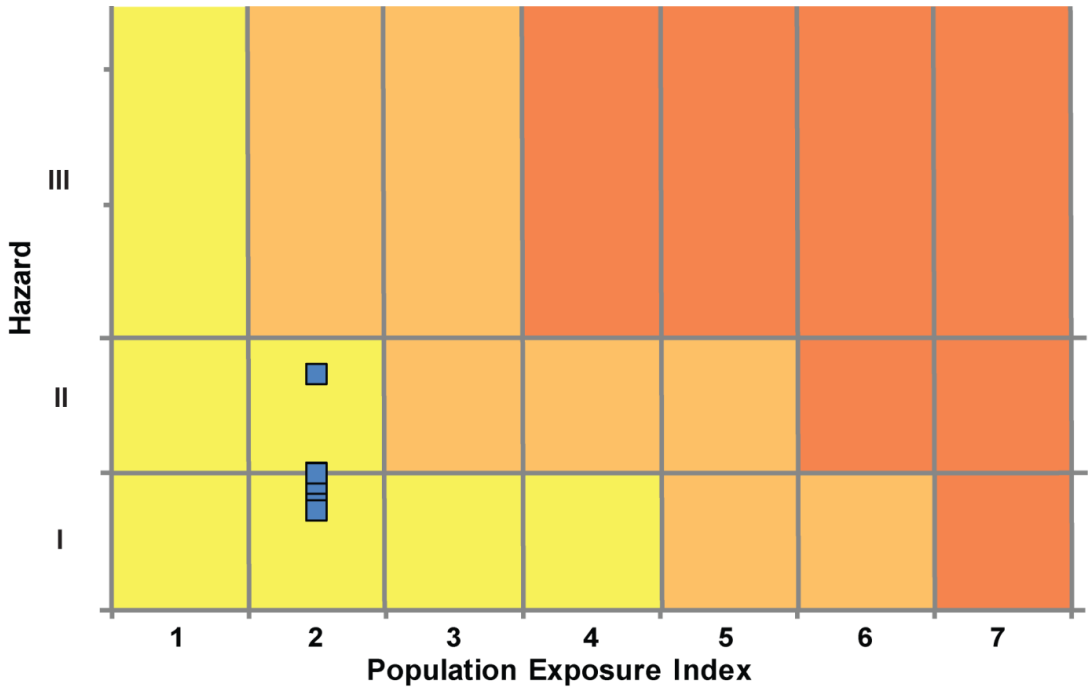

Figure 4.21 Distribution of Tonga's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

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.

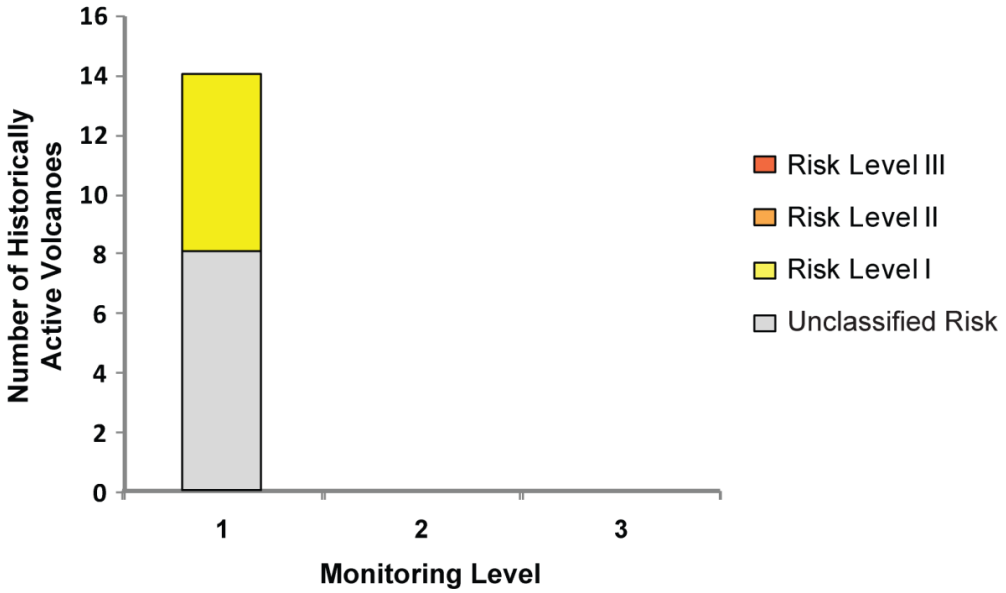

Figure 4.22 The monitoring and risk levels of the historically active volcanoes in Tonga. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates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