Appendix B – Region 16

Country and regional profiles of volcanic hazard and risk:

West Indies

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This download comprises the profiles for Region 16: West Indies 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 16: West Indies

The West Indies region comprises the islands of the Lesser Antilles. Some of these islands are independent countries, whilst other retain ties to Europe.

Country	Number of volcanoes
Dominica	5
France	2
Grenada	2
Netherlands –Dutch Antilles	2
St. Kitts and Nevis	2
St. Lucia	1
St. Vincent and the Grenadines	1
UK - Montserrat	1

Table 16.1 The countries represented in this region and the number of Holocene volcanoes.

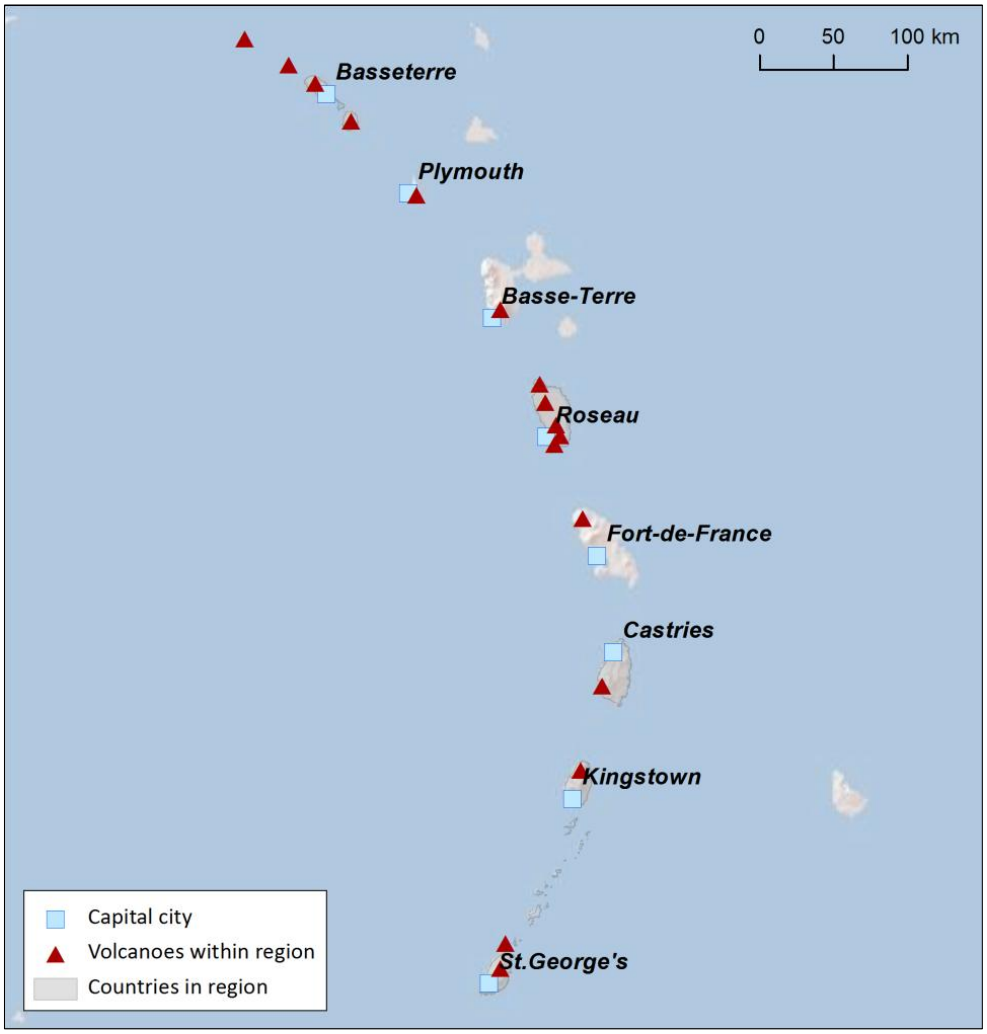

Figure 16.1 The distribution of Holocene volcanoes through the West Indies region. The capital cities of the constituent countries are shown.

The Lesser Antilles arc forms along the eastern edge of the Caribbean Plate, with volcanism generated by the subduction of the Atlantic Ocean crust beneath this Caribbean Plate.

Sixteen Holocene volcanoes are located in the Lesser Antilles, from the southernmost island of Grenada to the northern island of Saba, of the Dutch Antilles. Of these, nearly 90% are andesitic stratovolcanoes.

Activity here is dominantly explosive with most eruptions recorded with explosive elements. Whereas the most common eruption size in most regions is VEI 2, here nearly half of all eruptions with a given size have been VEI 4. Nearly 70% of the volcanoes have Holocene records of producing pyroclastic flows, and about three quarters of all recorded eruptions here produced pyroclastic flows. Pyroclastic flows are recorded in about half of all historical eruptions, whilst only 2% of historical events have recorded lava flows. About a third of historical eruptions have resulted in lahars. Four historical eruptions have generated tsunamis.

Comprising multiple small islands, the population of much of the West Indies is located in close proximity to the volcanoes. Whilst population sizes of individual islands may be low, commonly 100% of the population live within 30 or 100 km of one or more Holocene volcano. Critically, the proximity of the islands to each other also means that eruptions on one island may impact on neighbouring islands. This is particularly relevant for tsunamis.

The assessment of hazard by the Volcanic Hazard Index is complicated by large uncertainties at many of the volcanoes of the West Indies. Further efforts in understanding the size of those eruptions with unknown magnitudes and confirming the occurrence of some uncertain events would help understanding here, however, individual focussed hazard assessments based on likely eruption scenarios have been undertaken at the volcanoes here with detailed integrated hazard maps and descriptions of probable activity (see Lindsay et al., 2005).

The volcanoes of the West Indies are very well monitored, with both observatories in Guadeloupe and Martinique run by the Institut de Physique du Globe Paris and the Seismic Research Centre (SRC) of the University of West Indies operating comprehensive monitoring systems throughout the island chain. Most monitoring is undertaken through seismic stations, with deformation and additional monitoring (gases, geochemical etc) at some volcanoes. Informal arrangements are in place for access to Earth Observation data as needed. Plans and resources are available for responding to developing situations at un- or under-monitored volcanoes, and in the event of significant unrest temporary observatories would be established staffed by members of the SRC and local equivalent groups where possible.

Monitoring equipment is not manned continuously, instead a monitoring alert system is in place. The SRC is funded by annual contributions from island governments and additional grant funding. About 60% of the staff members of the SRC have experience of responding to eruptions.

In the event of unrest or eruption, the SRC will provide regular updates to the National Emergency Operations Committee and will contact the regional VAAC. Response is guided by an Alert Level Table. This outlines actions to be taken by Scientific Staff and Civil Authorities. Generally response to unrest involves increased/intensification of monitoring with additional measurements and instruments deployed, increased site visits and provision of advice to civil authorities via regular

Scientific Advisories. Response will depend on the signals derived from monitoring sites. Communications with local authorities is normally via the National Disaster Coordinator but there is allocation for contacting the highest office on the island if thought necessary by the SRC monitoring team.

The SRC are not responsible for providing risk assessments, but are involved in risk management and mitigation through the provision of educational materials, hazard maps and public outreach.

See also:

University of the West Indies Seismic Research Centre www.uwiseismic.com/

Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano facts

Number of Holocene volcanoes	16
Number of Pleistocene volcanoes with M≥4 eruptions	6
Number of volcanoes generating pyroclastic flows	11+ (101 eruptions)
Number of volcanoes generating lahars	6 (26 eruptions)
Number of volcanoes generating lava flows	3-4 (6 eruptions)
Number of eruptions with fatalities	4
Number of fatalities attributed to eruptions	31,283
Largest recorded Pleistocene eruption	The M6.4 eruption of the Roseau Tuff from Morne Trois Pitons in Dominica, about 36,000 years ago.
Largest recorded Holocene eruption	The 1812 AD M4.7 eruption of Soufrière St. Vincent is the largest recorded Holocene eruption in this region in LaMEVE.
Number of Holocene eruptions	132 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 4 and unknown
Number of historically active volcanoes	8
Number of historical eruptions	42

Number of volcanoes	Primary volcano type	Dominant rock type
1	Caldera(s)	Andesitic (1)
14	Large cone(s)	Andesitic (13), Dacitic (1)
1	Submarine	Basaltic (1)

Table 16.2 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)	10
Large (> VEI 3)	110

Table 16.3 Average recurrence interval (years between eruptions) for small and large eruptions in the West Indies.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about 10 years, whilst the ARI for large eruptions is longer, at about 110 years.

Eruption Size

Eruptions are recorded through the West Indies of VEI 0 to 4, representing a range of eruption styles from effusive events to large explosive eruptions. VEI 4 events dominate the record, with nearly 45% of all Holocene eruptions classed as such.

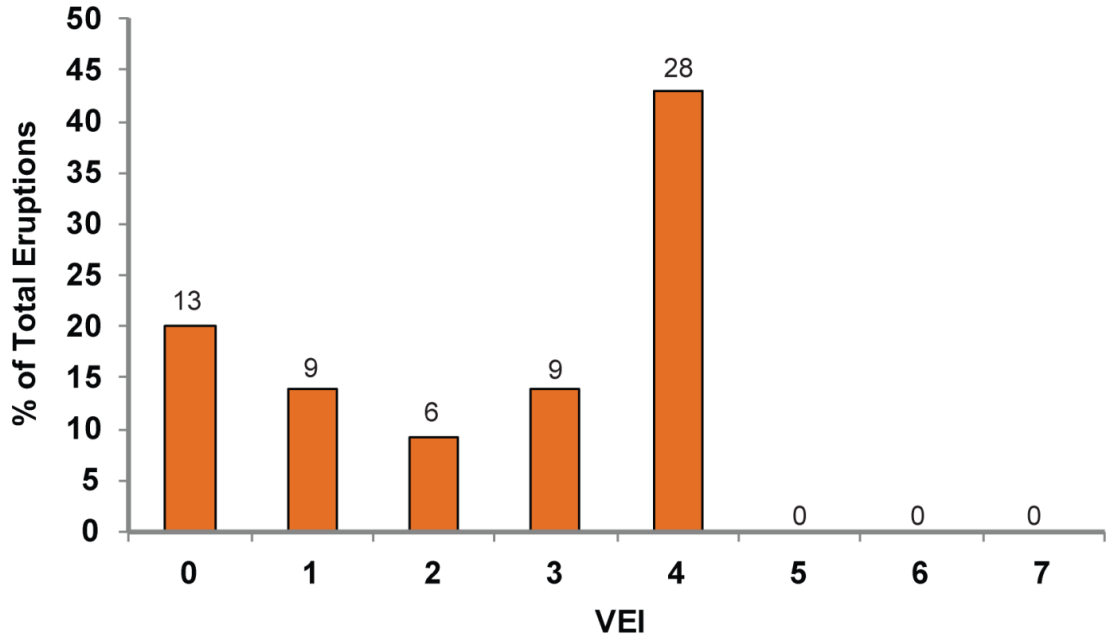

Figure 16.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 67 eruptions were recorded with unknown VEI.

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	309,233 (22.30 %)
Number (percentage) of people living within 30 km of a Holocene volcano	1,093,521 (78.87 %)
Number (percentage) of people living within 100 km of a Holocene volcano	1,388,737 (>100 %)

Infrastructure Exposure

Number of airports within 100 km of a volcano	5
Number of ports within 100 km of a volcano	14
Total length of roads within 100 km of a volcano (km)	753
Total length of railroads within 100 km of a volcano (km)	0

CLASSIFIED	**Hazard III**				Soufrière Hills; Pelée; Soufrière St. Vincent	Soufrière Guadeloupe		
	Hazard II							
	Hazard I			Kick 'em Jenny				
UNCLASSIFIED	**U – HHR**		**Saba**			**Watt, Morne**; **Qualibou**		
	U- HR		Quill, The	**Liamuiga**		**Trois Pitons, Morne**; Plat Pays, Morne		
	U-NHHR				**Nevis Peak**; **Diables, Morne aux;** Diablotins, Morne	St. Catherine		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 16.4 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
0	7
0	6
6	5
6	4
2	3
2	2
0	1

Table 16.5 The number of volcanoes in the West Indies classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
4	III
0	II
1	I
11	Unclassified

Table 16.6 The number of volcanoes in the West Indies region classified at each Risk Level.

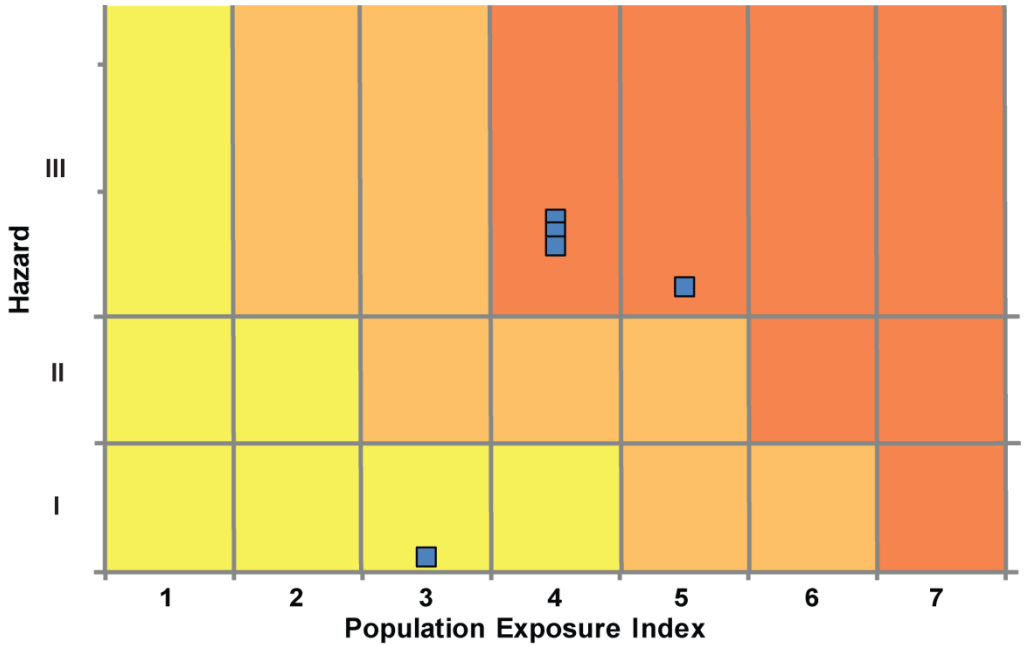

Figure 16.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

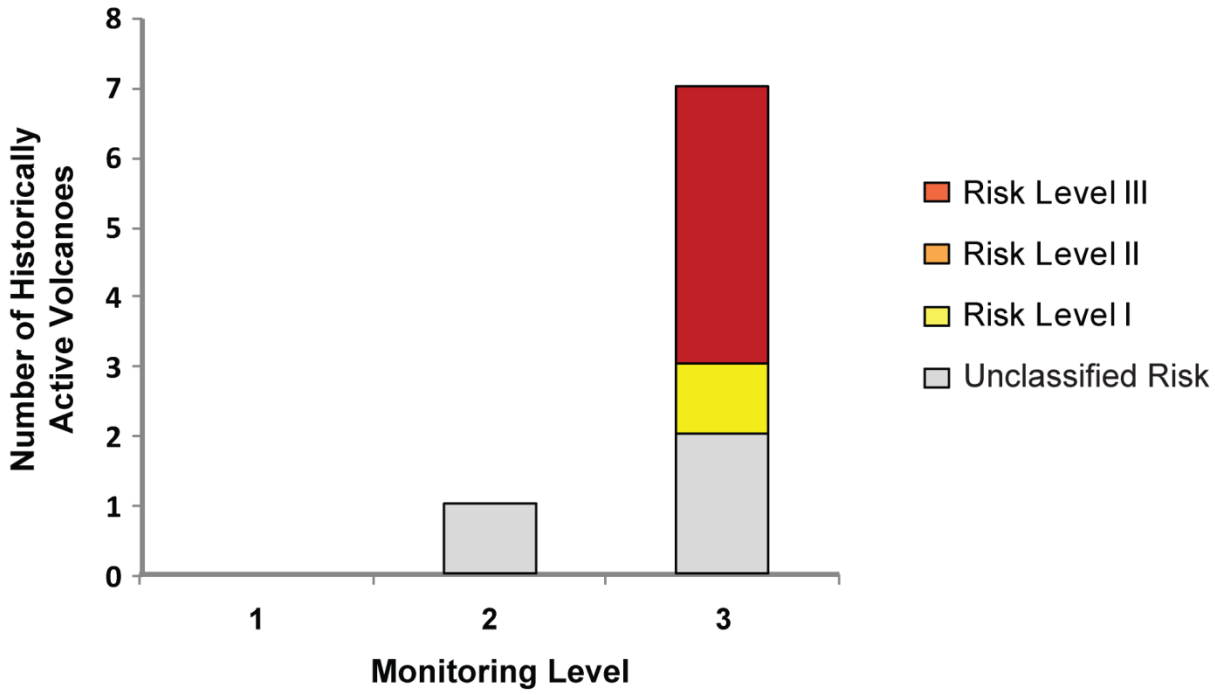

Figure 16.4 The monitoring and risk levels of the historically active volcanoes in the West Indies. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Dominica

Description

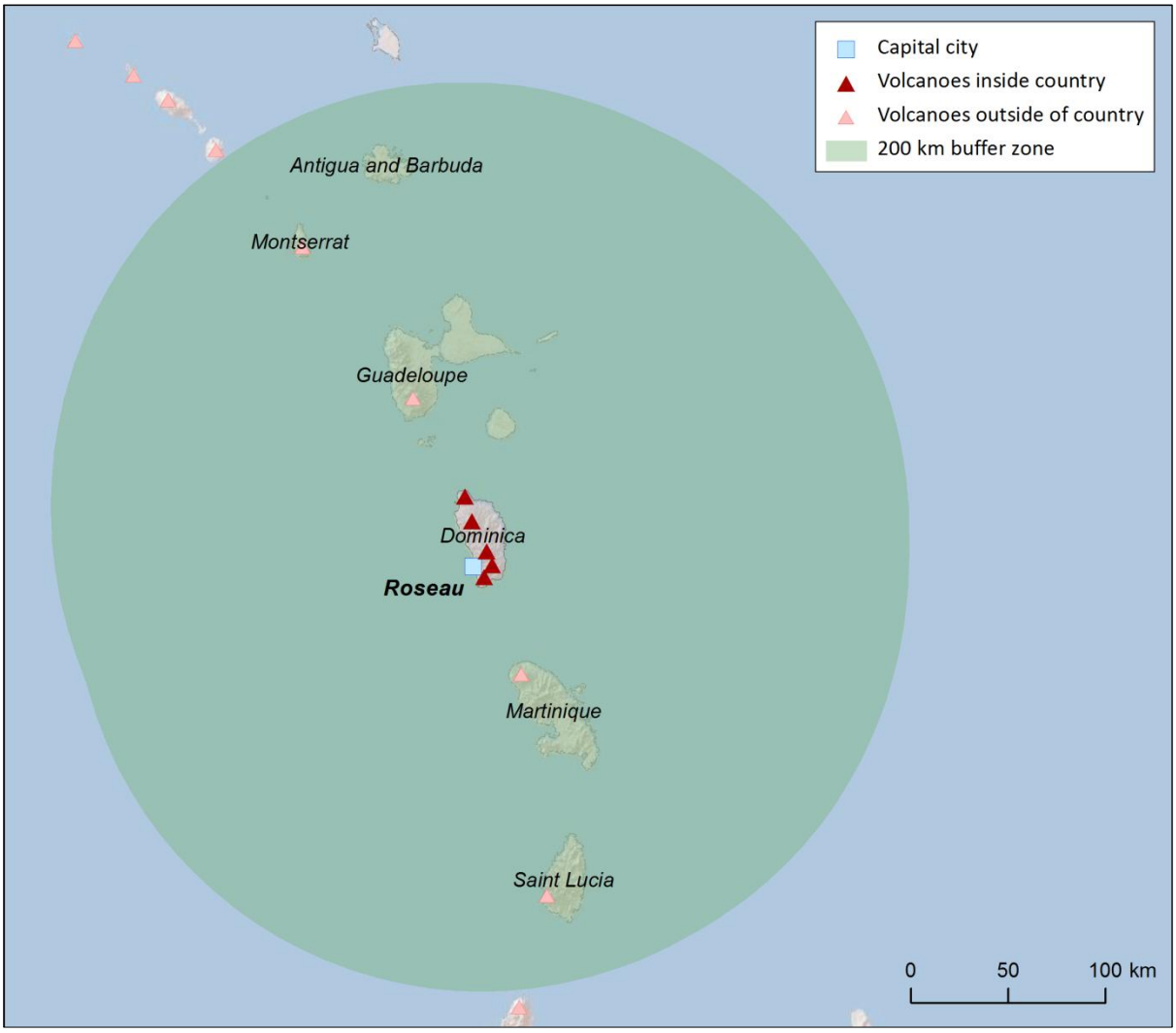

Figure 16.5 Location of Dominica's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Dominica.

Five Holocene volcanoes are listed in Dominica, aligned roughly in a chain north-south through the centre of the island. Five volcanoes are listed in VOTW4.0, however separate features of these volcanoes including domes and stratovolcanoes are described as separate volcanoes by the University of the West Indies Seismic Research Centre, making a total of nine Holocene volcanoes on Dominica. Here we consider the record of five volcanoes. Volcanism here is due to the subduction of the Atlantic Ocean crust beneath the Caribbean Plate. All volcanoes are stratovolcanoes and complex volcanoes, of dominantly andesitic composition.

Large explosive eruptions are recorded in Dominica from three volcanoes during the Pleistocene, including the M6.4 eruption of the Roseau Tuff from Morne Trois Pitons at about 36,000 years ago. Only Morne Trois Pitons, Morne Watt and Morne Plat Pays have a record of confirmed eruptions during the Holocene, with 11 eruptions of VEI 1 to 2. The other two volcanoes, Morne aux Diables and Morne Diablotins in the north of the island have suspected but unconfirmed Holocene activity. The largest recorded Holocene eruption was that of Morne Watt in 1880, however the size of nine of eleven eruptions is unknown. Morne Watt is the only historically active volcano here, with, in addition to the VEI 2 eruption of 1880, a VEI 1 eruption in 1997.

Despite the absence of data regarding the size of eruptions here, seven out of eleven eruptions produced pyroclastic flows, indicating explosive activity has been commonplace.

Being a relatively small volcanic island, the whole population resides within 30 km of one or more Holocene volcanoes. Indeed, about 84% of the population live within 10 km. The highest proximal population is at Morne Plat Pays, where several towns lie in the valleys radiating from the volcano and the capital, Roseau, lies within 10 km.

Lindsay et al. (2005) present hazard maps for a number of hazard scenarios on the island and present an integrated hazard map of the most likely eruption scenarios. This divides the island into four colour-coded zones, from Green Zone 4 Low hazard to Red Zone 1 Very High Hazard. The southern tip of the island is designated as Very High Hazard, as it includes the immediate area around Morne Watt. Much of the south of the Island is Zone 2, High Hazard, including the capital, Roseau. See Lindsay et al. (2005) for full details.

The University of the West Indies Seismic Research Centre (SRC) is responsible for the monitoring of Dominica's volcanoes. Indeed, they monitor the historically active Morne Watt with multiple dedicated ground-based systems, and also monitor those volcanoes with known or suspected Holocene activity. A monitoring alert system is in place. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre www.uwiseismic.com/

Lindsay, J.M., Smith, A.L., Roobol, M.J., and Stasiuk, M.V. (2005) Dominica, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition www.uwiseismic.com/Downloads/Dominica_VHA.pdf

Volcano Facts

Number of Holocene volcanoes	5
Number of Pleistocene volcanoes with M≥4 eruptions	3
Number of volcanoes generating pyroclastic flows	3
Number of volcanoes generating lahars	1

Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M6.4 eruption of the Roseau Tuff from Morne Trois Pitons at 36,385 BP.
Largest recorded Holocene eruption	The VEI 2 eruption of Morne Watt in 1880 AD.
Number of Holocene eruptions	11 confirmed eruptions.
Recorded Holocene VEI range	1 – 2 and unknown
Number of historically active volcanoes	1
Number of historic eruptions	2

Number of volcanoes	Primary volcano type	Dominant rock type
5	Large cone(s)	Andesitic (4), Dacitic (1)

Table 16.7 The number of volcanoes in Dominica, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	72,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	11,120
Gross National Income (GNI) per capita (2005 PPP $)	10,977
Human Development Index (HDI) (2012)	0.745 (High)

Population Exposure

Capital city	Roseau
Distance from capital city to nearest Holocene volcano	7.3 km
Total population (2011)	72,969
Number (percentage) of people living within 10 km of a Holocene volcano	61,224 (83.9%)
Number (percentage) of people living within 30 km of a Holocene	71,052 (97.4%)

volcano

Number (percentage) of people living within 100 km of a Holocene volcano	71,052 (97.4%)

Largest cities, as measured by population and their population size:

Roseau	16,571

Infrastructure Exposure

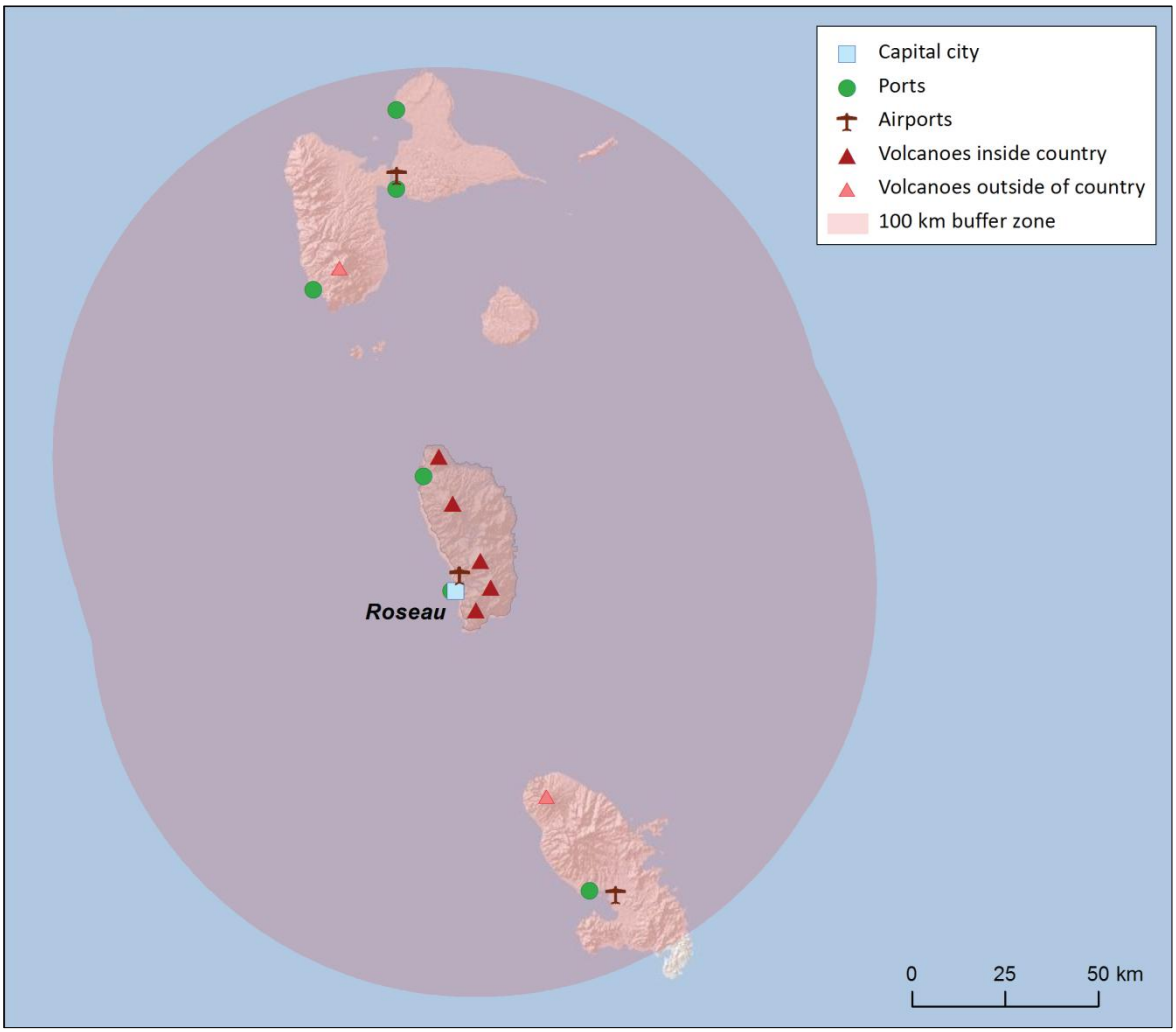

Figure 16.6 The location of Dominica's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	2
Total length of roads within 100 km of a volcano (km)	0

Total length of railroads within 100 km of a volcano (km) 0

The volcanoes in Dominca form a chain across the island. Being only a small island, measuring no more than 50 km across the country in its entirety lies within a short distance from Holocene volcanoes. Indeed the 100 km radii of the Dominican volcanoes extends beyond Dominica to encompass Guadeloupe and much of Martinique, exposing much of the critical infrastructure on these islands. The volcanoes of Martinique and Guadeloupe likewise have 100 km radii extending to expose Dominica and the infrastructure here. The capital of Dominica, Roseau, lies less than 10 km from three Holocene volcanoes – Morne Plat Pays, Morne Trois Pitons and the historically active Morne Watt. All infrastructure in Dominica and the whole population lie within 50 km of a Holocene volcano.

Hazard, Uncertainty and Exposure Assessments

No volcanoes in Dominica have a sufficiently detailed eruption record to be able to define the hazard level through the calculation of the VHI. These volcanoes are therefore unclassified. Two volcanoes have no confirmed Holocene activity on record. Morne Trois Pitons, Morne Plat Pays and Morne Watt have a Holocene eruption record, including historical activity at the latter. Unrest has been described at Morne aux Diables and Morne Trois Pitons since 1900 AD.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**					**Morne Watt**		
	U- HR					**Morne Trois Pitons;** Morne Plat Pays		
	U-NHHR				**Morne aux Diables;** Morne Diablotins			
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Table 16.8 Identity of Dominica's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified

*with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

The PEI ranges from 4 to 5 in Dominica, with moderate to high proximal populations. The risk levels cannot be determined here due to the absence of a hazard classification.

National Capacity for Coping with Volcanic Risk

One volcano, Morne Watt, has a record of historical eruptions. This volcano and all Holocene volcanoes here are actively monitored by the Seismic Research Centre (University of the West Indies). At Morne Watt a seismic and deformation network is continuously in operation. Additional monitoring of gases and geochemistry of waters and fumaroles is also regularly undertaken.

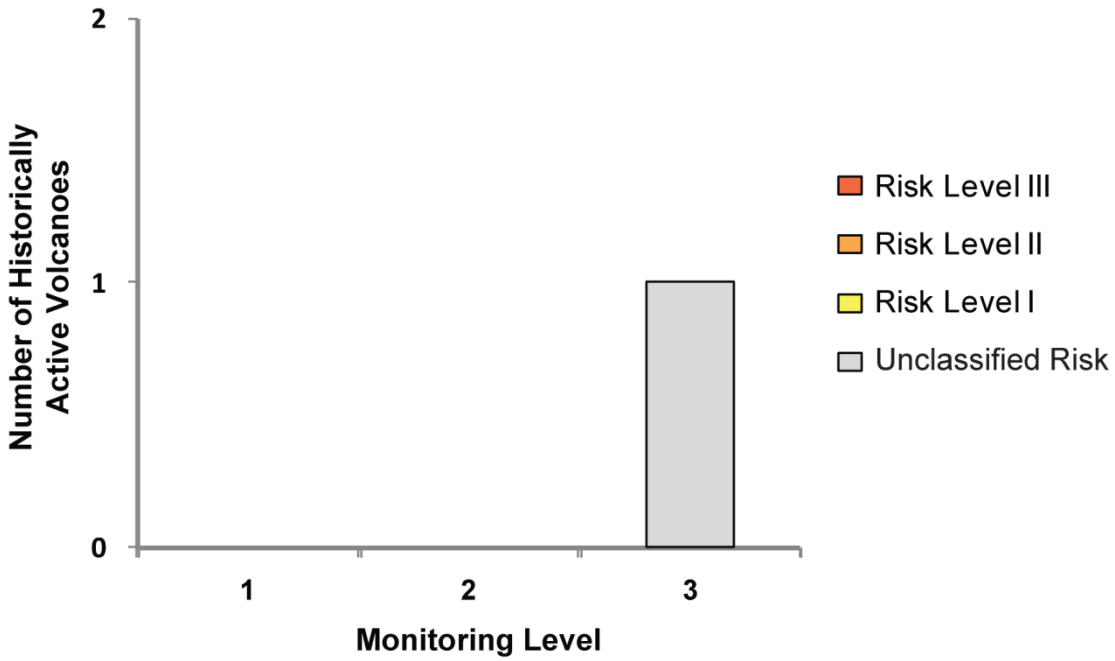

Figure 16.7 The monitoring and risk levels of the historically active volcanoes in Dominica. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

France – Martinique, Guadeloupe

See Region 1 for mainland France, Region 3 for French territories in the Indian Ocean, Region 13 for French territories in the Pacific Ocean.

Description

Figure 16.8 Location of Guadeloupe and Martinique's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Guadeloupe and Martinique.

Two islands in the Lesser Antilles are overseas territories of France: Martinique and Guadeloupe. Both of these islands have a Holocene volcano. On Guadeloupe, the La Soufrière Guadeloupe volcano sits in the southern tip of the island. On Martinique, Montagne Pelée is situated in the northern tip of the island. Both these volcanoes are andesitic stratovolcanoes, related to the subduction of the North American Plate beneath the Caribbean Plate.

Both La Soufrière Guadeloupe and Montagne Pelée have a record of Holocene and Pleistocene eruptions. The largest Pleistocene eruption was at La Soufrière of Guadeloupe at about 46,000 years ago, with the M5.3 Pintade eruption.

During the Holocene a total of 74 eruptions are confirmed between the two volcanoes, with most, 54, being recorded at Pelée. These eruptions were of VEI 1 – 4, with large explosive eruptions of VEI 4 recorded at both volcanoes. Twenty-three events were of this size, demonstrating the prevalence of explosive activity on these French islands. Indeed, 86% of recorded eruptions have associated pyroclastic flows.

Eight historical eruptions are recorded at La Soufrière of Guadeloupe, and five at Montagne Pelée. These eruptions have ranged in size from VEI 1 to 4. The largest historical eruption was that of Montagne Pelée in 1902. This catastrophic VEI 4 eruption produced pyroclastic flows and destroyed the city of St. Pierre, resulting in nearly 30,000 fatalities.

Being small islands, relatively high proportions of the population live within 10 km of the volcanoes here, with about 5% of the population of Martinique and 17% of the population of Guadeloupe living within this distance. The whole population lives within 100 km of these volcanic centres.

Boudon et al. (2005) present possible future eruption scenarios for Martinique and suggest that the most probable activity is phreatic events, dome-forming eruptions or open-vent pumiceous eruptions. They also suggest that collapse of the south-western flank of the volcano is of low probability, but consider it due to the devastating effects it could have, including potential for directed blasts and tsunami generation. They present a hazard map for Martinique based on a quantitative assessment of volcanic hazard, showing hazard concentrated around Montagne Pelée and St. Pierre, with much of the southern half of the island being of low hazard.

Komorowski et al., (2005) suggest future eruption scenarios for Guadeloupe in order of decreasing probability of occurrence of: intense prolonged fumarolic activity, phreatic eruptions, edifice collapse eruptions, effusive and explosive dome-forming eruptions and large explosive eruptions. They present an integrated hazard map for these scenarios with the area of highest hazard being located around the summit of La Soufrière of Guadeloupe and to the south-west, with additional high hazard in the valleys radiating from the volcano.

Both La Soufrière of Guadeloupe and Montagne Pelée have dedicated volcano observatories. The Observatoire Volcanologique et Sismologique de la Guadeloupe and the Observatoire Volcanologique et Sismologique de la Martinique run by the Institut de Physique du Globe de Paris manage extensive seismic, deformation and geochemical monitoring networks that are complemented by other geophysical techniques and geological surveys. The monitoring equipment is also used for regional seismic monitoring and tsunami alerts. These monitoring institutions also conduct scientific research to better understand activity here. About 10% of the staff have experience of responding to an eruption. These monitoring institutions do not present risk assessments but are involved in management and mitigation of risks, through interactions with national responsible agencies as well as through a programme of hazard education for the public. Since 1999, the level of activity and main results of the monitoring of La Soufrière of Guadeloupe and Montagne Pelée as well as the regional seismic activity are communicated on a monthly basis

widely to the authorities, population and stakeholders through a bulletin available on the internet and via email.

In the event of unrest and eruptions the institutions release alerts using an alert level system. Alert levels are also communicated regularly.

See also:

Observatoire Volcanologique et Sismologique de la Guadeloupe - www.ipgp.fr/pages/03030402.php

Observatoire Volcanologique et Sismologique de la Martinique - www.ipgp.fr/pages/03030302.php

Boudon, G., Le Friant, A., Villemant, B., and Viode, J-P. (2005) Martinique, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Komorowski, J-C., Boudon, G., Semet, M., Beauducel, F., Anenor-Habazac, C., Bazin, S., and Hammouya, G. (2005) Guadeloupe, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	Martinique: 1; Guadeloupe: 1
Number of Pleistocene volcanoes with M≥4 eruptions	Martinique: 1; Guadeloupe: 1
Number of volcanoes generating pyroclastic flows	Martinique: 1; Guadeloupe: 1
Number of volcanoes generating lahars	Martinique: 1; Guadeloupe: 1
Number of volcanoes generating lava flows	Martinique: - Guadeloupe: 1
Number of fatalities caused by volcanic eruptions	Martinique:29,523
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption:	The M5.3 Pintade eruption of Soufrière Guadeloupe at 46,465 BP.

Largest recorded Holocene eruption	The P1, P2 and P3 eruptions of Pelée on Martinique are all recorded as M4.6 and occurred at 610, 1,600 and 1,940 BP.
Number of Holocene eruptions	Guadeloupe: 20 confirmed. Martinique: 54 confirmed eruptions.
Recorded Holocene VEI range	1 – 4 and Unknown
Number of historically active volcanoes	Guadeloupe:1 Martinique: 1
Number of historic eruptions	Guadeloupe: 8 Martinique: 5

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

Table 16.9 The number of volcanoes in the French West Indies, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	Martinique: 403,000; Guadeloupe: 464,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	-
Gross National Income (GNI) per capita (2005 PPP $)	-
Human Development Index (HDI) (2012)	-

Population Exposure

Capital city	Martinique: Fort-de-France; Guadeloupe: Basse-Terre
Distance from capital city to nearest Holocene volcano	Martinique: 26.3 km Guadeloupe: 7.7 km
Total population (2011)	Martinique: 412,465 Guadeloupe: 456,703
Number (percentage) of people living within 10 km of a Holocene volcano	Martinique: 20,924 (5.1%) Guadeloupe: 78,100 (17.1%)

Number (percentage) of people living within 30 km of a Holocene volcano	Martinique: 281,424 (68.2%) Guadeloupe: 296,828 (65%)
Number (percentage) of people living within 100 km of a Holocene volcano	Martinique: 402,028 (97.5%) Guadeloupe: 460,883 (100%)

Largest cities, as measured by population and their population size (2011 census data from Institut National de la Statisique et des Études Économiques (INSEE, www.insee.fr):

Fort-De-France	88,182
Les Abymes	60,079
Pointe-à-Pitre	16,191
Basse-Terre	11,962

Infrastructure Exposure

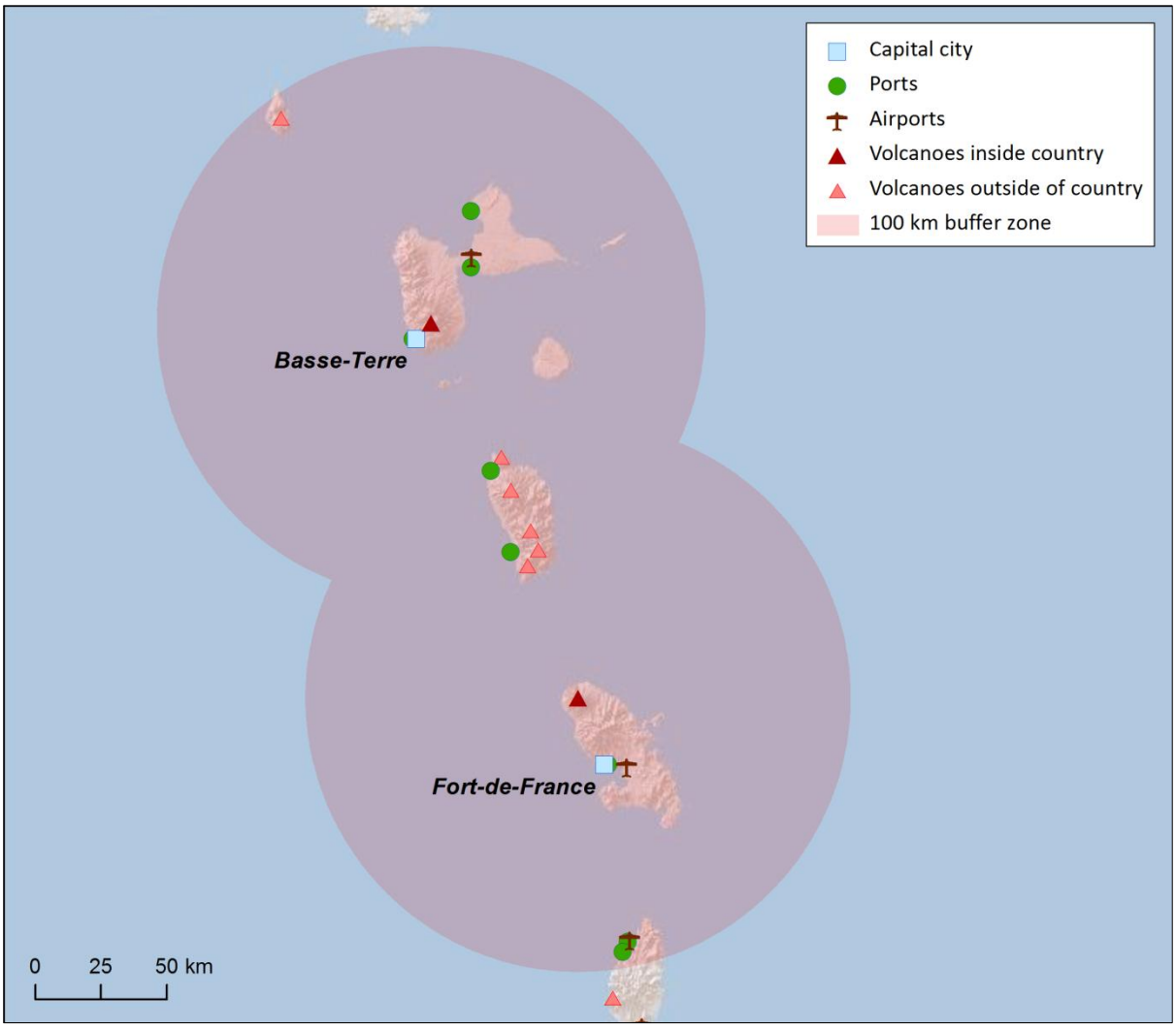

Figure 16.9 The location of Guadeloupe's and Martinique's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	4
Total length of roads within 100 km of a volcano (km)	753
Total length of railroads within 100 km of a volcano (km)	0

The volcanoes in the French West Indies are located on the southern tip of the island of Guadeloupe and the northern tip of the island of Martinique. Being small islands, measuring no more than 70 km across, these are in their entirety within the 100 km radii of these volcanoes, exposing all infrastructure and population on Guadeloupe and Martinique. The 100 km radii also extend to fully encompass Dominica, exposing all infrastructure here. The 100 km radius of Pelée on Martinique extends to encompass the northern tp of St. Lucia, whilst much of the island of Montserrat is exposed in the 100 km radius of La Soufrière of Guadeloupe. Likewise, the radii of Soufrière Hills Volcano extends to Guadeloupe.

Hazard, Uncertainty and Exposure Assessments

Both La Soufrière of Guadeloupe and Montagne Pelée have sufficient information in their eruption records to define a hazard level through calculation of the VHI. Both are classed as Hazard Level III, with VEI 4 Holocene eruptions and a history of explosive eruptions producing pyroclastic flows.

The PEI at La Soufrière of Guadeloupe and Montagne Pelée is 5 and 4 respectively, with moderate to large proximal populations, including over 70,000 living within 10 km at Soufrière Guadeloupe. With a Hazard Level of III, both volcanoes are classed at Risk Level III.

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

*Table 16.10 Identity of Martinique's and Guadeloupe's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Soufrière Guadeloupe	5	III
Pelée	4	III

Table 16.11 Classified volcanoes of Guadeloupe and Martinique ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 2 volcanoes.

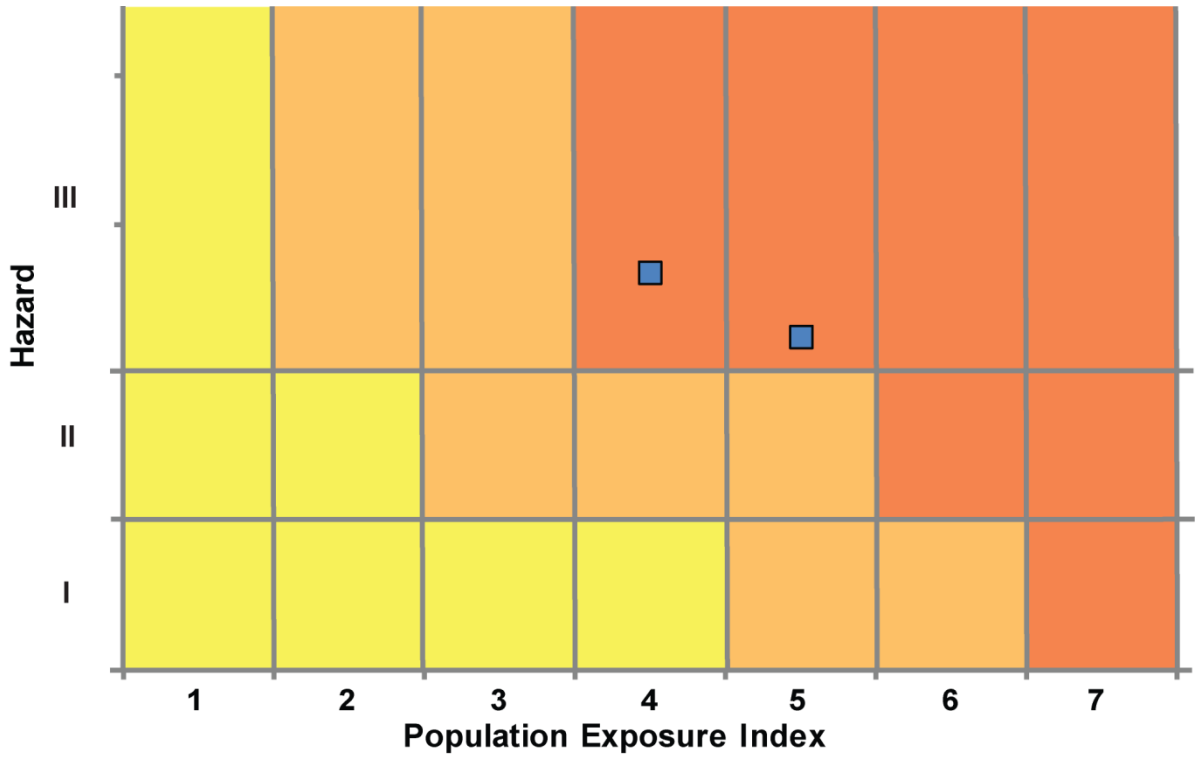

Figure 16.10 Distribution of Martinique and Guadeloupe's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Both Soufrière Guadeloupe and Pelée are monitored by the Observatoire Volcanologique et Sismologique de Guadeloupe (OVSG/IPGP) and Observatoire Volcanologique et Sismologique de Martinique (OVSM/IPGP) respectively. Extensive seismic, deformation and geochemical networks are in place at both volcanoes.

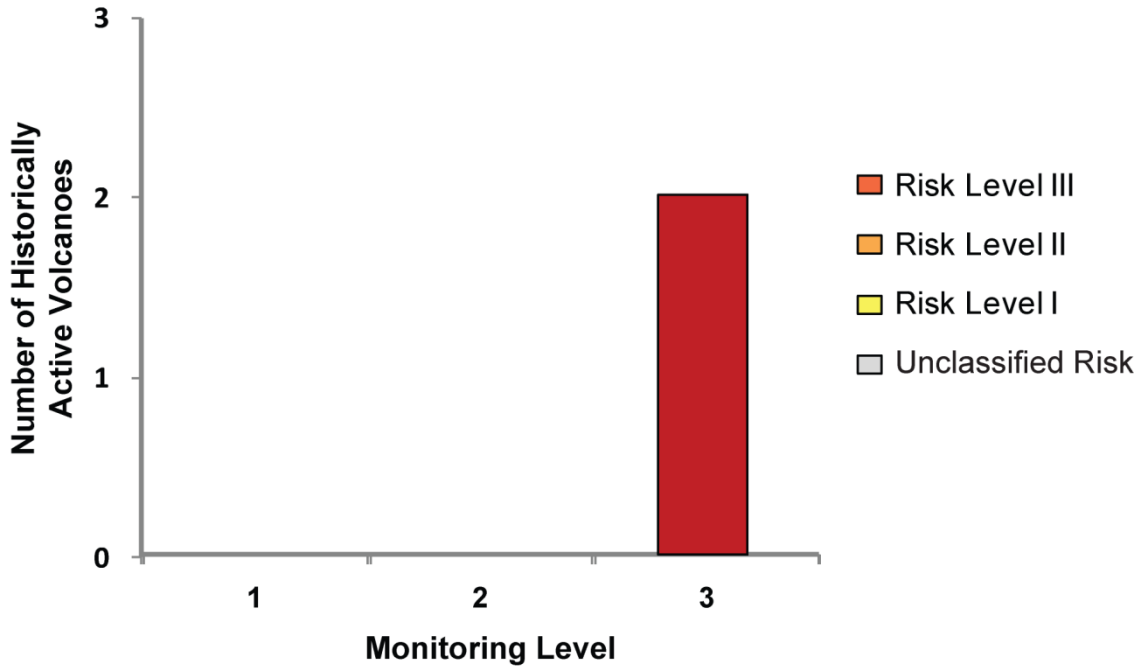

Figure 16.11 The monitoring and risk levels of the historically active volcanoes in Martinique and Guadeloupe. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Grenada

Description

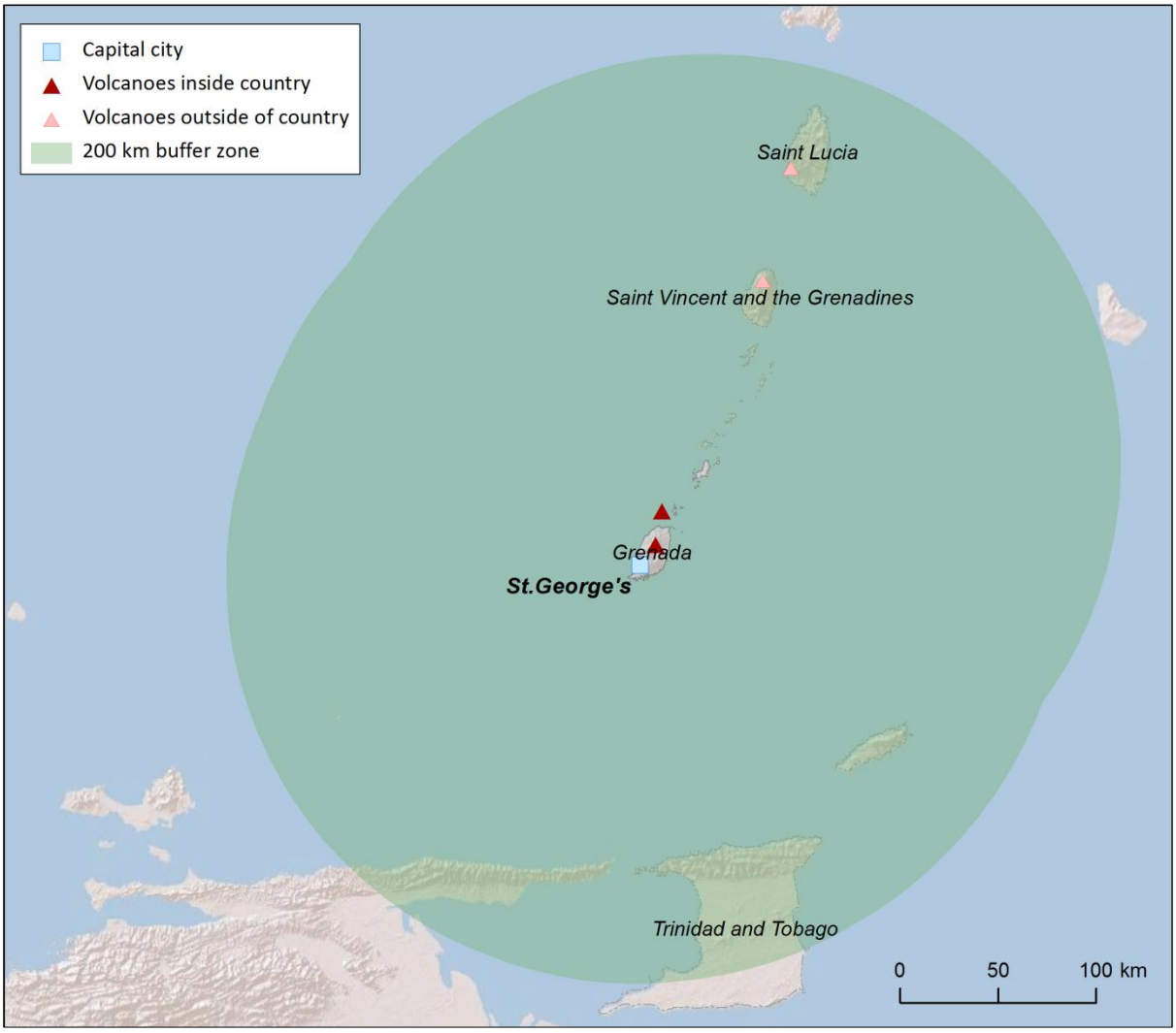

Figure 16.12 Location of Grenada volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Grenada.

Two Holocene volcanoes are present in Grenada: one, the andesitic stratovolcano St.Catherine is situated in the north of the island, and the second, the basaltic submarine Kick 'em Jenny located off the northern shore. Volcanism here is due to the subduction of the Atlantic Ocean beneath the Caribbean Plate.

Only Kick 'em Jenny has a Holocene record of confirmed eruptions, with 13 VEI 0 – 1 eruptions. St. Catherine is also suspected of having Holocene age activity. Activity at Kick 'em Jenny has involved both explosions and lava effusion. The largest eruption on record occurred in 1939 when an eruption cloud rose to nearly 300 m above the surface of the sea.

Being a small island group, the entire population lives close to the volcanoes. Being the only subaerial volcano here, the largest proximal population is located at St. Catherine.

Submarine volcanoes can pose various hazards. Ballistics may breach the surface though these are unlikely to reach the main island of Grenada. Gas release from the volcanoes can lower the water density. Ships may lose buoyancy and sink due to this, and indeed it is suggested that Kick 'em Jenny may have caused the sinking of the Island Queen with over 60 people on board in 1944.

Robertson (2005) presents eruption scenarios for the island, comprising dome growth and explosive eruption. Integrated hazard maps are presented in which the highest hazard is concentrated in the north of the island around St. Catherine volcano. Also of note is the presence of explosion craters running approximately NNE-SSW through the island, which may suggest that further craters may develop.

The University of the West Indies Seismic Research Centre (SRC) is responsible for the monitoring of Grenada's volcanoes. Indeed, they monitor the historically active Kick 'em Jenny with multiple seismic and deformation stations placed on islands close to this submarine volcano. They also monitor the Holocene volcano St. Catherine. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre: www.uwiseismic.com/

Robertson, R. (2005) Grenada, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The VEI 1 eruption of Kick 'em Jenny of 1939 AD.
Number of Holocene eruptions	13 confirmed eruptions.
Recorded Holocene VEI range	0 – 1 and unknown
Number of historically active volcanoes	1

Number of historic eruptions	12

Number of volcanoes	Primary volcano type	Dominant rock type
1	Large cone(s)	Andesitic (1)
1	Submarine	Basaltic (1)

Table 16.12 The number of volcanoes in Grenada, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	106,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	9,806
Gross National Income (GNI) per capita (2005 PPP $)	9,257
Human Development Index (HDI) (2012)	0.770 (High)

Population Exposure

Capital city	St. George's
Distance from capital city to nearest Holocene volcano	12.6 km
Total population (2011)	108,419
Number (percentage) of people living within 10 km of a Holocene volcano	50,457 (46.5%)
Number (percentage) of people living within 30 km of a Holocene volcano	103,820 (95.8%)
Number (percentage) of people living within 100 km of a Holocene volcano	105,009 (96.9%)

Largest cities, as measured by population and their population size:

Saint George's	7,500

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	1

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

The volcanoes of Grenada are located on the main island and about 8 km off the coast of the main island. Being a group of small islands, with Grenada itself measuring no more than 40 km across, the country in its entirety lies within 100 km of the Holocene volcanoes, exposing all infrastructure here. Indeed, the 100 km radii of the volcanoes here extends beyond Grenada to encompass much of the Grenadines.

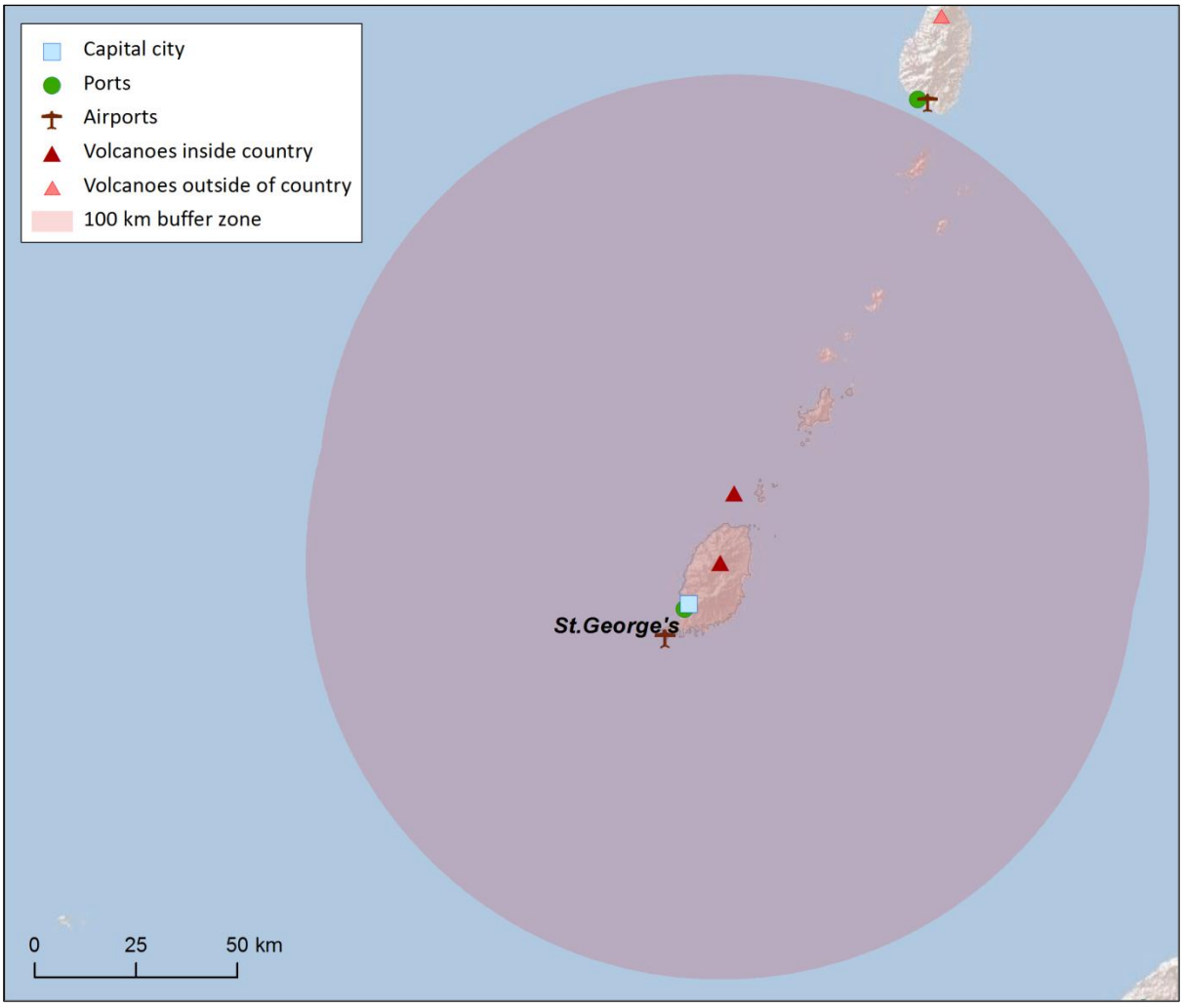

Figure 16.13 The location of Grenada's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

The two volcanoes of Grenada have very different eruption records. St. Catherine has no confirmed Holocene eruptions, and this volcano cannot therefore have a hazard level determined without large associated uncertainties. Kick 'em Jenny is sufficiently well known to classify this volcano as Hazard Level I. Kick'em Jenny has a moderate PEI and is classed at Risk Level I.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I			Kick 'em Jenny				
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR					St. Catherine		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 16.13 Identity of Grenada's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Kick 'em Jenny	3	I

Table 16.14 Volcanoes of Grenada ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 0 volcanoes; Risk Level III – 0 volcanoes.

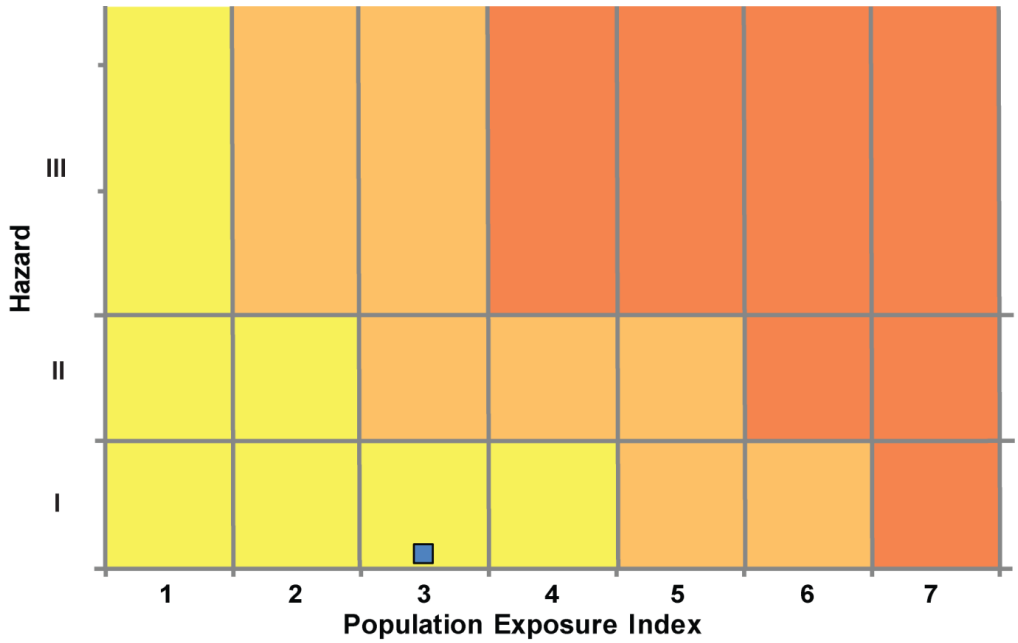

Figure 16.14 Distribution of Grenada's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Kick'em Jenny, the only historically active volcano in Grenada is monitored by the University of West Indies Seismic Research Centre. Being a submarine volcano, monitoring is undertaken using seismic and deformation stations on nearby islands. The SRC also monitor the Holocene volcano St. Catherine.

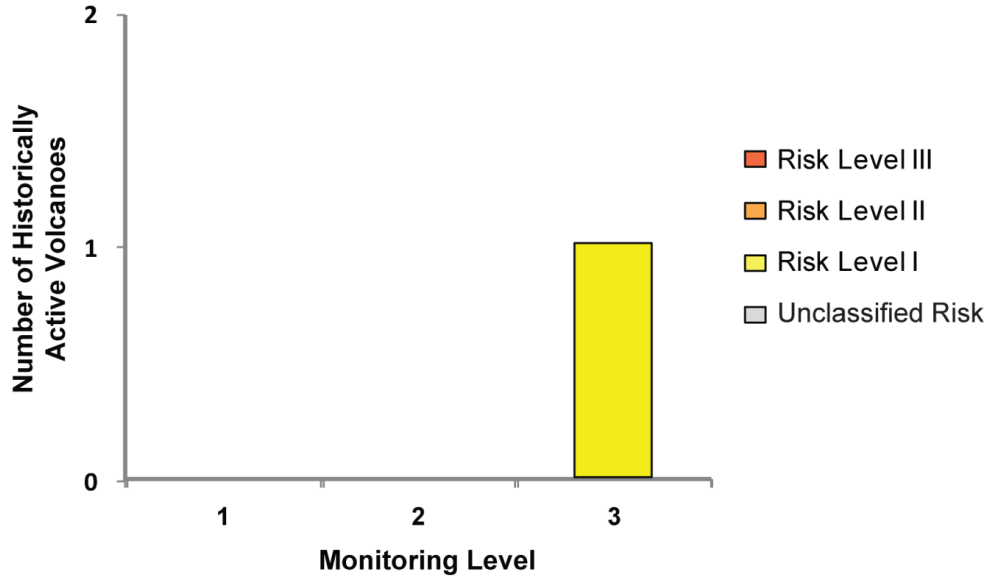

Figure 16.15 The monitoring and risk levels of the historically active volcanoes in Grenada. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Netherlands (Dutch Antilles)

Description

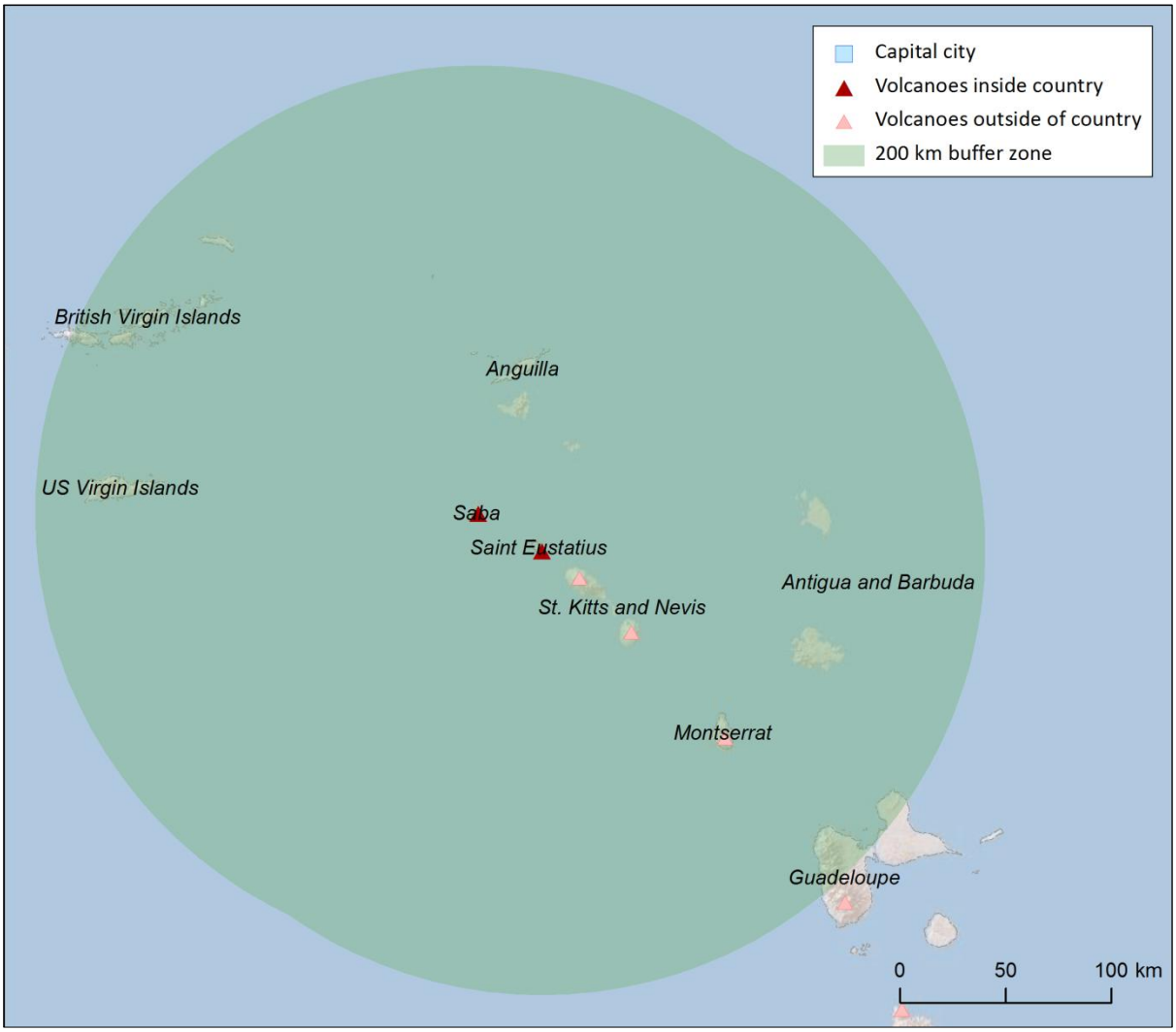

Figure 16.16 Location of the Dutch Antilles' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect the Dutch Antilles.

Two Holocene volcanoes are located in the Dutch Antilles, on the islands of Saba and Sint Eustatius in the northern Lesser Antilles. These andesitic stratovolcanoes result from the subduction of the Atlantic Ocean Crust beneath the Caribbean Plate.

Both Saba and The Quill volcanoes have confirmed Holocene eruptions on record, with just one historic eruption at Saba in 1640, and three Holocene eruptions at The Quill from 6140 BC to 250 AD. Only the 6140 BC eruption of The Quill has a known size, at VEI 4; the other eruptions are of unknown magnitude. Despite the absence of data regarding the size of eruptions, all four events produced pyroclastic flows, indicating explosive activity has been commonplace. Hot springs are located on these islands and recent unrest in the form of seismicity is recorded.

Being small islands, the population of Saba and Sint Eustatius are situated in close proximity to the volcanoes. This accounts for about 25% of the population of the Dutch Antilles, with much of the population located in another island group off the Venezuela coast.

Smith and Roobol (2005) present eruption scenarios and suggest that the most likely style of future magmatic activity at Saba will involve the growth of a lava dome and associated block and ash flows and surges. They present volcanic hazard maps for Saba indicating that the entire island is considered Very High Hazard in the event of a dome-forming eruption. Smith and Roobol (2005) suggest that the most likely eruption scenario for future activity at The Quill is an explosive eruption producing pyroclastic flows, surges and ash fall. They indicate that only the north-west section of the island of Sint Eustatius lies outside of the High hazard zone for pyroclastic flows and surges (but still considered moderate), with much of the island being considered Very High Hazard and the whole island being High to Very High Hazard. See Smith and Roobol (2005) for full details.

The Koninklijk Nederlands Meteorologisch Instituut is responsible for the monitoring of the volcanoes of the Dutch Antilles. Indeed, they monitor the historically active Saba volcano with seismic and deformation stations, and also monitor The Quill. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

Smith, A.L., and Roobol, M.J. (2005) Saba, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Smith, A.L., and Roobol, M.J. (2005) St. Eustatius, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	2
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The M4 6140 BC eruption of The Quill.

Number of Holocene eruptions	4 confirmed eruptions.
Recorded Holocene VEI range	4 and unknown
Number of historically active volcanoes	1
Number of historic eruptions	1

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

Table 16.15 The number of volcanoes in the Dutch Antilles, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	44,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	
Gross National Income (GNI) per capita (2005 PPP $)	
Human Development Index (HDI) (2012)	

Population Exposure

Capital city	Willemstad
Distance from capital city to nearest Holocene volcano	789.3 km
Total population (2011)	15,021
Number (percentage) of people living within 10 km of a Holocene volcano	3,797 (25.3%)
Number (percentage) of people living within 30 km of a Holocene volcano	3,797 (25.3%)
Number (percentage) of people living within 100 km of a Holocene volcano	3,797 (25.3%)

Largest cities, as measured by population and their population size:

Willemstad	125,000

Infrastructure Exposure

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

The islands of the Dutch Antilles form two groups in the Caribbean, one group off the coast of Venezuela and another in the northern Lesser Antilles. It is this northern group where the volcanoes are situated on the islands of Saba and Sint Eustatius. Being small islands, these are encompassed in their entirety within the 100 km radii of the volcanoes, as are the islands of St. Kitts and Nevis and north beyond Anguilla. Indeed, the 100 km radii of the volcanoes of St. Kitts and Nevis extend to encompass these northern islands of the Dutch Antilles exposing the infrastructure here. All infrastructure in this group of islands is exposed.

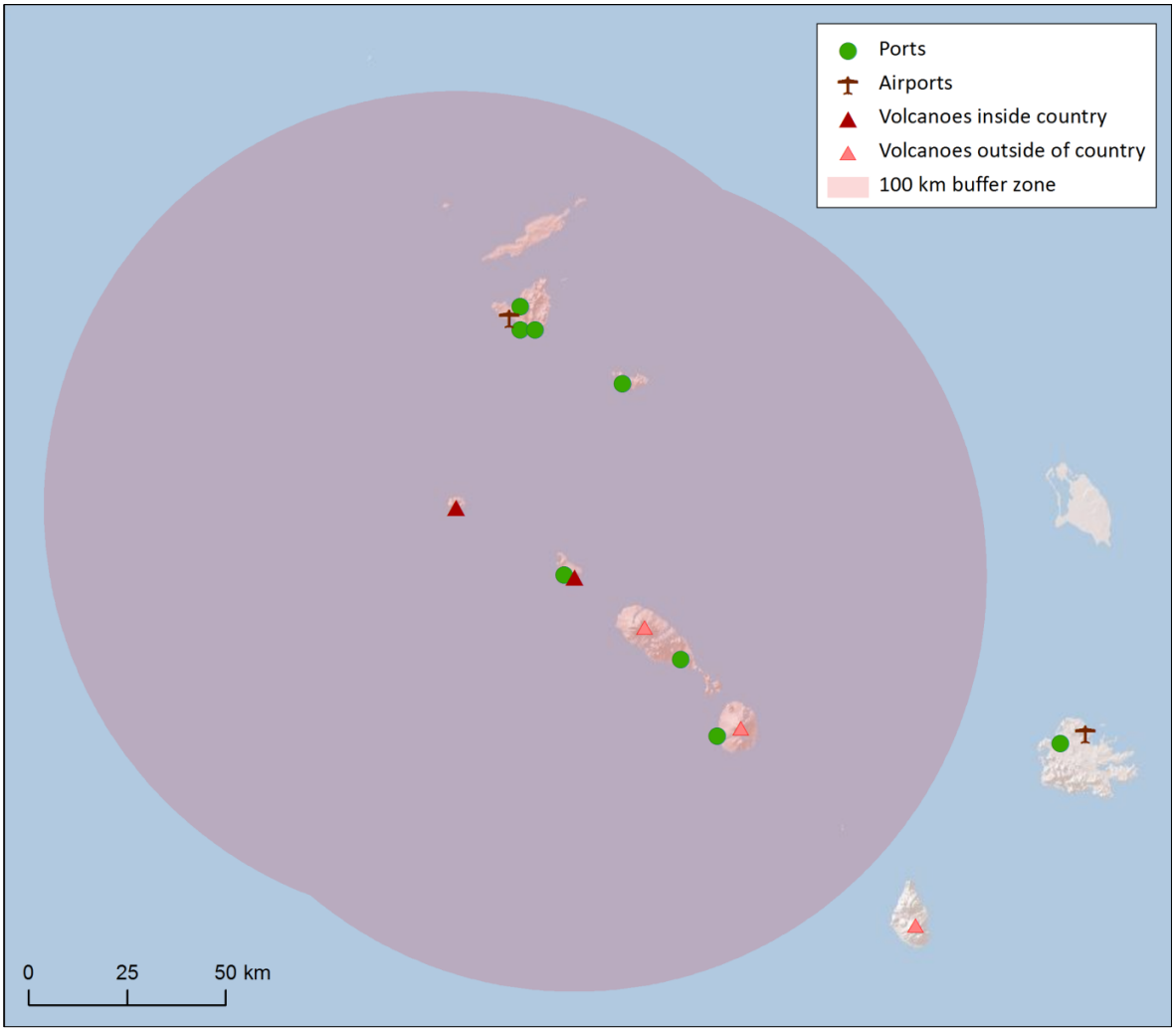

Figure 16.17 The location of the Dutch Antilles volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Neither Saba nor The Quill have sufficiently detailed eruptive records to enable hazard classification through calculation of the VHI. Saba has a historical record of activity, along with unrest documented since 1900 AD. The Quill has three known Holocene eruptions, with one a VEI 4.

The PEI at Saba and The Quill is low at PEI 2.

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

*Table 16.16 Identity of the Dutch Antilles' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

National Capacity for Coping with Volcanic Risk

Seismometers are in place for monitoring of the Saba volcano, operated by the Koninklijk Nederlands Meteorologisch Instituut.

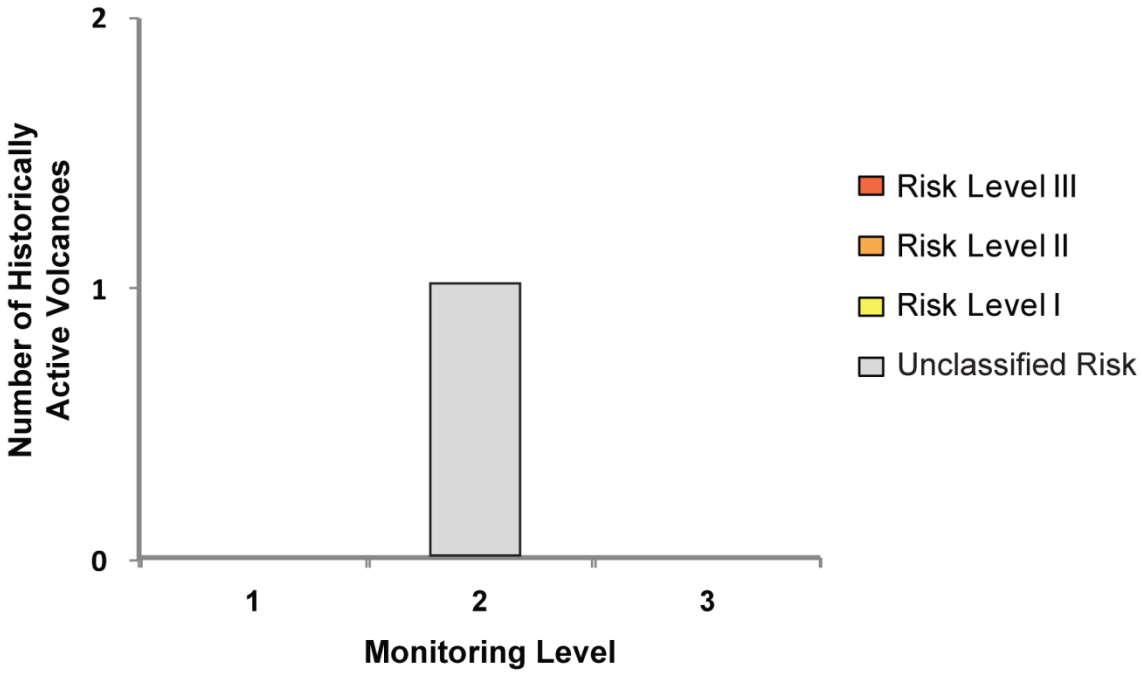

Figure 16.18 The monitoring and risk levels of the historically active volcanoes in the Dutch Antilles. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

St. Kitts and Nevis

Description

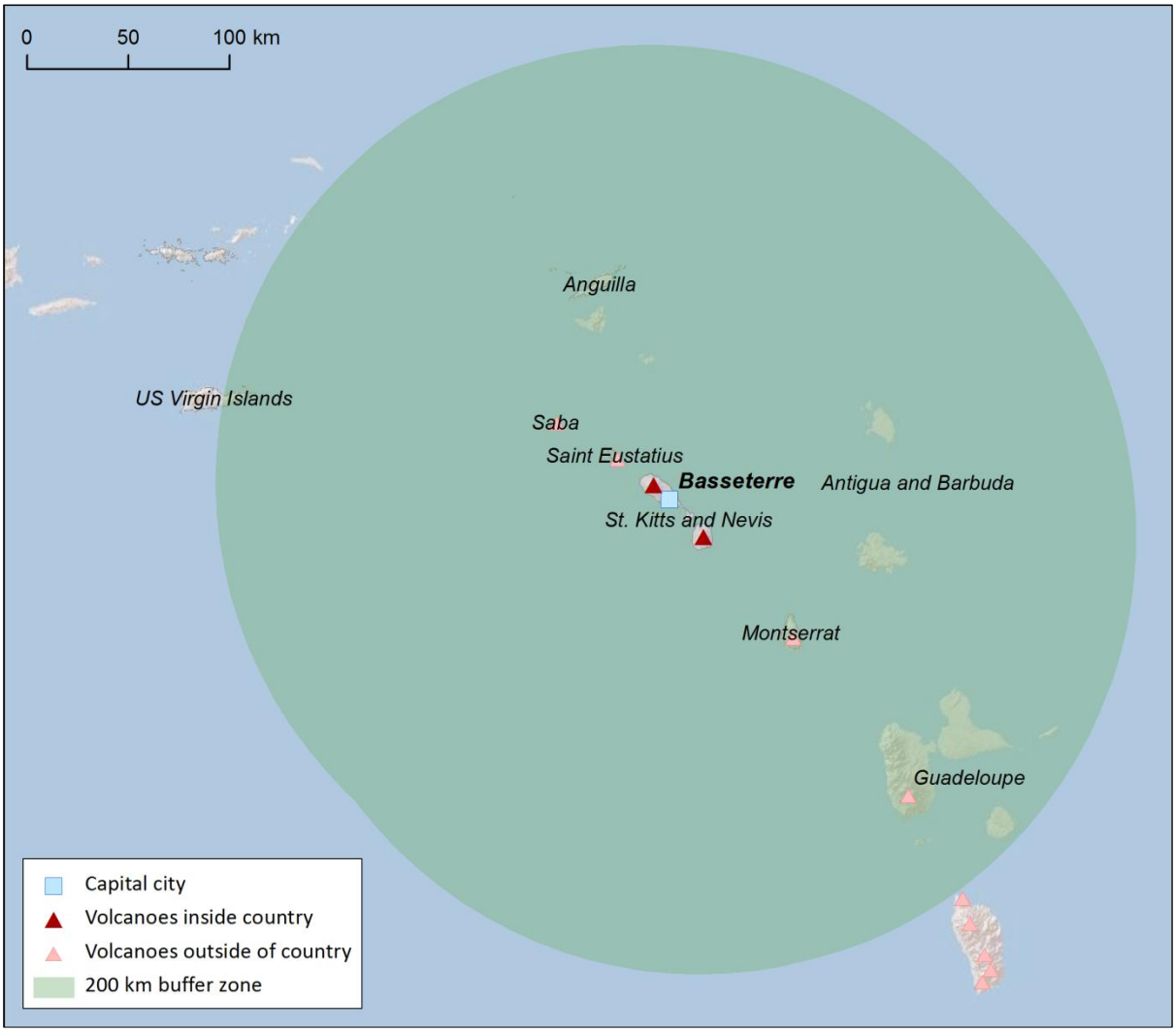

Figure 16.19 Location of St Kitts and Nevis' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect St Kitts and Nevis.

Two Holocene volcanoes are located in St. Kitts and Nevis: Liamuiga on the island of St. Kitts and Nevis Peak central on Nevis. These two andesitic stratovolcanoes have formed due to the subduction of the Atlantic Ocean crust beneath the Caribbean Plate.

Only Liamuiga has a confirmed Holocene record of eruptions, with two eruptions of VEI 4 and one of unknown magnitude recorded in 2010 BC, 160 AD and 60 AD, respectively. All three eruptions of Liamuiga reportedly produced pyroclastic flows, indicating that explosive activity is prevalent here. One of these events also resulted in a lahar and the deposits of this now underlie populated coastal regions on the island. The most recent dated eruption of Nevis Peak was about 100,000 years ago

and the Holocene age of other activity here is questionable, however, active fumaroles and hot springs on Nevis Island and seismic swarms during the 20th century indicate unrest.

With a sparse eruptive record, assessment of hazard at Nevis Peak is difficult and associated with large uncertainties. The record is better constrained at Liamuiga, however recent historical eruptions are uncertain. Robertson (2005) present hazard maps for a number of eruption scenarios at Liamuiga and present integrated hazard maps, where the north of the island of St. Kitts is considered the area of highest hazard. Simpson (2005) present hazard maps for effusive dome building eruptions from Nevis Peak and shows that the whole of Nevis Island is considered Very High Hazard or High Hazard with a large proportion of the island susceptible to inundation by pyroclastic flows.

Being relatively small islands, the whole country is situated close to these Holocene volcanoes, and about three quarters of the population live within 10 km of a Holocene volcano.

The University of the West Indies Seismic Research Centre (SRC) monitors the volcanoes of St. Kitts and Nevis using seismic and deformation networks and additional monitoring of springs and fumaroles when activity permits. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre www.uwiseismic.com/

Robertson, R. (2005) St. Kitts, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Simpson, K. (2005) Nevis, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Both the D and F eruptions of Liamuiga, at 4470 and 1777 BP respectively, are recorded at

	M4.
Number of Holocene eruptions	3 confirmed eruptions. 2 uncertain eruptions.
Recorded Holocene VEI range	4 and unknown
Number of historically active volcanoes	-
Number of historic eruptions	-

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

Table 16.17 The number of volcanoes in St. Kitts and Nevis, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	54,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	13,291
Gross National Income (GNI) per capita (2005 PPP $)	12,460
Human Development Index (HDI) (2012)	0.745 (High)

Population Exposure

Capital city	Basseterre
Distance from capital city to nearest Holocene volcano	10 km
Total population (2011)	50,314
Number (percentage) of people living within 10 km of a Holocene volcano	37,080 (73.7%)
Number (percentage) of people living within 30 km of a Holocene volcano	52,989 (>100%)
Number (percentage) of people living within 100 km of a Holocene volcano	52,989 (>100%)

Largest cities, as measured by population and their population size:

Basseterre	12,920

Infrastructure Exposure

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

The volcanoes of St. Kitts and Nevis are located on both islands. Being small islands measuring no more than about 50 km across, this country in its entirety lies close to Holocene volcanoes. The 100 km radii of these volcanoes extend beyond the country's borders to encompass the northern islands of the Dutch Antilles, Montserrat, Antigua and Barbuda and much of Anguilla, exposing much of the infrastructure in the northern Lesser Antilles. Indeed the 100 km radii of the volcanoes of these other islands, including Soufriere Hills on Montserrat and Saba and The Quill of the Dutch Antilles encompasses and exposes St.Kitts and Nevis to the volcanic hazard.

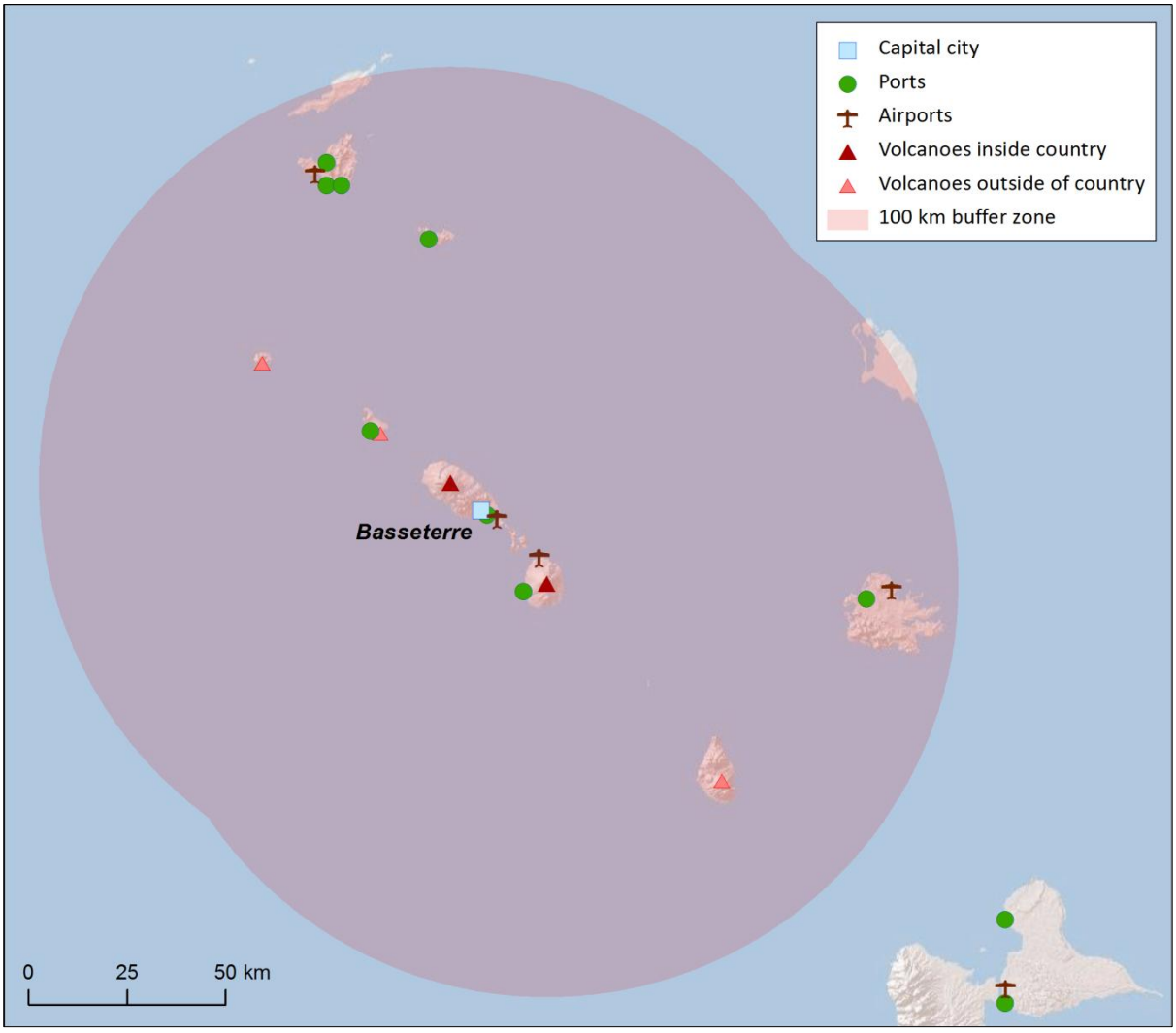

Figure 16.20 The location of St. Kitts and Nevis' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Neither Liamuiga nor Nevis Peak have sufficient eruption records to determine the hazard level through calculation of the VHI. Indeed, there are no confirmed Holocene age eruptions at Nevis Peak. Three Holocene eruptions are recorded at Liamuiga, with two VEI 4 events. Both volcanoes have experienced unrest since 1900 AD suggesting active systems.

With moderate proximal populations in St. Kitts and Nevis, these volcanoes are classed at PEI 3 and 4. Risk levels cannot be determined due to lack of hazard data.

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

*Table 16.18 Identity of St Kitts and Nevis' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 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 St. Kitts and Nevis have recorded historical eruptions, however seismic and deformation monitoring is undertaken here by the Seismic Research Centre.

St. Lucia

Description

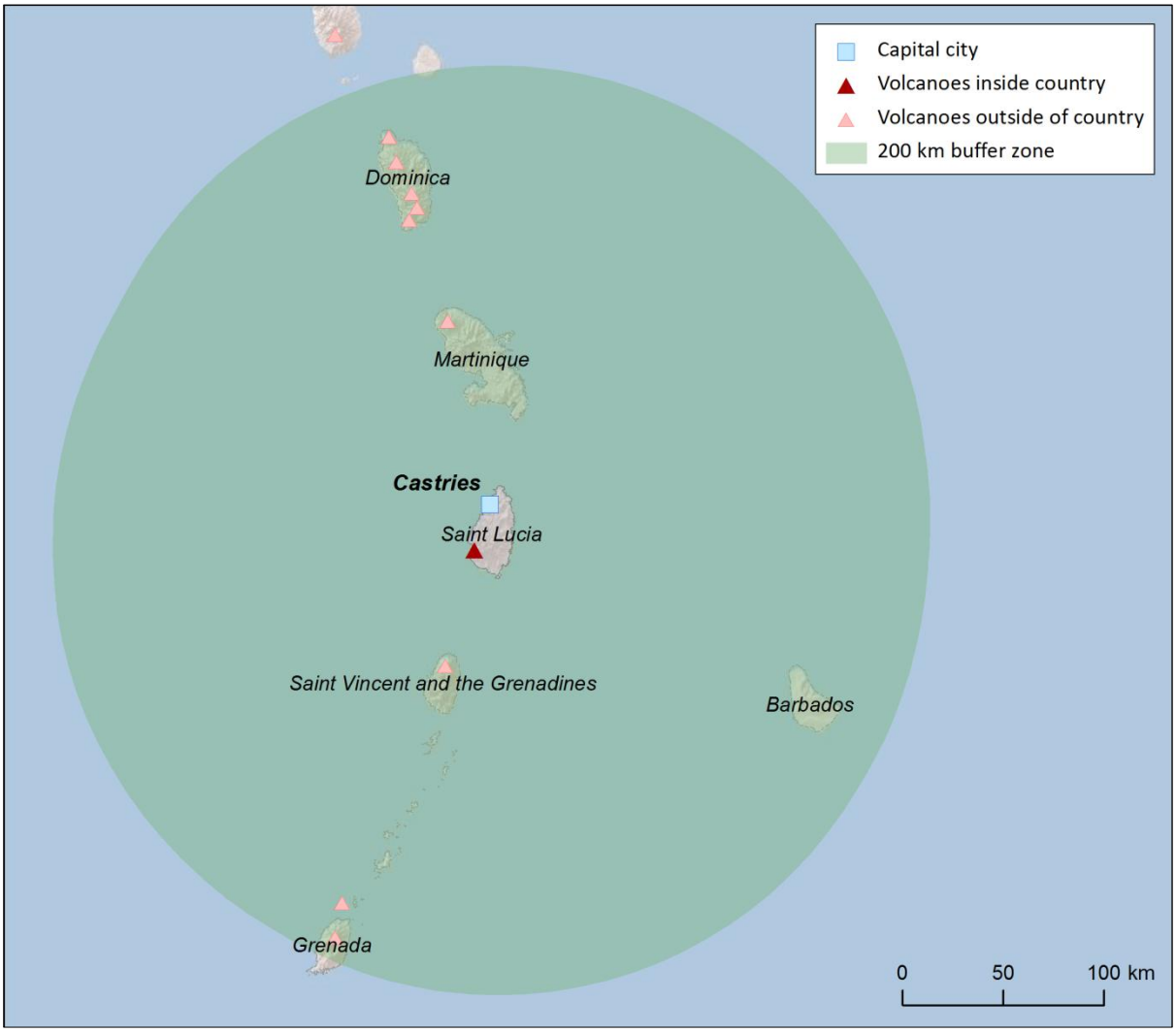

Figure 16.21 Location of St. Lucia's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect St. Lucia.

One Holocene volcano, Qualibou, is located in the south-east of the island of St. Lucia. This andesitic caldera is due to the subduction of the Atlantic Ocean crust beneath the Caribbean Plate.

Qualibou has a Pleistocene record of large explosive eruptions, with the M6.1 eruption of the Choiseul Tuff about 42,000 years ago forming the present caldera. Numerous post-caldera lava dome fill the crater floor. Only one Holocene eruption is confirmed, with a small VEI 1 phreatic eruption in 1766 that produced a thin layer of ash over an extensive area. The history of large explosive eruptions and andesitic composition suggests that future large explosive eruptions cannot be ruled out. However, Lindsay (2005) suggests that phreatic or hydrothermal eruptions or small explosive eruptions forming explosion craters are most likely. Unrest occurred in 1990 with a volcanic earthquake swarm.

Lindsay (2005) presents eruption scenarios and hazard maps for dome forming eruptions and explosive Plinian eruptions at Qualibou. These show the hazard concentrated in the south-east of the island, around the volcanic centre, with High and Very High Hazard across much of the south and centre of St. Lucia in the event of an explosive Plinian eruption. See Lindsay (2005) for further detail.

Being a relatively small island, the whole population resides close to the volcano, with about 20% of the population living within 10 km.

The University of the West Indies Seismic Research Centre (SRC) is responsible for the monitoring of St. Lucia's volcanoes. Indeed, they monitor Qualibou with multiple dedicated ground-based systems. A monitoring alert system is in place. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre www.uwiseismic.com/

Lindsay, J.M. (2005) St. Lucia, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B. and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M6.1 eruption of the Choiseul Tuff from Qualibou at 42,264 BP.
Largest recorded Holocene eruption	The VEI 1 eruption of Qualibou in 1766 AD.
Number of Holocene eruptions	1 confirmed eruption.
Recorded Holocene VEI range	1
Number of historically active volcanoes	1
Number of historic eruptions	1

Number of volcanoes	Primary volcano type	Dominant rock type
1	Caldera(s)	Andesitic (1)

Table 16.19 The number of volcanoes in St. Lucia, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	181,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	8,231
Gross National Income (GNI) per capita (2005 PPP $)	7,971
Human Development Index (HDI) (2012)	0.725 (High)

Population Exposure

Capital city	Castries
Distance from capital city to nearest Holocene volcano	23.5 km
Total population (2011)	161,557
Number (percentage) of people living within 10 km of a Holocene volcano	28,310 (17.5%)
Number (percentage) of people living within 30 km of a Holocene volcano	178,196 (>100%)
Number (percentage) of people living within 100 km of a Holocene volcano	179,005 (>100%)

Largest cities, as measured by population and their population size:

Cul De Sac	8,467
Castries	<50,000

Infrastructure Exposure

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

Qualibou volcano is located in the south-east of the island of St. Lucia. Being only a small island, measuring no more than about 50 km across, this country in its entirety lies within the 100 km radius of this volcano and thus all infrastructure and population is exposed here. Indeed the 100 km radius extends beyond St. Lucia to fully encompass St. Vincent and extend into the Grenadines, and largely encompass Martinique, exposing the infrastruture and population on these islands. The 100 km radii of Pelée on Martinique and Soufrière St.Vincent on the island of St. Vincent also extend to encompass St. Lucia and thus expose the infrastructure here.

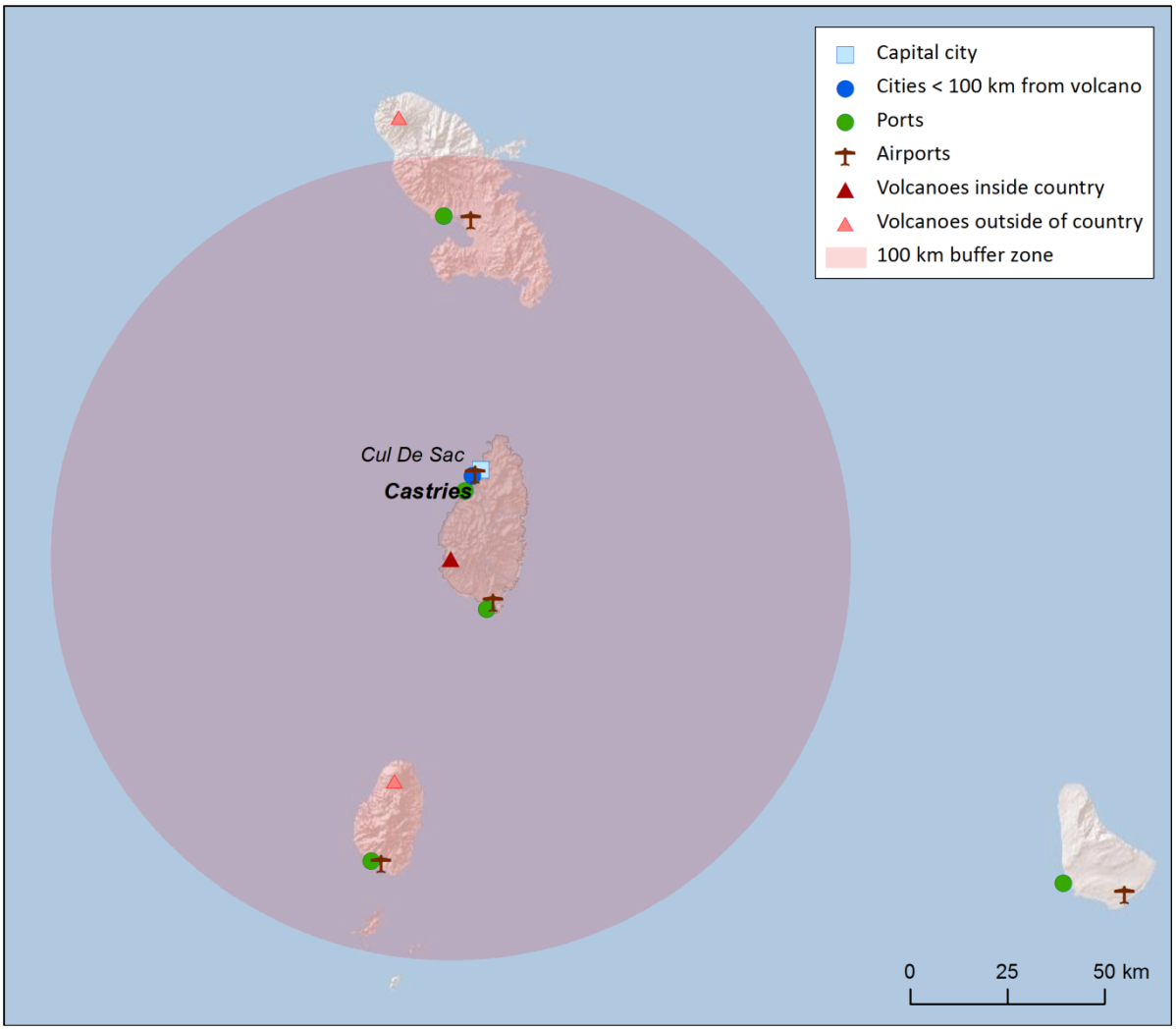

Figure 16.22 The location of St. Lucia's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

Qualibou in St. Lucia has just one confirmed eruption recorded during the Holocene, with a VEI 1 event in 1766. This is insufficient to calculate the VHI and therefore a hazard level is not determined here. Qualibou has a high local population, and is classed at PEI 5 suggestive of a risk level of II to III.

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

*Table 16.20 Identity of St. Lucia's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

National Capacity for Coping with Volcanic Risk

The University of the West Indies Seismic Research Centre monitors the historically active volcano Qualibou through a seismic network and multiple deformation stations.

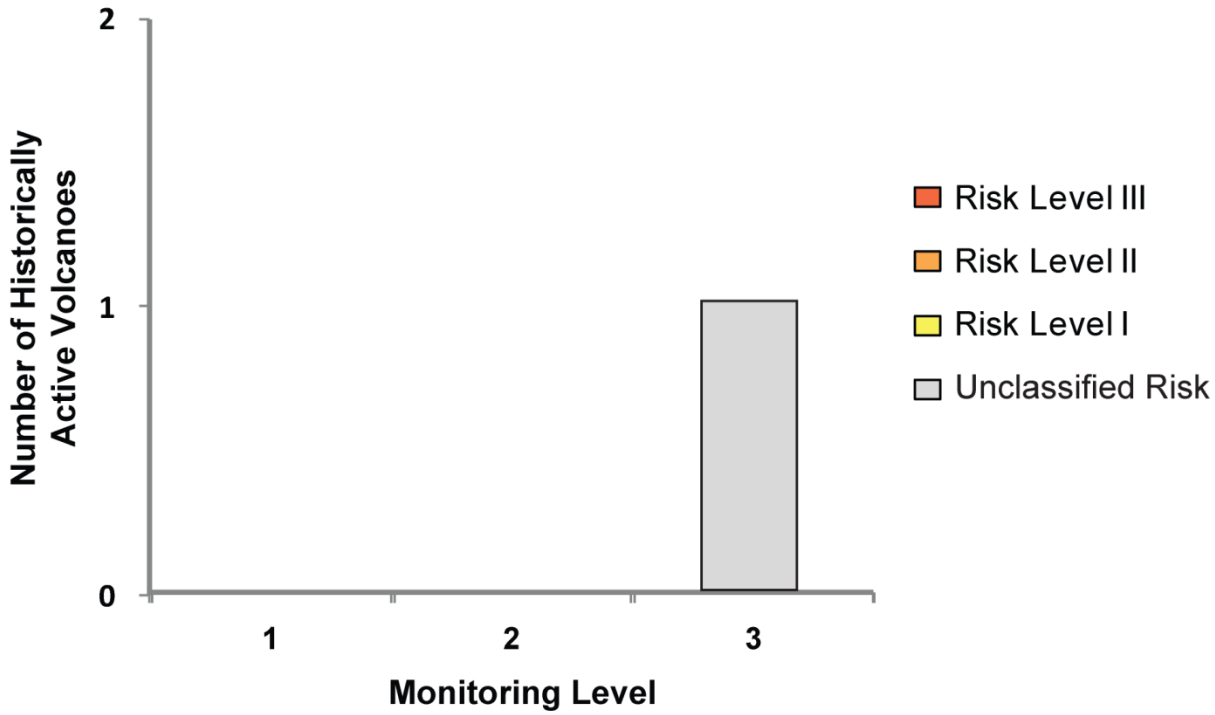

Figure 16.23 The monitoring and risk levels of the historically active volcanoes in St Lucia. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

St. Vincent and the Grenadines

Description

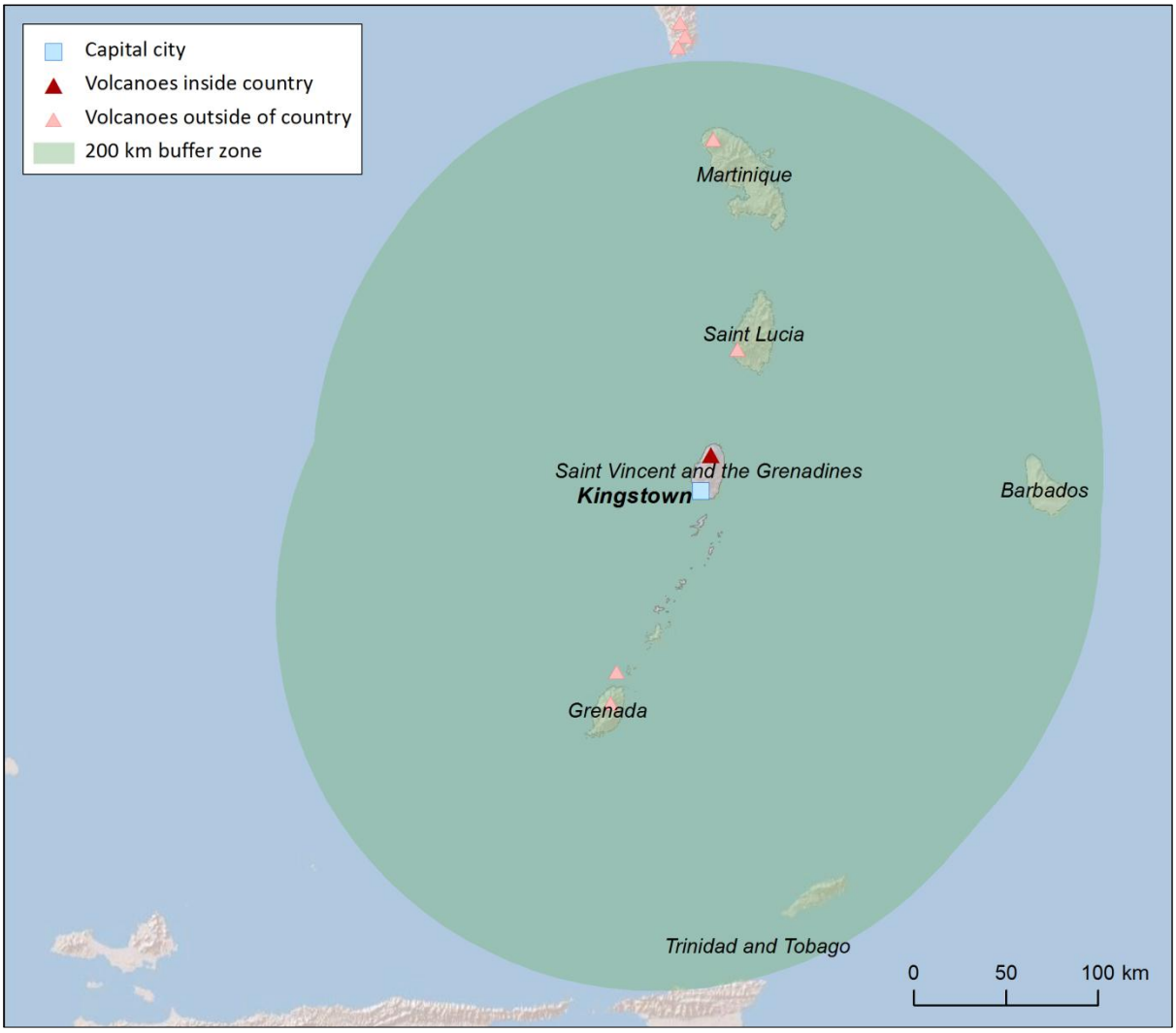

Figure 16.24 Location of St. Vincent and the Grenadines' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect St. Vincent and the Grenadines.

One Holocene volcano, Soufrière St. Vincent, is located in the north of the main island of St. Vincent and the Grenadines. This andesitic stratovolcano has developed as a result of the subduction of the Atlantic Ocean crust beneath the Caribbean Plate.

Twenty-one Holocene eruptions are confirmed at Soufrière St. Vincent, between 2380 BC and 1979 AD. These eruptions have varied in size from VEI 0 to 4, however all eruptions prior to the 1700s are of unknown magnitude. These eruptions however, all have records of producing explosive products including pyroclastic flows. Indeed 17 out of 21 eruptions recorded here have produced pyroclastic

flows and much of the island is blanketed with deposits from these eruptions, indicating that explosive activity has been commonplace.

Two historical eruptions of VEI 4 are recorded here, including the VEI 4 eruption of 1902 which devastated much of the northern part of the island.

Being a relatively small island, the whole population is located close to the volcano, with about a quarter of the population living within 10 km alone. Four eruptions have resulted in fatalities with about 1,700 recorded, of which most occurred during the 1902 eruption.

Robertson (2005) described eruption scenarios at Soufrière St. Vincent and presents integrated hazard maps for effusive dome-forming and explosive eruptions, showing much of the north of the island as Very High Hazard, with decreasing hazard moving southwards. See Robertson (2005) for full details.

The University of the West Indies Seismic Research Centre (SRC) is responsible for the monitoring of St. Vincent and the Grenadines' volcanoes. Indeed, they monitor the Soufrière St. Vincent with multiple dedicated ground-based systems. A monitoring alert system is in place. See Region 16 West Indies regional profile for discussion of the SRC and policies for handling unrest and eruption.

See also:

University of the West Indies Seismic Research Centre www.uwiseismic.com/

Robertson, R. (2005) St. Vincent, in Lindsay, J.M., Robertson, R.E.A., Shepherd, J.B and Ali, S. (Eds) Volcanic Hazard Atlas of the Lesser Antilles, Seismic Research Centre, 1st edition

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	1
Number of fatalities caused by volcanic eruptions	?1,741
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	The M4.7 eruption of Soufrière St. Vincent in 1812 AD.
Number of Holocene eruptions	21 confirmed eruptions. 1 uncertain eruption.

Recorded Holocene VEI range	0 – 4 and unknown
Number of historically active volcanoes	1
Number of historic eruptions	9

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

Table 16.21 The number of volcanoes in St. Vincent and the Grenadines, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	110,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	9,482
Gross National Income (GNI) per capita (2005 PPP $)	9,367
Human Development Index (HDI) (2012)	0.733 (High)

Population Exposure

Capital city	Kingstown
Distance from capital city to nearest Holocene volcano	19.7 km
Total population (2011)	103,869
Number (percentage) of people living within 10 km of a Holocene volcano	24,415 (23.5%)
Number (percentage) of people living within 30 km of a Holocene volcano	100,414 (96.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	108,973 (>100%)

Largest cities, as measured by population and their population size:

Kingstown	24,518

Infrastructure Exposure

Number of airports within 100 km of a volcano	8

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

Soufrière St. Vincent lies in the north of the main island of St. Vincent and the Grenadines. Being only a small island, the whole of St. Vincent lies within a short distance of this volcano, and the 100 km radius of this volcano extends to nearly fully encompass the islands of the Grenadines. This radius also extends to fully encompass and expose St. Lucia, and indeed, the 100 km radius of the Qualibou volcano on St. Lucia extends to encompass the whole of St. Vincent. All infrastructure is exposed here.

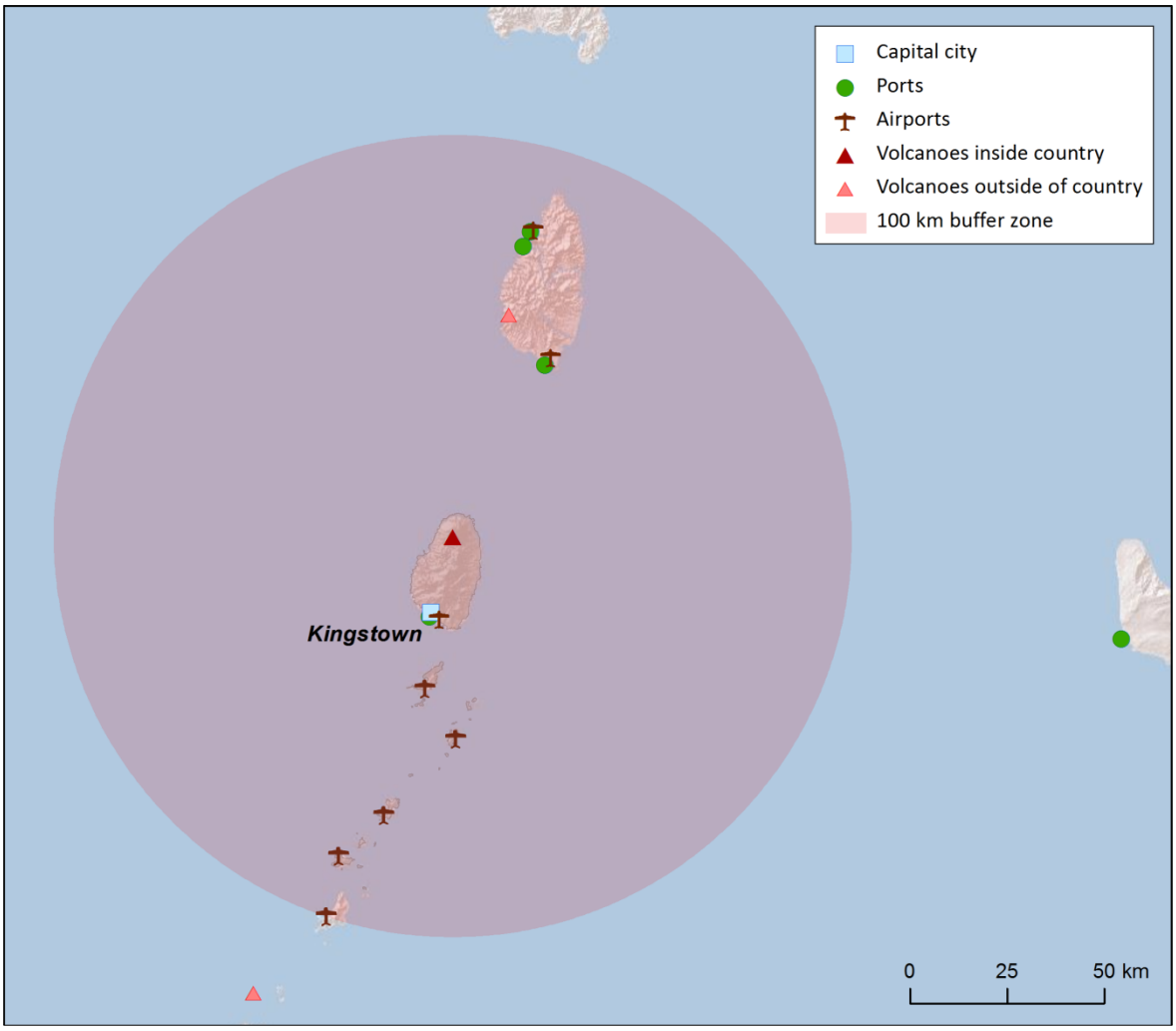

Figure 16.25 The location of St. Vincent and the Grenadines' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

With a Holocene record of 21 confirmed eruptions including seven with a known size, Soufrière St. Vincent has sufficient data available to determine the hazard level through the calculation of the VHI. With a record of VEI 4 eruptions and explosive events producing pyroclastic flows, this volcano is classified at Hazard Level III.

With a Hazard Level of III and a moderate PEI of 4, Soufrière St. Vincent is classed at Risk Level III.

CLASSIFIED	**Hazard III**				Soufrière St. Vincent			
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR							
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 16.22 Identity of the volcano of St. Vincent and the Grenadines and its Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Soufrière St. Vincent	4	III

Table 16.23 Classified volcanoes of St. Vincent and the Grenadines ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 1 volcano.

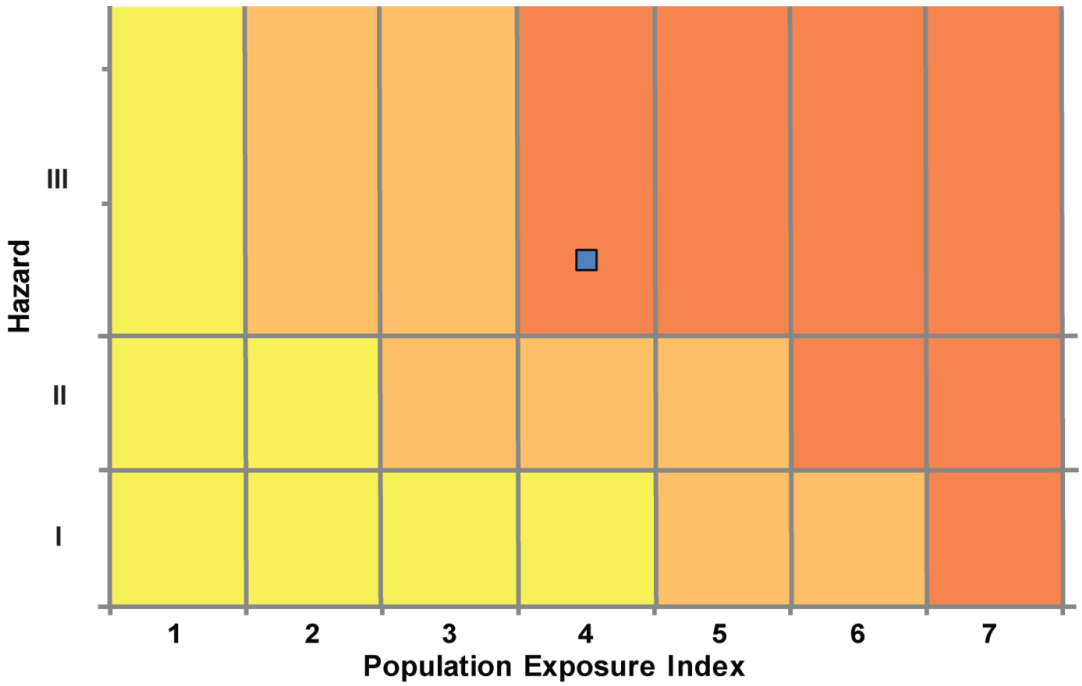

Figure 16.26 Distribution of St. Vincent and the Grenadines' classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The University of the West Indies Seismic Research Centre monitors the historically active Soufrière St. Vincent volcano through a seismic network and multiple deformation stations.

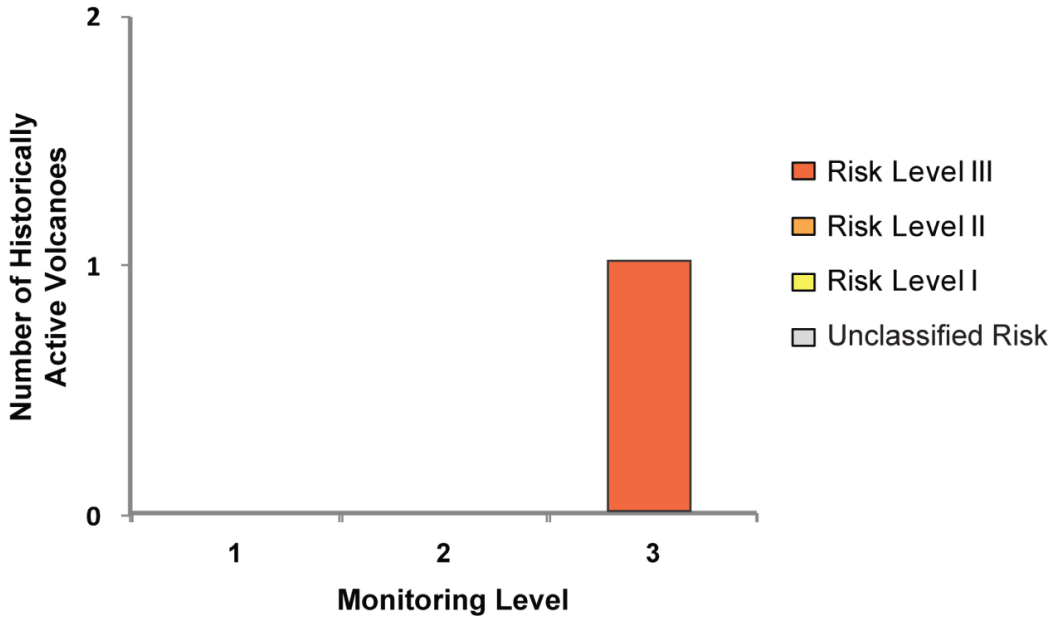

Figure 16.27 The monitoring and risk levels of the historically active volcanoes in St. Viincent and the Grenadines. Monitoring Level 1indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

UK – Montserrat

Description

Montserrat is a British Overseas Territory. There is one Holocene volcano on Montserrat, Soufrière Hills volcano, located in the southern half of the island. It is an andesitic stratovolcano related to the subduction of the Atlantic Ocean crust beneath the Caribbean Sea.

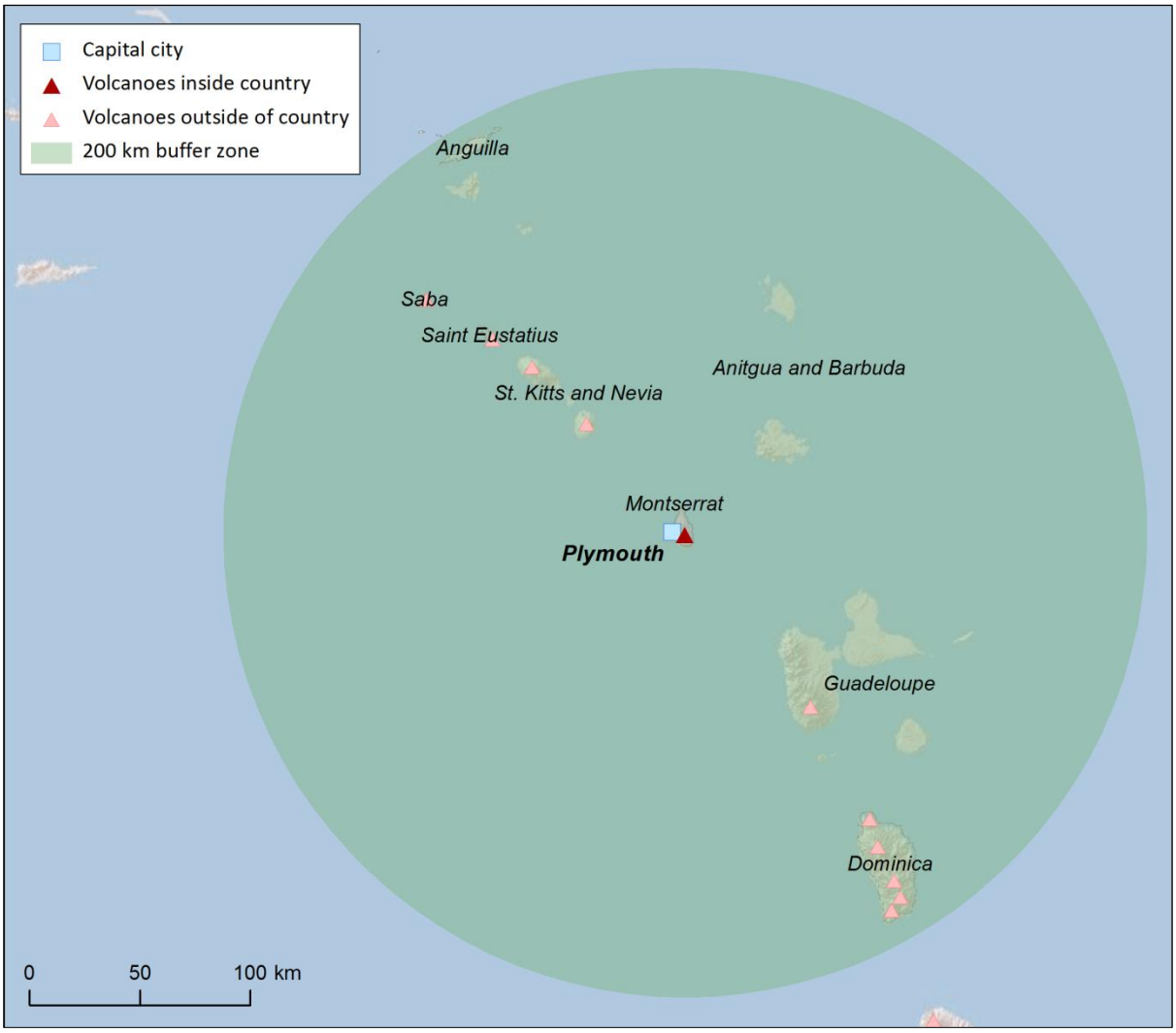

Figure 16.28 Location of Montserrat's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Montserrat.

Soufrière Hills volcano is currently active. Historic activity in the 17th Century produced the Castle Peak lava dome and seismic activity has occurred in swarms at 30 year intervals in the 20th Century. No other eruptions are recorded until the ongoing eruptions which started in August 1995. Eruptive activity is typified by lava dome growth followed by collapse resulting in pyroclastic density currents, lahars and ash plumes. Three VEI 3 eruptions were recorded in 1995, 2004 and 2005.

Parts of the southern half of the island were evacuated in 1995. In June 1997, 19 people were killed by pyroclastic density currents resulting from partial dome collapse. As a direct result of this, the

entire southern half of the island was made an exclusion zone. Since then, several different exclusion zones have been imposed on Montserrat. At present, southern Montserrat is divided into several distinct zones and access to these is controlled depending on the level of volcanic activity.

By 1998, approximately 70% of the population had left the island (Kokelaar, 2002). The capital city of Plymouth has been destroyed by multiple ash fall and pyroclastic density current deposits. Montserrat is a small island with the whole population (c.5000) living within 12 km of the volcano.

Montserrat has a dedicated volcano observatory: Montserrat Volcano Observatory (MVO) run by the University of the West Indies Seismic Research Centre (SRC). MVO provides regular updates on alert levels and short-term hazard assessments. An international panel of scientists and practitioners, the Scientific Advisory Committee on Montserrat Volcanic Activity (SAC) provides hazard and risk assessments [Chapter 21].

See also:

Montserrat Volcano Observatory – www.mvo.ms

Kokelaar, B. P. (2002). Setting, chronology and consequences of the eruption of Soufrière Hills Volcano, Montserrat (1995-1999). *Geological Society, London, Memoirs*, *21*(1), 1-43.

Wadge, G., Robertson, R.E.A., and Voight, B. (eds) (2014). The Eruption of Soufriere Hills Volcano, Montserrat from 2000 to 2010. Geological Society Memoir No.39.

Volcano Facts

Number of Holocene volcanoes	1
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	1
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	19
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	Three VEI 3 eruptions are recorded at Soufrière Hills in 1995, 2004 and 2005.
Number of Holocene eruptions	5 confirmed eruptions.
Recorded Holocene VEI range	3 and unknown
Number of historically active volcanoes	1
Number of historic eruptions	4

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

Table 16.24 The number of volcanoes in Montserrat, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2011)	5,140
Gross Domestic Product (GDP) per capita (2005 PPP $)	-
Gross National Income (GNI) per capita (2005 PPP $)	-
Human Development Index (HDI) (2012)	-

Population Exposure

Capital city (Montserrat)	Plymouth (abandoned)
Distance from capital city to nearest Holocene volcano	5.4 km
Total population (2011)	5,140
Number (percentage) of people living within 10 km of a Holocene volcano	4,900 (~95 %)
Number (percentage) of people living within 30 km of a Holocene volcano	5,140 (100%)
Number (percentage) of people living within 100 km of a Holocene volcano	5,140 (100%)

Infrastructure Exposure

Number of airports within 100 km of a volcano	3 (1 on Montserrat)
Number of ports within 100 km of a volcano	7 (1 on Montserrat)
Total length of roads within 100 km of a volcano (km)	-
Total length of railroads within 100 km of a volcano (km)	0

The Soufriere Hills volcano is situated to the south of central Montserrat. Being a small island, all infrastructure and population here lies within 20 km of the volcano. Indeed the 100 km radius of

Soufriere Hills extends to encompass much of Guadeloupe, St. Kitts and Nevis and Antigua and Barbuda, exposing much of the infrastructure here. The 100 km radii of the volcanoes of Guadeloupe and St. Kitts and Nevis likewise extend to encompass the island of Montserrat.

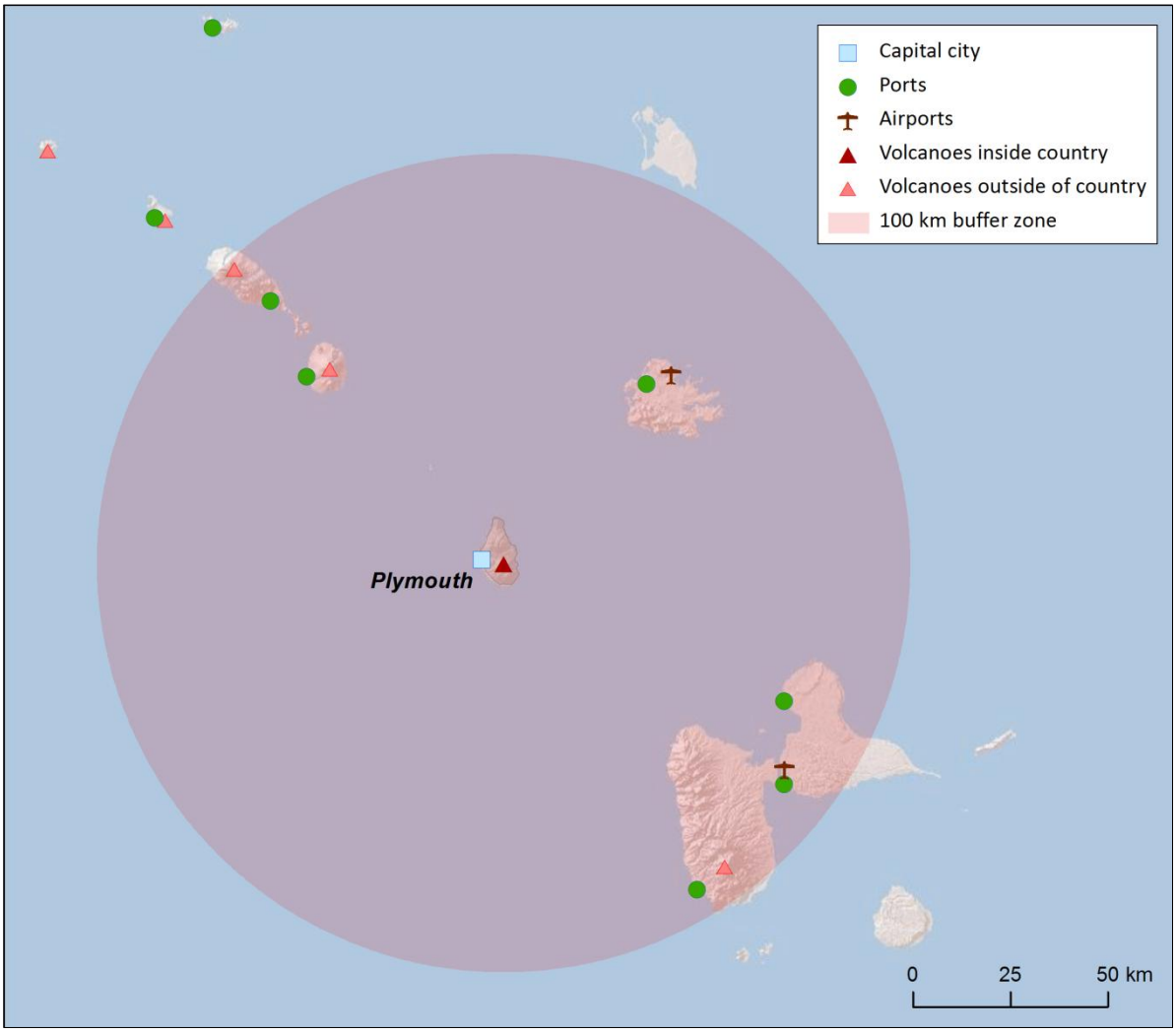

Figure 16.29 The location of Montserrat's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

With a Holocene record of five eruptions, three of which with a known size, the hazard level at Soufrière Hills volcano in Montserrat can be classified through the calculation of the VHI only when considering the recent long-duration activity as separate events. This is therefore classified at Hazard Level III with a history of VEI 3 eruptions accompanied by pyroclastic flows.

With the high Hazard Level and a moderate PEI of 4, Soufrière Hills Volcano is classed at Risk Level III.

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

*Table 16.25 Identity of Montserrat's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Soufrière Hills	4	III

Table 16.26 Classified volcanoes of Montserrat ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 1 volcano.

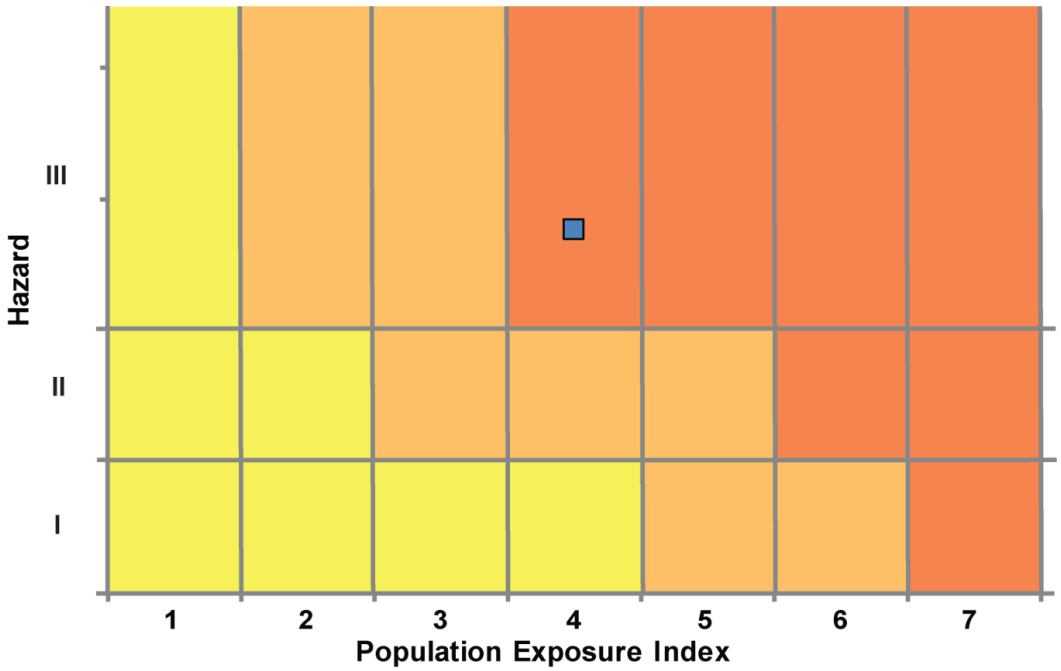

Figure 16.30 Distribution of Montserrat's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels: Risk Level I - III.

National Capacity for Coping with Volcanic Risk

The historically active Risk Level III Soufrière Hills Volcano is monitored by the Montserrat Volcano Observatory. Dedicated seismic, deformation and gas monitoring networks are in place.

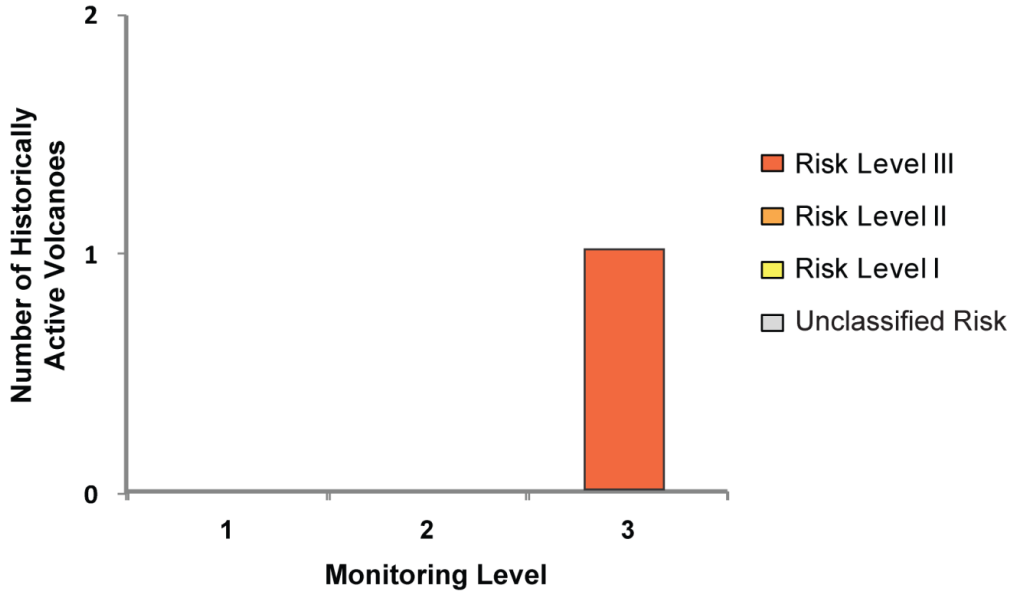

Figure 16.31 The monitoring and risk levels of the historically active volcanoes in Montserrat. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.