Appendix B – Region 14

Country and regional profiles of volcanic hazard and risk:

Mexico and Central America

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This download comprises the profiles for Region 14: Mexico and Central America 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:

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	Costa Rica	548
	El Salvador	556
	Guatemala	564
	Honduras	573
	Mexico	578
	Nicaragua	587
	Panama	594

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 14: Mexico and Central America

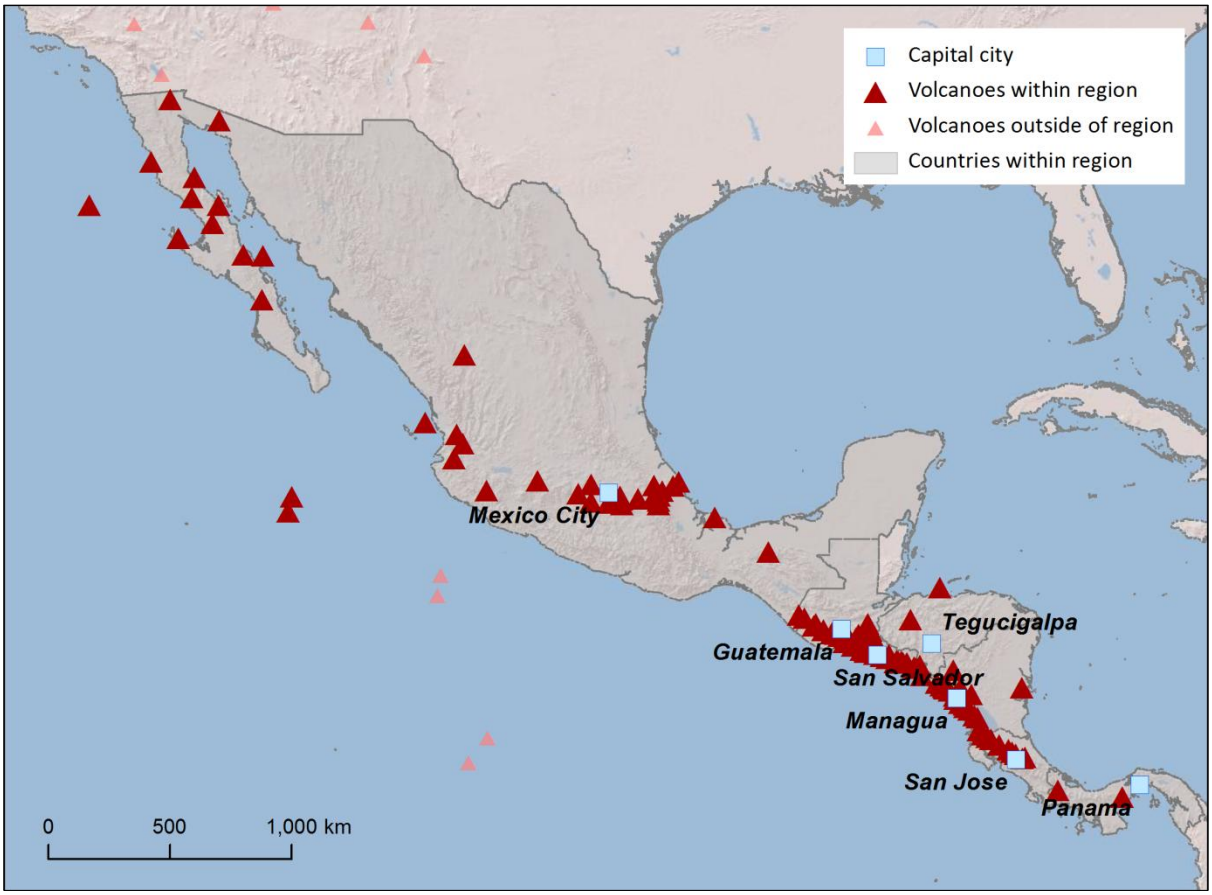

Figure 14.1 The distribution of Holocene volcanoes through the Melanesia and Australia region. The capital cities of the constituent countries are shown.

Description

Region 14: Mexico and Central America comprises volcanoes from Panama in the south to the Mexico-US border in the north. Seven countries are represented here.

Country	Number of volcanoes
Costa Rica	10
El Salvador	22
Guatemala	23
Honduras	4
Mexico	40
Nicaragua	19
Panama	2

Table 14.1 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.

There are 118 Holocene volcanoes located in Mexico and Central America with most of these volcanoes located in Mexico. Volcanism here is largely related to the subduction of the Cocos Plate beneath the Caribbean and North American Plates.

A range of volcano types are present in this region, though most (about 60%) are stratovolcanoes. The rock type through this region is dominantly andesitic, but ranges from basaltic to rhyolitic.

A range of activity styles and eruption sizes are recorded through the Holocene, with eruptions of VEI 0 to 6. About 73% of eruptions have been small, at VEI 0 – 2, however about 11% (70) of eruptions have been large explosive VEI ≥4 events. The only countries in this region with no Holocene record of producing such eruptions are Honduras and Panama, though pyroclastic flows are recorded in Panama. The largest Holocene eruption in this region was the VEI 6 Terra Blanca Joven (TBJ) eruption of Ilopango in El Salvdor in about 450 AD. This eruption produced widespread pyroclastic flows and devastated Mayan cities. The capital of El Salvador lies within 20 km of this volcano.

Thirty-seven volcanoes have historical records of 578 eruptions, 98% of which were recorded through direct observations. Just 203 eruptions were recorded before 1500 AD. 12% of historical events produced pyroclastic flows, and 7% generated lahars. 23% of eruptions produced lava flows.

Lives were lost in 4% of historical eruptions, accounting for over 40,000 fatalities. This region has a high population, with most volcanoes (64%) having high proximal populations and as such many are considered relatively high risk. However the hazard (VHI) is poorly constrained at many volcanoes here so about 80% of volcanoes are unclassified in hazard and risk.

Thirty-one of thirty-seven historically active volcanoes in this region are monitored using at least one dedicated seismometer, with active monitoring groups in many of this region's countries.

Volcano Facts

Number of Holocene volcanoes	118
Number of Pleistocene volcanoes with M≥4 eruptions	39
Number of volcanoes generating pyroclastic flows	35 (171 eruptions)
Number of volcanoes generating lahars	22 (52 eruptions)
Number of volcanoes generating lava flows	31 (162 eruptions)
Number of eruptions with fatalities	26
Number of fatalities attributed to eruptions	46,317
Largest recorded Pleistocene eruption	The largest eruption in this region during the Quaternary is recorded at 84 ka with the M7.8 eruption of Los Chocoyos Ash (H) from Atitlán in Guatemala.

Largest recorded Holocene eruption	The largest recorded Holocene eruption in this region is the 1500 BP M6.7 TBJ eruption of Ilopango.
Number of Holocene eruptions	781 confirmed Holocene eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	37
Number of historical eruptions	578

Number of volcanoes	Primary volcano type	Dominant rock type
6	Caldera(s)	Basaltic (1), Dacitic (3), Rhyolitic (2)
68	Large cone(s)	Andesitic (44), Basaltic (18), Dacitic (5), Unknown (1)
4	Lava dome(s)	Andesitic (1), Dacitic (2), Rhyolitic (1)
8	Shield(s)	Andesitic (3), Basaltic (4), Trachytic / Andesitic (1)
33	Small cone(s)	Andesitic (7), Basaltic (20), Dacitic (1), Rhyolitic (2), Trachytic / Andesitic (1), Unknown (2)
1	Submarine	Unknown (1)

Table 14.2 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)	50

Table 14.3 Average recurrence interval (years between eruptions) for small and large eruptions in Mexico and Central America.

The eruption record indicates that on average small to moderate sized eruptions of VEI <4 occur in this region with an average recurrence interval (ARI) of about a year, whilst the ARI for large eruptions is longer, at about 50 years.

Eruption Size

Eruptions are recorded through Mexico and Central America of VEI 0 to 6, representing a range of eruption styles from gentle effusive events to large explosive eruptions. VEI 2 events dominate the record, with about 50% of all Holocene eruptions classed as such. Nearly 11% of eruptions here are explosive at VEI ≥4.

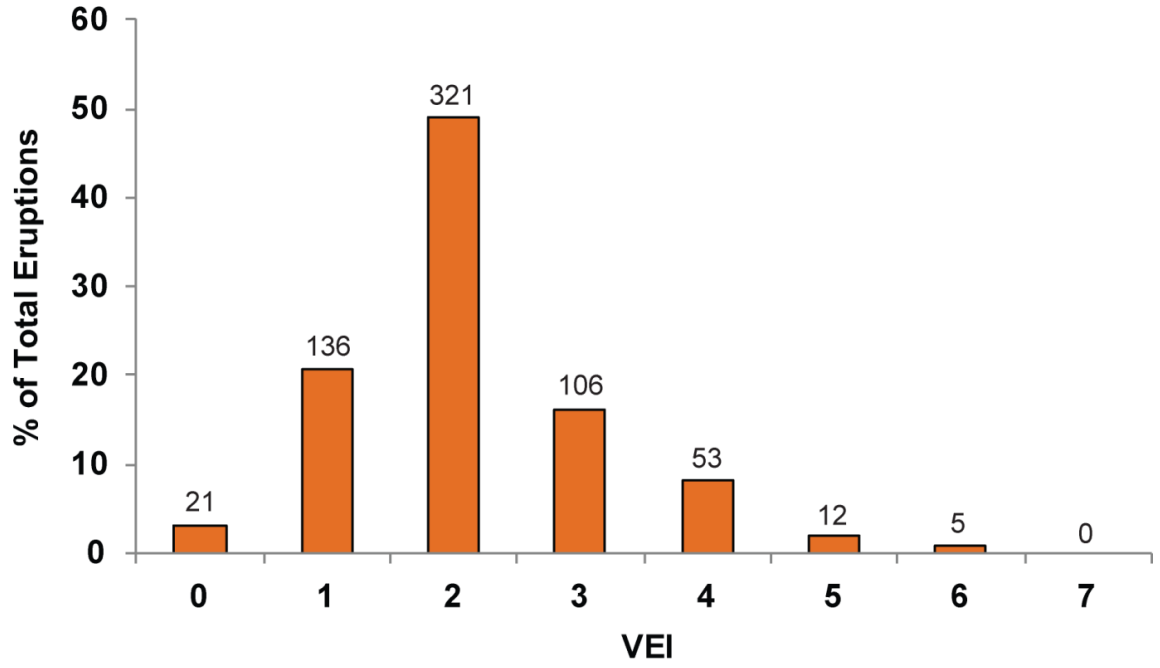

Figure 14.2 Percentage of eruptions in this region recorded at each VEI level; the number of eruptions is also shown. The percentage is of total eruptions with recorded VEI. A further 127 eruptions were recorded with unknown VEI.

Socio-Economic Facts

Total population (2011)	155,467,352
Gross Domestic Product (GDP) per capita (2005 PPP $)	2,579 – 13,766 (Mean 7,686)
Gross National Income (GNI) per capita (2005 PPP $)	2,551 – 13,519 (Mean 7,649)
Human Development Index (HDI) (2012)	0.581 – 0.78 (Medium to High, Mean 0.689 Medium)

Population Exposure

Number (percentage) of people living within 10 km of a Holocene volcano	5,647,382 (3.63 %)
Number (percentage) of people living within 30 km of a Holocene volcano	36,638,320 (23.57 %)
Number (percentage) of people living within 100 km of a Holocene volcano	96,977,702 (62.38 %)

Infrastructure Exposure

Number of airports within 100 km of a volcano	29
Number of ports within 100 km of a volcano	43
Total length of roads within 100 km of a volcano (km)	34,152
Total length of railroads within 100 km of a volcano (km)	2,308

CLASSIFIED	**Hazard III**				Colima	Orizaba, Pico de; Fuego; Irazú; Turrialba	Santa María; Pacaya; Apoyeque	
	Hazard II			Rincón de la Vieja	San Cristóbal; Momotombo	Popocatépetl; Santa Ana; Telica; Concepción	Atitlán	Chichinautzin; Masaya
	Hazard I				Negro, Cerro; Arenal	San Miguel; Poás	Izalco	
UNCLASSIFIED	**U – HHR**	**Bárcena**; **Socorro**		**Cosigüina**	San Martín; **Chichón, El**; Conchagüita; **Pilas, Las**; **Miravalles**; Barú	Ceboruco; **Tacaná**	**Acatenango**	**Michoacán-Guanajuato**; Almolonga; **San Salvador;** Ilopango
	U- HR				Cumbres, Las	Malinche, La; Cofre de Perote; Tecuamburro; Barva	Zitácuaro-Valle de Bravo; Jocotitlán; Toluca, Nevado de; Naolinco Volcanic Field	**Nejapa-Miraflores**
	U-NHHR	Guadalupe; Isabel, Isla	Pinacate; San Luis, Isla; Jaraguay Volcanic Field; Coronado; San Borja Volcanic Field; Unnamed; Tres Vírgenes; Tortuga, Isla; Comondú-La Purísima	Utila Island; Maderas; Azul, Volcán; Orosí	San Quintín Volcanic Field; Sangangüey; Mascota Volcanic Field; Atlixcos, Los; Tigre, Isla el; Zacate Grande, Isla; Zapatera; Ciguatepe, Cerro el; Lajas, Las; Tenorio; Valle, El	Prieto, Cerro; Iztaccíhuatl; Humeros, Los; Moyuta; Tahual; Suchitán; Ipala; Quezaltepeque; Cinotepeque, Cerro; Taburete; Conchagua; **Rota**; **Mombacho**; **Platanar**	Papayo; Serdán-Oriental; Gloria, La; Tajumulco; Tolimán; Agua; Cuilapa-Barbarena; Jumaytepeque; Flores; Santiago, Cerro; Ixtepeque; Chiquimula Volcanic Field; San Diego; Singüil, Cerro; **Apaneca Range**; Guazapa; San Vicente; **Tecapa**; Usulután; Tigre, El; Chinameca; Aramuaca, Laguna; Yojoa, Lake; Granada; Estelí	Durango Volcanic Field; Chingo; Coatepeque Caldera; Apastepeque Field
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 14.4 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
11	7
35	6
30	5
23	4
6	3
9	2
4	1

Table 14.5 The number of volcanoes in Mexico and Central America classed in each PEI category.

Risk Levels

Number of Volcanoes	Risk Level
11	III
10	II
2	I
95	Unclassified

Table 14.6 The number of volcanoes in the Mexico and Central America region classified at each Risk Level.

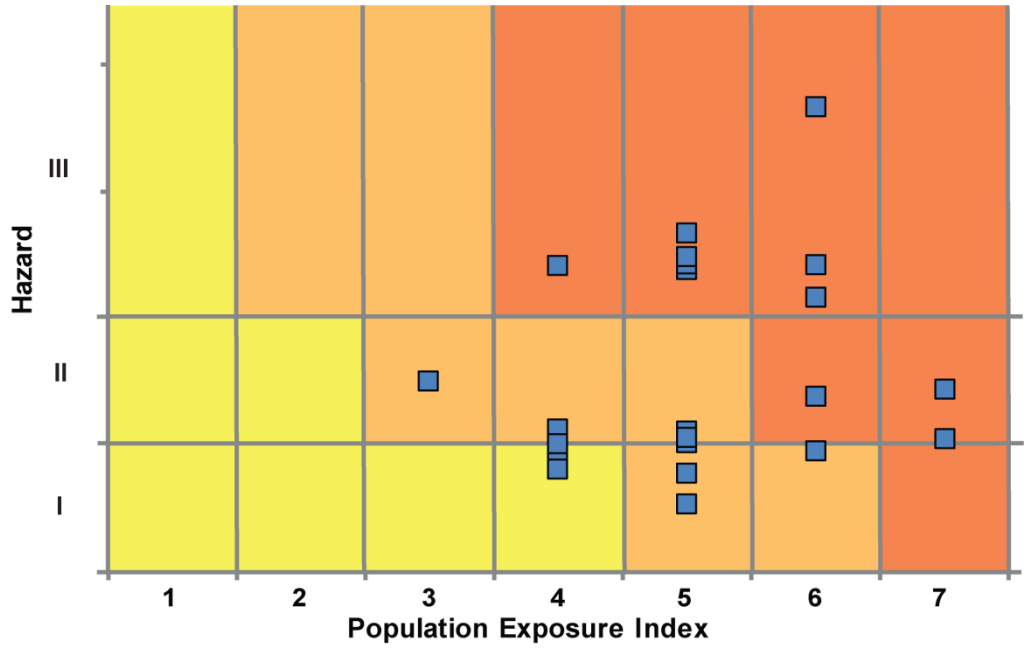

Figure 14.3 Distribution of the classified volcanoes of this region across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

Regional monitoring capacity

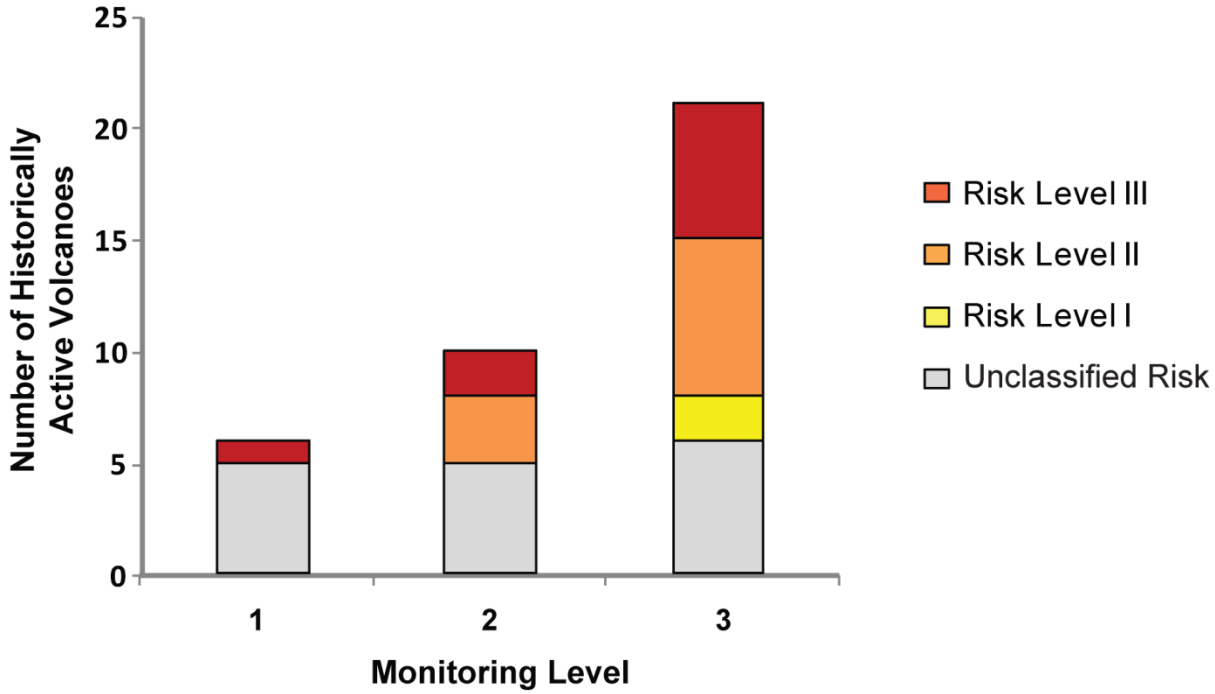

Figure 14.4 The monitoring and risk levels of the historically active volcanoes in Mexico and Central America. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Costa Rica

Description

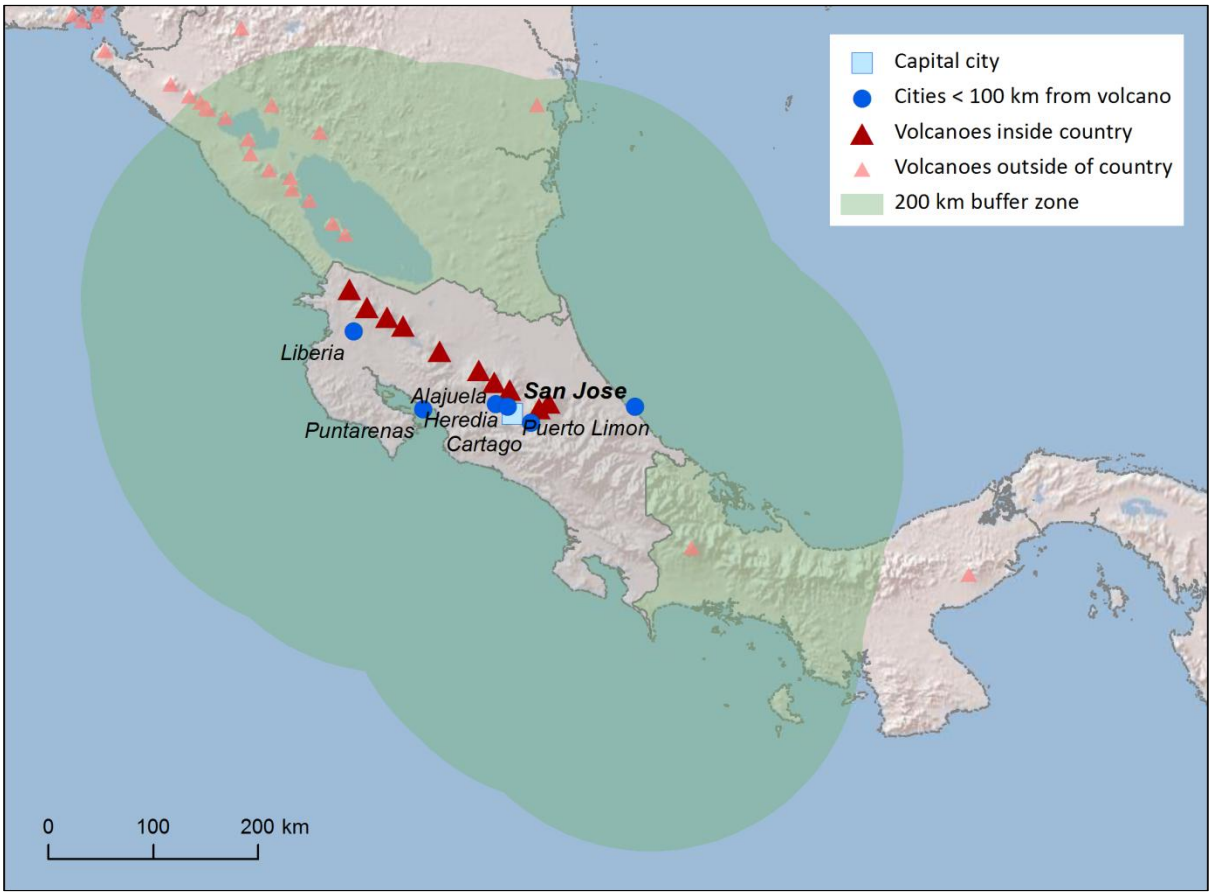

Figure 14.5 Location of Costa Rica's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Costa Rica.

Ten Holocene volcanoes are located in northern Costa Rica. Volcanism here is the result of the subduction of the Cocos Plate beneath the Caribbean Plate, forming a chain of andesitic stratovolcanoes and complex volcanoes about 60 km inland, stretching from central Costa Rica to the border with Nicaragua.

VOTW4.22 records 151 confirmed eruptions during the Holocene from eight volcanoes until 2013. The remaining two volcanoes have suspected activity of Holocene age. Most eruptions were recorded historically: 103 eruptions are recorded since 1500 AD at seven volcanoes. These historical eruptions are listed at VEI 0 to 3, indicating moderate explosive activity. Twenty-two VEI 4 eruptions have been recorded during the Holocene, and larger events exist in the Pleistocene record. Pyroclastic flows and lahars are recorded in 10 and 12 historical eruptions, respectively. Lahars are a frequent feature in volcanism in the tropics due to rainfall, and secondary lahars can continue for years after the eruption.

The distribution of volcanoes throughout Costa Rica and neighbouring Panama and Nicaragua means that almost the entirety of the country and population lie within 100 km of one or more Holocene volcanoes.

The assessment of Hazard at the Holocene volcanoes of Costa Rica is associated with large uncertainties. However, almost all of the historically active volcanoes here are more fully understood and so have better constrained, and high, hazard levels. With moderate to large proximal populations at Costa Rican volcanoes the volcanic risk must be considered.

Irazú is one of Costa Rica's most active volcanoes, with frequent historical (post-1500 AD) explosive eruptions documented. An eruption in 1963 – 1965, one of Irazú's largest at VEI 3, caused ash fall that led to significant disruption of San José and surrounding areas. Indeed, it was estimated that 49% of Costa Rica's population was affected by ash fall from this eruption (GCROP, 1964 in Aguilar & Alvarado, 2014). Five major explosive eruptions have occurred at Turrialba during the past 3,500 years, and Turriable has had six eruptions between 2010 and March 2015.

In terms of fatalities, the most destructive eruption in Costa Rica's history is that of Arenal in July 1968. Situated towards the middle of Costa Rica's southeast to northwest trending line of volcanoes and roughly 70 km from the border with Nicaragua, Arenal is one of Costa Rica's most active volcanoes. The 1968 eruption initiated persistent activity which continued until 2010; 78 people were killed in the first three days, mostly by pyroclastic flows but also by ballistic bombs (Alvarado et al., 2006). The village of Tabacon, 3.5 km northwest of the volcano, was almost totally obliterated. Other destructive eruptions include the 1963 – 1965 eruption of Irazú, which led to approximately twenty fatalities (Aguiler & Alvarado, 2014).

The Observatorio Sismológico y Vulcanológico Arenal-Miravalled (OSIVAM), part of the Costa Rican Institute of Electricity (ICE), is responsible for the monitoring of Costa Rica's volcanoes. They maintain networks of seismometers at all historically active volcanoes, and have additional dedicated ground-based monitoring at three of the volcanoes.

OSIVAM, the Red Sismológica Nacional (RSN: UCR-ICE) have a Volcano Alert Level system, comprising seven levels over three colour-codes. Green, phases 1 to 3, are used for dormant volcanoes and those with active fumaroles and seismicity to minor eruptive activity limited to the vicinity of the crater. Yellow, phases 1 to 2 are used for increases in the volcanic activity, where seismic data exceeds baseline activity and magmatic movements are suspected, with phreatic eruptions and indications that a magmatic eruption will occur within a week. Red, phases 1 to 2, indicate magmatic eruptions, with chance of increased hazard affecting the local region and beyond. OSIVAM, RSN and OVSICORI (El Observatorio Vulcanológico y Sismológico de Costa Rica) release bulletins and reports describing activity, and all are available to the public.

The research and monitoring OSIVAM conduct help to understand activity in Costa Rica, to generate hazard maps and to present information for decision making purposes to the National Emergency Commission.

See also:

Observatorio Sismologico y Vulcanologico Arenal-Miravalles (OSIVAM) website: www.rsn.ucr.ac.cr/index.php/es/vulcanologia/informacion-general

Aguilar, I. & Alvarado, G.E. (2014) Human and economic losses caused by the volcanism in Costa Rica from 1953 to 2005. *Revista Geológica de América Central*, 51: 93-128.

Alvarado-Induni, G.E. (2005) *Costa Rica: Land of Volcanoes*. EUNED, Costa Rica, pp.306.

Alvarado, G.E., Soto, G.J., Schmincke, H-U., Bolge, L.L. and Sumita, M. (2006) The 1968 andesitic lateral blast eruption at Arenal volcano, Costa Rica. Journal of Volcanology and Geothermal Research, 157, 9 - 33.

Molina, F., Marti, J., Aguirre, G., Vega, E. & Chavarria, L. (2014) Stratigraphy and structure of the Canas Dulces caldera (Costa Rica). Geological Society of America Bulletin, 126: 1465-1480.

Volcano Facts

Number of Holocene volcanoes	10*
Number of Pleistocene volcanoes with M≥4 eruptions	4
Number of volcanoes generating pyroclastic flows	6
Number of volcanoes generating lahars	4+
Number of volcanoes generating lava flows	3
Number of fatalities caused by volcanic eruptions	103 (Aguilar & Alvarado, 2014)
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M7.7 eruption of the Liberia ignimbrite from Rincón de la Vieja at about 1.43 Ma (Molina et al., 2014)
Largest recorded Holocene eruption	19 eruptions of Arenal are recorded of VEI 4 during the Holocene.
Number of Holocene eruptions	151 confirmed eruptions. 18 uncertain and 8 discredited eruptions.
Recorded Holocene VEI range	0 – 4 and Unknown
Number of historically active volcanoes	6-
Number of historic eruptions	103

*Further volcanoes may have had Holocene age activity as suggested by a young appearance of their morphology, however detailed dating has not yet been undertaken. In some cases, what are considered sub-features of volcanoes in VOTW4.0 can be described as separate volcanoes. For example Chato is considered in VOTW4.0 as a stratovolcano of Arenal.

+Further volcanoes have had lahars in the Holocene, which are not specifically recorded in VOTW.4.22.

-In VOTW4.22 Irazu, Poas, Arenal, Rincón de la Vieja, Turrialba and Miravalles have records of confirmed historical (post-1500 AD) eruptions. However, the 1946 eruption of Miravalles is described as a non-volcanic hydrothermal explosion by Alvardo-Induni (2005).

Number of volcanoes	Primary volcano type	Dominant rock type
10	Large cone(s)	Andesitic (10)

Table 14.7 The number of volcanoes in Costa Rica, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Gross Domestic Product (GDP) per capita (2005 PPP $)	10,732
Gross National Income (GNI) per capita (2005 PPP $)	10,863
Human Development Index (HDI) (2012)	0.773 (High)

Population Exposure

Capital city	San José
Distance from capital city to nearest Holocene volcano	~25 km
Total population (2011)	4,576,562
Number (percentage) of people living within 10 km of a Holocene volcano	144,235 (3.2%)
Number (percentage) of people living within 30 km of a Holocene volcano	3,424,754 (74.8%)
Number (percentage) of people living within 100 km of a Holocene volcano	4,707,288 (>100%)

Ten largest cities, as measured by population and their population size (2011, data via data.un.org):

San José	284,054
Alajuela	254,886
Desamparados	208,411
San Carlos	163,745
Cartago	147,898
Perez Zeledón	134,534
Pococí	125,962
Heredia	123,616
Goicoechea	115,084
Puntarenas	115,019

Infrastructure Exposure

Number of airports within 100 km of a volcano	3
Number of ports within 100 km of a volcano	5
Total length of roads within 100 km of a volcano (km)	3,031

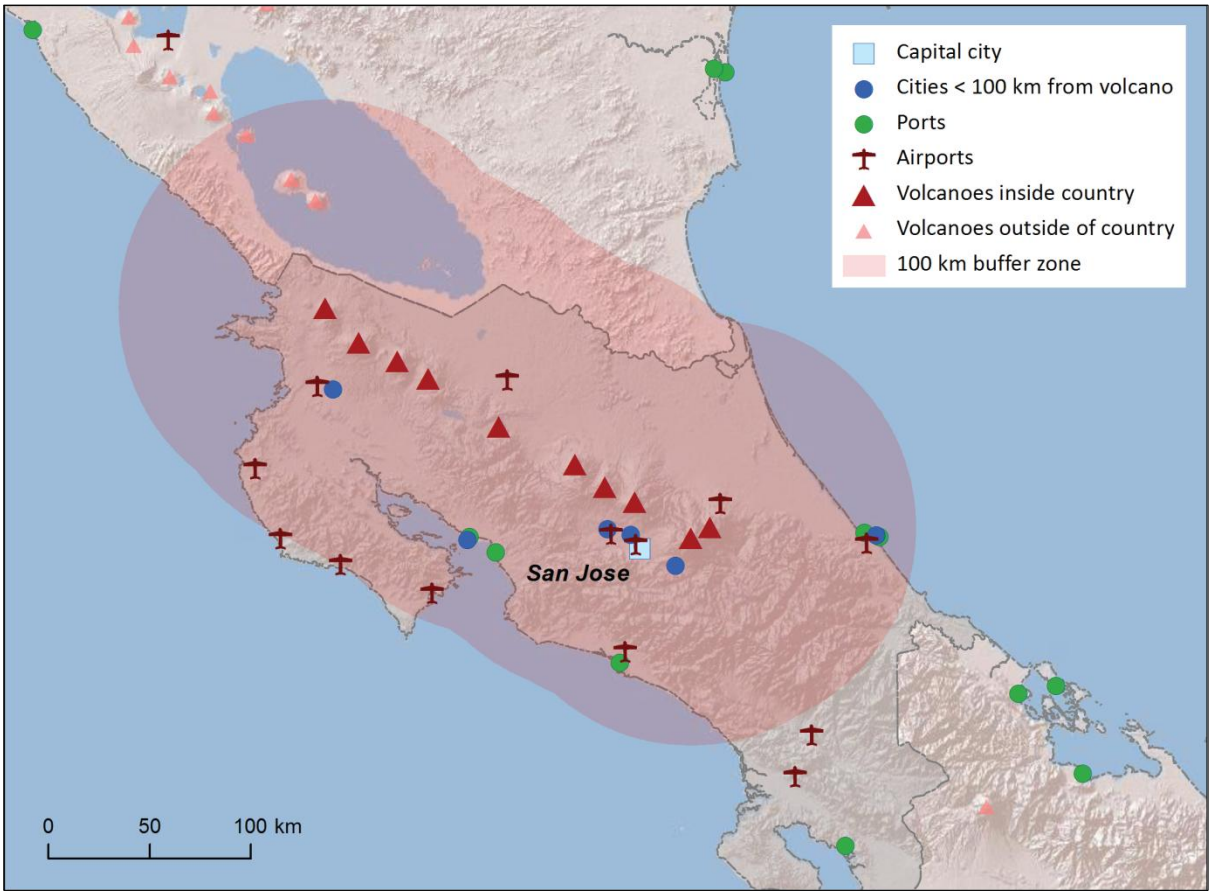

Figure 14.6 The location of Costa Rica's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

The Holocene volcanoes in Costa Rica form a chain through the centre to the north-west of the country. Being a relatively narrow country, the 100 km radii of these volcanoes forms a continuous band of exposure throughout much of the country, with only the southernmost region bordering Panama lying outside of this zone. The 100 km radii also extend beyond Costa Rica's borders and into Nicaragua, exposing a significant area here. Whilst the area around the Panama border lies outside of the radii of the Costa Rican volcanoes, it falls within the 100 km radius of Barú in Panama. Six of the largest cities in Costa Rica lie within 100 km of the country's Holocene volcanoes, including the capital, San José. San José lies within 100 km of five historically active volcanoes. Much of the critical infrastructure in the country is exposed to the volcanic hazard, including ports, airports and an extensive road network.

Hazard, Uncertainty and Exposure Assessments

The data availability in the eruption records of Costa Rica's volcanoes is varied. Half of the volcanoes here have adequate data to allow the calculation of the VHI and the determination of a hazard level. These classified volcanoes are classed at Hazard Levels I, II and III. Irazú and Turrialba both have records of VEI 3 and 4 Holocene eruptions and explosive eruptions producing pyroclastic flows, and these are therefore scored most highly at Hazard Level III.

Five volcanoes here are unclassified as calculation of the VHI would be associated with large uncertainties due to the absence of sufficient information in the record. Indeed, three volcanoes have no confirmed Holocene eruptions. Barva and Miravalles both have a Holocene record. In 1980 and 1997 a seismic swarm and felt earthquakes occurred near Platanar, which may have been related to local faults. The 1946 steam explosion at Miravalles was described as non-volcanic. In 1997 there was a seismic swarm at Miravalles, which did not correlate with local faults.

The PEI in Costa Rica ranges from moderate to high at PEI 3 to 5. Coupled with the hazard levels, this categorises the volcanoes here at Risk Levels I to III. Irazú and Turialba are classed at Risk Level III, with over 3 million people living within 100 km and a hazard classification of Level III.

CLASSIFIED	**Hazard III**					Irazú; Turrialba		
	Hazard II			Rincón de la Vieja	Arenal			
	Hazard I					Poás		
UNCLASSIFIED	**U – HHR**				**Miravalles**			
	U- HR					Barva		
	U- NHHR			Orosí	Tenorio	**Platanar**		
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 14.8 Identity of Costa Rica's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Irazú	5	III
Turrialba	5	III
Poás	5	II
Arenal	4	II
Rincón de la Vieja	3	II

Table 14.9 Classified volcanoes of Costa Rica ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 3 volcanoes; Risk Level III – 2 volcanoes.

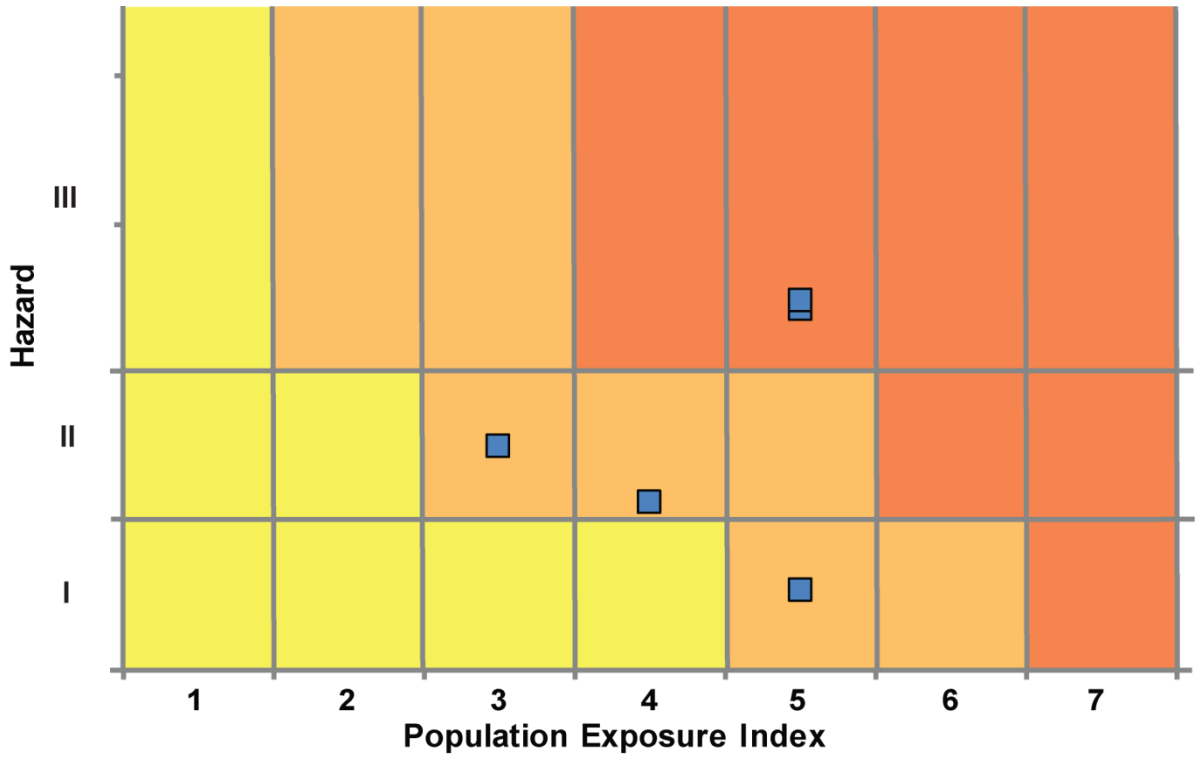

Figure 14.7 Distribution of Costa Rica's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Six volcanoes are recorded as having historical activity in Costa Rica. The Observatorio Sismológico y Vulcanológico Arenal-Miravalled (OSIVAM), part of the Red Sismológica Nacional and OVSICORI, is responsible for seismological and volcanological monitoring in northern Costa Rica. All historically active volcanoes have dedicated ground-based monitoring systems in place, all with seismic networks, and additional deformation and gas monitoring used at Arenal and Poás (Risk II), and Miravalles (Risk unclassified). The two Risk Level III volcanoes, Irazú and Turrialba, have regular visits by the observatory staff for further monitoring.

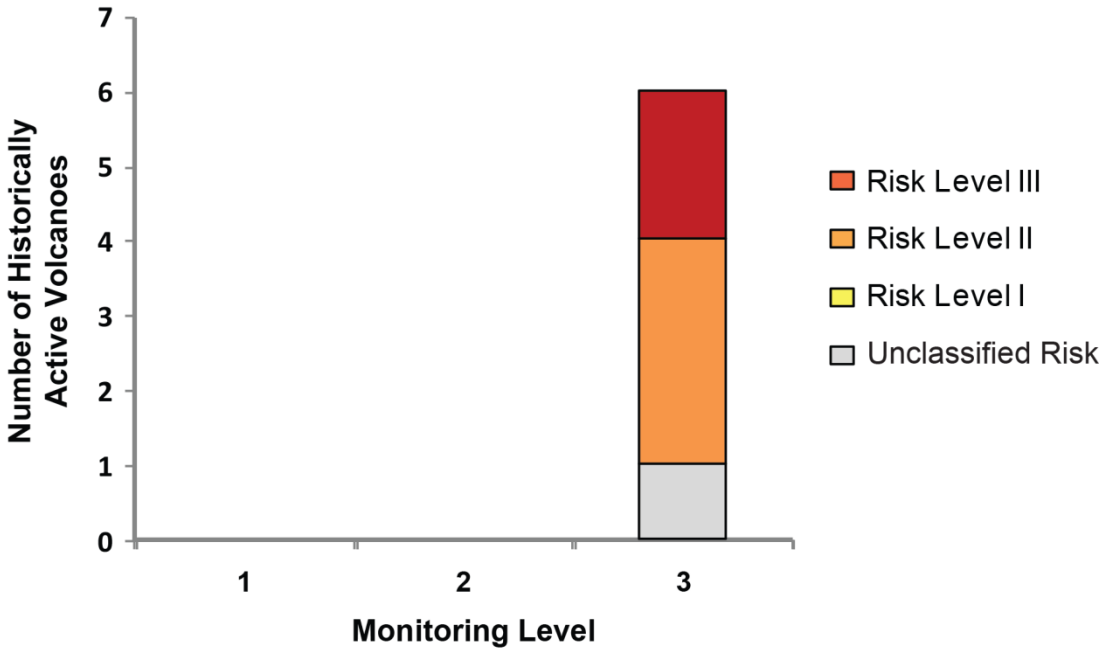

Figure 14.8 The monitoring and risk levels of the historically active volcanoes in Costa Rica. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

El Salvador

Description

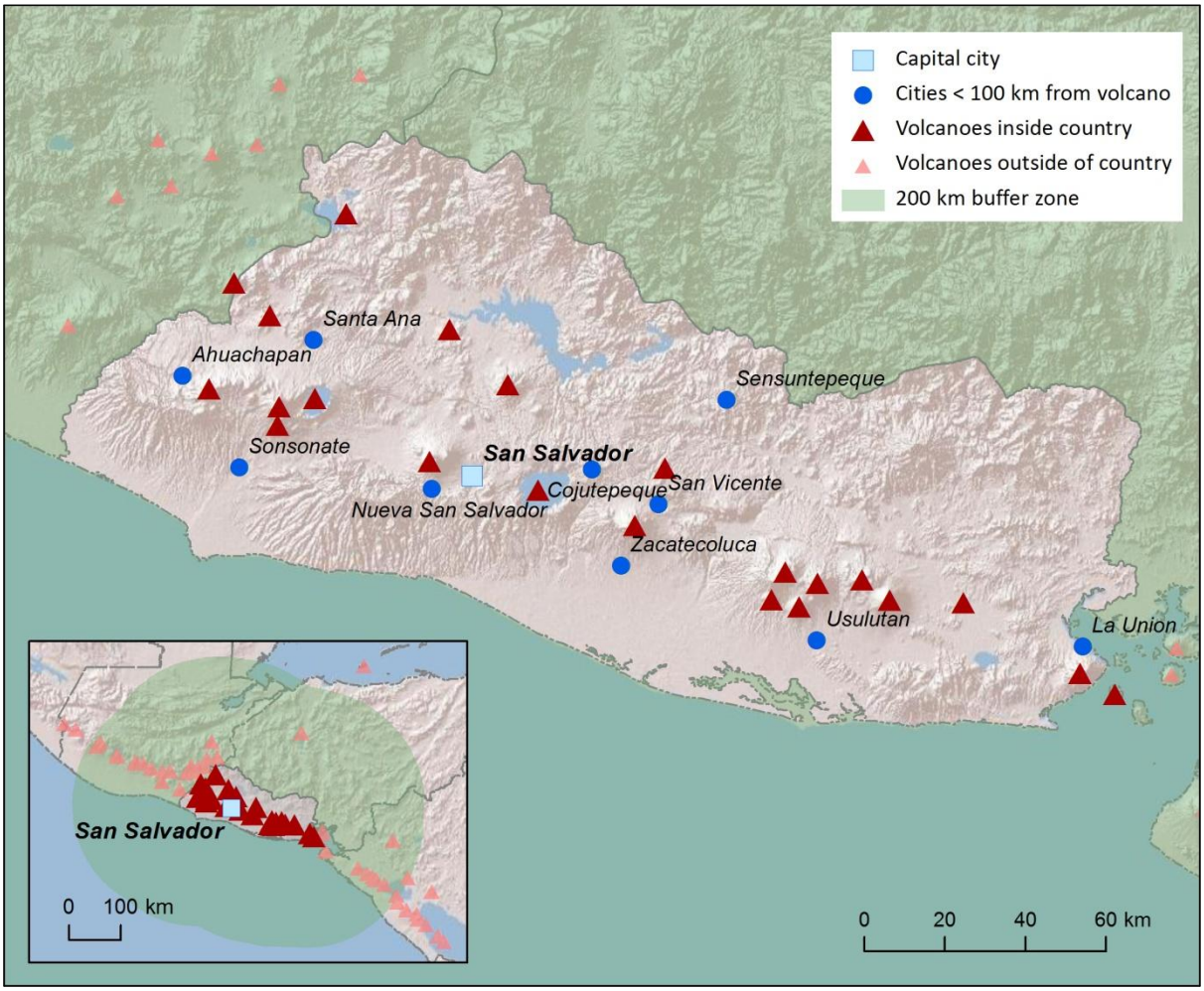

Figure 14.9 Location of El Salvador's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect El Salvador.

Twenty-two Holocene volcanoes are located throughout El Salvador, in a chain parallel to the coastline stretching from Guatemala in the north to the Gulf of Fonseca between El Salvador, Honduras and Nicaragua. Volcanism here is related to the subduction of the Cocos Plate beneath the Caribbean Plate.

The volcanoes of El Salvador are dominantly basaltic and andesitic stratovolcanoes, but there are also volcanic fields and more felsic calderas.

Six volcanoes have produced 102 eruptions during the Holocene, with the remaining volcanoes suspected of having activity of Holocene age. Eruptions have ranged in size from small VEI 0 events to large explosive VEI 6 events. Of these 102 eruptions, only three are recorded before 1500 AD, indicating that the eruption record is poorly known before historical times. All historical eruptions were small to moderate at VEI 0 – 3.

The assessment of hazard at most of the volcanoes of El Salvador is complicated by poorly constrained eruptive histories, with hazard scores assigned here with large associated uncertainties. Further work is required to more fully understand the age and size of El Salvador's eruptions.

The distribution of the volcanoes through El Salvador means that the entirety of the country falls within 100 km of one or more Holocene volcano, thus all infrastructure and the total population fall in this zone. The capital, San Salvador, lies within 20 km of two historically active volcanoes – Ilopango and San Salvador, both of which have produced VEI 3 eruptions during historic times and VEI 4 - 6 eruptions pre-1500 AD. The most frequently active volcano in El Salvador, Izalco, lies within 50 km of the capital. Major et al. (2004) suggest that even short (>4 km) debris flows or lahars at San Salvador, San Vicente and San Miguel volcanoes could "put hundreds to thousands of lives, property and infrastructure at risk", with areas within 10 km of volcanoes being inundated within minutes to tens of minutes.

Over twenty eruptions have resulted in property damage in El Salvador and six eruptions of Santa Ana, Izalco, San Salvador, Ilopango and Apaneca Range have resulted in the loss of about 30,000 lives. The largest loss of life resulted from the 450 AD eruption of Ilopango, which produced widespread pyroclastic flows.

The Servicio Geologico Nacional, part of the Ministerio de Medio Ambiente y Recursos Naturales, DGOA-MARN is responsible for monitoring the volcanoes of El Salvador. DGOA-MARN monitor historically active volcanoes with dedicated instrumentation networks. Continuous monitoring is undertaken to establish baseline data, which allows for anomalous behaviour to be identified. Various techniques are used, with a network of telemetered seismic stations being the principal technique. Additional geochemical, gas and hydrogeochemical, deformation and visual monitoring is also undertaken. DGOA-MARN collaborate with the Volcanological Research Group at the National University of El Salvador in geochemical monitoring of gases.

About 10% of personnel at DGOA-MARN have experience of responding to an eruption, which can be expected to be beneficial in future responses to eruptions. Set procedures have been developed which will be followed in the event of unrest or eruption, with an activity ladder of forewarning – warning – alert – emergency. DGOA-MARN would inform civil defence as unrest and eruption occurs. Resources are currently not available to respond to and extend monitoring to developing situations at currently unmonitored or unrecognised volcanoes. Volcanic risk could be reduced through additional resources and increase in monitoring capacity.

See also:

DGOA-MARN website: www.snet.gob.sv/ver/vulcanologia

Major, J.J., Schiling, S.P., Pullinger, C.R., and Demetrio Escobar, C. (2004) Debris-flow hazards at San Salvador, San Vicente, and San Miguel volcanoes, El Salvador. *GSA Special Papers*, v.375, 89-108.

Volcano Facts

Number of Holocene volcanoes	22, inclusive of one on the border with Guatemala
Number of Pleistocene volcanoes with M≥4 eruptions	5
Number of volcanoes generating pyroclastic flows	4
Number of volcanoes generating lahars	1 eruption of Santa Ana in 2005 resulted in lahars according to VOTW4.22. However, lahars and secondary have also occurred at San Miguel, San Salvador and San Vicente.
Number of volcanoes generating lava flows	4 - 5
Number of fatalities caused by volcanic eruptions	?30,383
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M7.1 Conacaste (CCT) eruption of Coatepeque Caldera at 51 ka.
Largest recorded Holocene eruption	The M6.7 TBJ eruption of Ilopango at 1.5 ka.
Number of Holocene eruptions	102 confirmed eruptions. 13 uncertain and 4 discredited eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	6
Number of historic eruptions	99

Number of volcanoes	Primary volcano type	Dominant rock type
2	Caldera(s)	Dacitic (1), Rhyolitic (1)
14	Large cone(s)	Andesitic (7), Basaltic (7)
5	Small cone(s)	Basaltic (2), Dacitic (1), Unknown (2)

Table 14.10 The number of volcanoes in El Salvador, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	6,309,000

Gross Domestic Product (GDP) per capita (2005 PPP $)	6,032
Gross National Income (GNI) per capita (2005 PPP $)	5,915
Human Development Index (HDI) (2012)	0.680 (Medium)

Population Exposure

Capital city	San Salvador
Distance from capital city to nearest Holocene volcano	12.3 km
Number (percentage) of people living within 10 km of a Holocene volcano	2,104,232 (34.7%)
Number (percentage) of people living within 30 km of a Holocene volcano	5,810,384 (95.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	6,309,000 (100%)

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

San Salvador	525,990
San Miguel	247,119
Santa Ana	176,661
Santa Tecla	124,694
Sonsonate	59,468
Usulutan	51,910
Cojutepeque	48,411
Zacatecoluca	39,613
San Vicente	37,326
Ahuachapan	34,102
La Union	26,807

Infrastructure Exposure

Number of airports within 100 km of a volcano	2
Number of ports within 100 km of a volcano	3
Total length of roads within 100 km of a volcano (km)	2,019
Total length of railroads within 100 km of a volcano (km)	0

The numerous Holocene volcanoes in El Salvador are distributed throughout the country. Being a relatively small country, measuring no more than about 250 km across, the country in its entirety lies within the 100 km radii of the Holocene volcanoes. All infrastructure in the country is therefore

exposed to the volcanic hazard. The capital, San Salvador, lies within 100 km of 15 Holocene volcanoes in El Salvador, including two historically active volcanoes within 20 km. The radii also extend beyond the country's border into Guatemala, Honduras and Nicaragua, and indeed volcanoes in these neighbouring countries have 100 km radii, which extend into El Salvador, including Cosiguina in Nicaragua and eleven volcanoes in Guatemala.

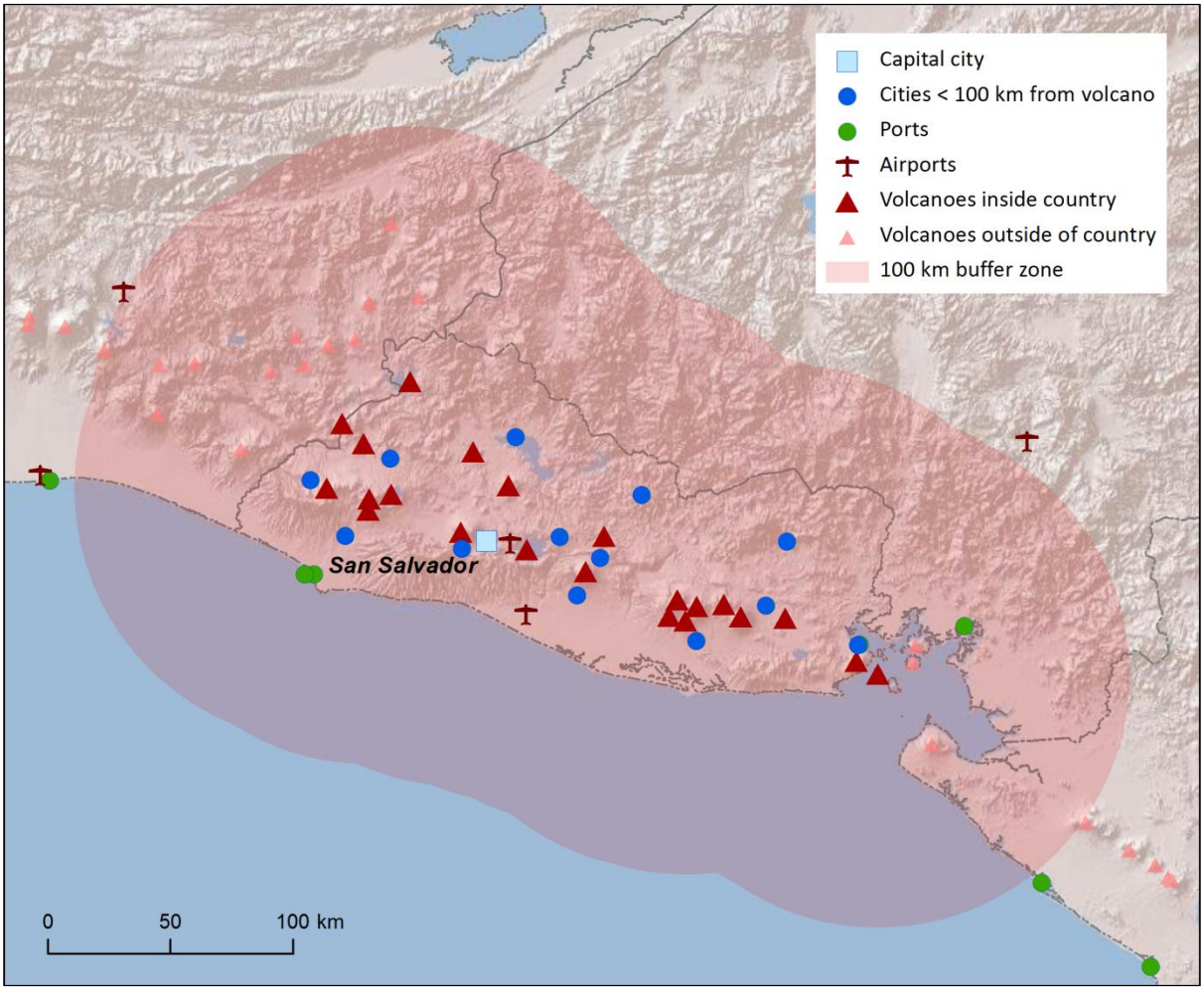

Figure 14.10 The location of El Salvador's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying amounts of information available in the eruption records of El Salvador's volcanoes. Just three volcanoes out of 22 have a detailed enough record to define hazard through the calculation of VHI, without large associated uncertainties. These three classified volcanoes are classed as Hazard Level I and II.

Of the unclassified volcanoes, 16 have no recorded confirmed Holocene eruptions. Three have historical records (post-1500 AD), including San Salvador and Ilopango which both have Holocene records of large VEI ≥4 eruptions.

The PEI ranges from moderate to very high in El Salvador with large proximal populations. The classified volcanoes Izalco, Santa Ana and San Miguel are all classed at Risk Level II, with high local populations. Although unclassified for hazard, five volcanoes (San Salvador, Ilopango, Chingo, Coatepeque Caldera and Apastepeque Field) would be classed at Risk Level III given their PEI of 7.

CLASSIFIED	**Hazard III**							
	Hazard II					Santa Ana		
	Hazard I					San Miguel	Izalco	
UNCLASSIFIED	**U – HHR**				Conchagüita			**San Salvador;** Ilopango
	U- HR							
	U-NHHR					Cinotepeque, Cerro; Taburete; Conchagua	San Diego; Singüil, Cerro; **Apaneca Range;** Guazapa; San Vicente; **Tecapa**; Usulután; Tigre, El; Chinameca; Aramuaca, Laguna	Chingo; Coatepeque Caldera; Apastepeque Field
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 14.11 Identity of El Salvador's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Izalco	6	II
Santa Ana	5	II
San Miguel	5	II

Table 14.12 Classified volcanoes of El Salvador ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 3 volcanoes; Risk Level III – 0 volcanoes.

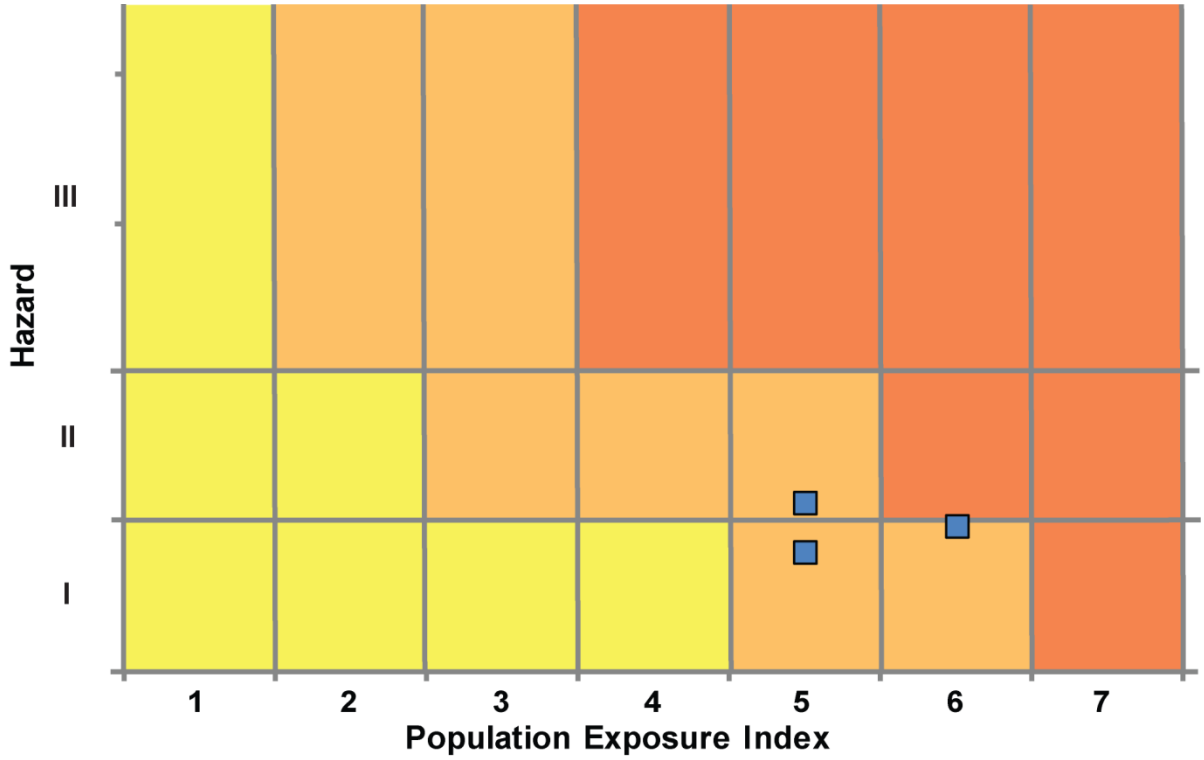

Figure 14.11 Distribution of El Salvador's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Six volcanoes have records of historical activity in El Salvador. The institution responsible for the monitoring of these volcanoes in DGOA-MARN the Servicio Geologico Nacional, part of the Ministerio de Medio Ambiente y Recursos Naturales. Seismic monitoring is undertaken at all volcanoes, with additional gas monitoring at San Miguel and San Salvador. Additional gas and deformation monitoring is undertaken at Santa Ana.

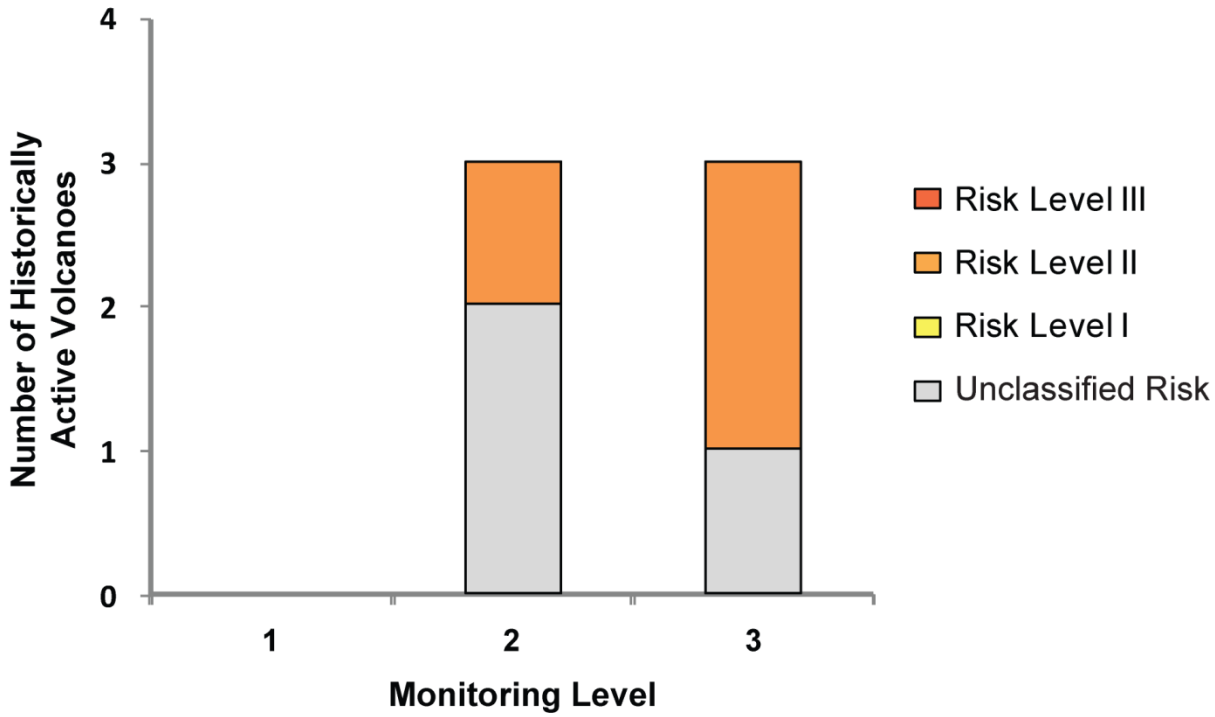

Figure 14.12 The monitoring and risk levels of the historically active volcanoes in El Salvador. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Guatemala

Description

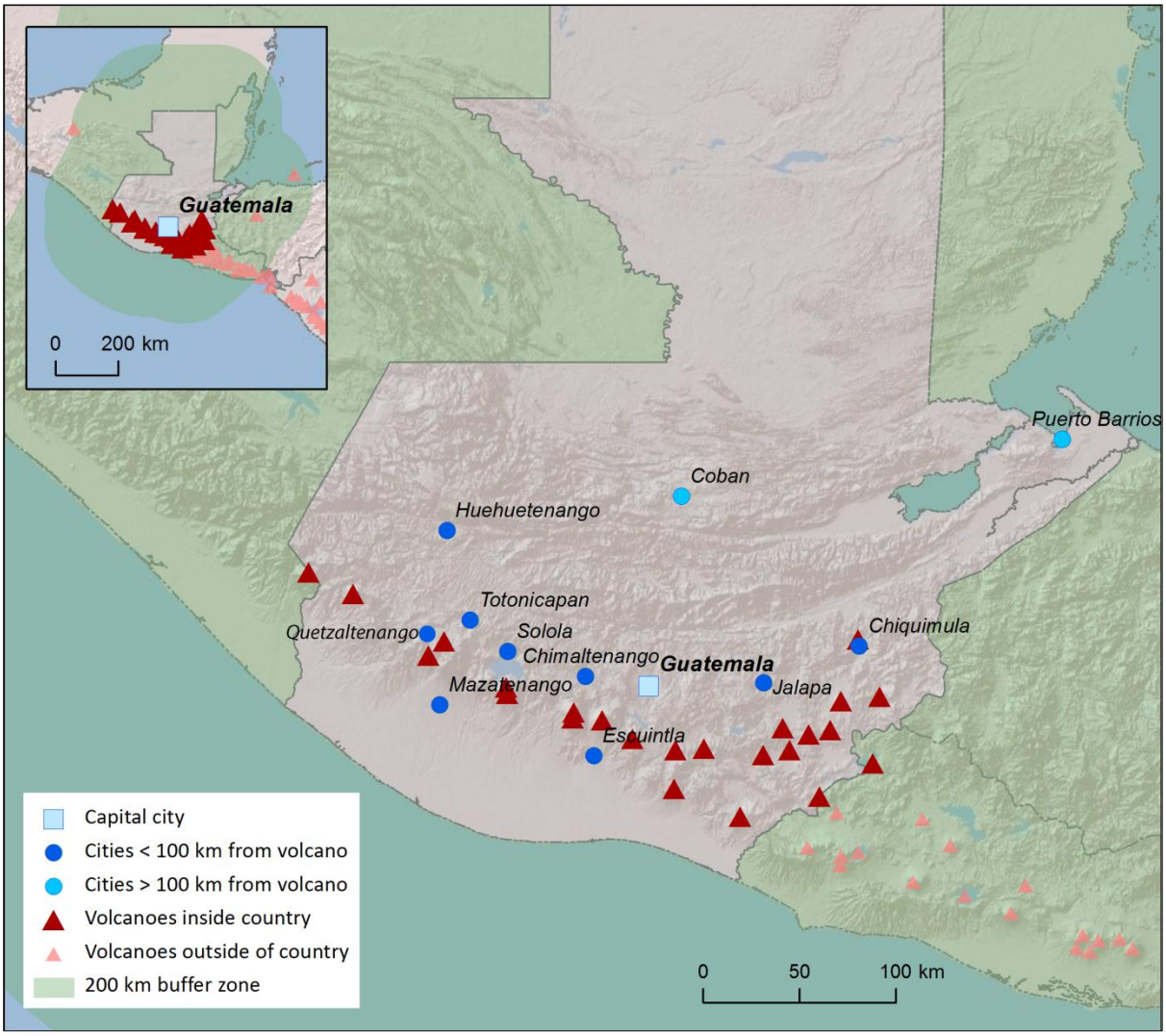

Figure 14.13 Location of Guatemala's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Guatemala.

Twenty-four Holocene volcanoes are located in Guatemala, dominantly in a chain parallel to the country's Pacific coastline stretching from El Salvador in the south to Mexico in the north. Volcanism here is due to the subduction of the Cocos Plate beneath the Caribbean Plate.

Most of the volcanoes in Guatemala (17) are stratovolcanoes most frequently of basaltic to andesitic composition. A number of volcanic fields and cinder cones are present here, dominantly situated in the south-east towards the border with El Salvador. Counting individual cones and vents, INSIVUMEH, the Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología states that 324 Quaternary volcanic vents are present throughout Guatemala from Bohnenberger (1969).

During the Holocene, 128 eruptions of VEI 1 - 6 are recorded at seven of Guatemala's volcanoes. The remaining volcanoes have suspected though unconfirmed eruptions. The Holocene VEI record indicates a range of eruption styles and sizes, from mild eruptions to large explosive events. Of these

eruptions, 104 are historical (recorded since 1500 AD) suggesting the record is poorly known before historic times. Of the seven active volcanoes, all but Tecuamburro have records of producing pyroclastic flows, but only Santa Maria, Fuego and Tacana have a Holocene record of VEI ≥4 eruptions. An eruption of Cerro Quemada at Almolonga in 1150 BP is classed at VEI 3 in VOTW4.22, but has a volume which might indicate VEI4 (caldera volume of 0.1km^3, Conway et al., 1992) and numerous VEI 3 eruptions are recorded at Pacaya. The largest Holocene eruption occurred at Santa Maria in 1902, with a VEI 6 eruption, which devastated much of south-west Guatemala and resulted in about 10,000 fatalities through ash fall and secondary disease.

Eight eruptions at Santa Maria, Fuego and Pacaya have resulted in fatalities, and numerous evacuations have been ordered with a record of many eruptions resulting in property damage. Lahars in 1541 at Agua, during a non-eruptive phase, destroyed the then capital, Ciudad Vieja. The mobilisation of old tephra deposits during intense rainfall to form lahars can occur for years after eruptions, producing a long-term hazard.

A large population resides close to the volcanoes, with 95% of Guatemala's population living within 100 km of one or more Holocene volcanoes. Three large stratovolcanoes, Acatenango, Agua, and Fuego, overlook Guatemala's former capital, Antigua Guatemala, whilst much of the population of the present capital, Guatemala City, lives within 15 to 20 km of Pacaya. About 2 million live within the Pleistocene Amatitlan caldera, just north of Pacaya. The historically active Atitlán, Fuego and Acatenango are also located within about 70 km of the capital. Though with no recorded historical eruptions, but with a catastrophic historical lahar, Agua is also located within this distance. Further, Guatemala's second city and fourth largest population centre, Quetzaltenango, is situated approximately 10 km north-northeast of Santa María, and less than 5 km from the Cerro Quemado dome complex (part of the Almolonga caldera and volcanic field (Ewert and Harpel, 2004). Guatemala's volcanoes also threaten rural communities, as all have over 100,000 residents within 30 km of their summits.

INSIVUMEH, a government funded agency, which is part of the Communications, Infrastructure and Housing Ministry, is responsible for monitoring of Guatemala's volcanoes and the provision of advice to the government regarding volcanic activity. INSIVUMEH run four Volcano Observatories: Santiaguito Observatory (OVSAN), Fuego Observatory (OVFGO I) in Panimache I and Sangre de Cristo (OVFGO II), and the Pacaya Observatory (OVPAC). Visual monitoring is undertaken and continuous seismic monitoring is in place with real-time telemetry of the data to the INSIVUMEH headquarters. The seismic equipment used to monitor volcanoes is part of the national seismic network. The resources are not available to respond to developing situations at previously unknown/inactive or un-monitored volcanoes.

A colour-coded alert scheme is used to communicate volcanic activity. INSIVUMEH communicate with the civil protection agency CONRED to recommend alert levels. These alert levels are communicated to the public via bulletins. If unrest increases at a volcano, INSIVUMEH communicate this to CONRED. Protocols are in place for increasing unrest and eruption, including the issuing of regular bulletins and communication with the Civil Aviation Authority and regional VAAC. INSIVUMEH are primarily responsible for the hazard evaluation, while CONRED and other civil authorities undertake risk assessments.

See also:

Bohnenberger, O.H. (1969) Los focus eruptivos Cuaternarios de Guatemala. Publicaciones Geologicas del ICAITI, 23-24.

Conway, F.M., Vallance, J.W., Rose, W.I., Johns, G.W. and Paniagua, S. (1992) Cerro Quemado, Guatemala: the volcanic history and hazards of an exogenous volcanic dome complex. *Journal of Volcanology and Geothermal Research*, 52:4, 303 – 308, 311-323.

Ewert, J.W. and Harpel, C.J. (2004) In Harm's Way: Population and Volcanic Risk. *Geotimes*, April 2004.

INSIVUMEH: www.insivumeh.gob.gt/

CONRED: www.conred.gob.gt/www/index.php

Volcano Facts

Number of Holocene volcanoes	24, inclusive of two on the border with El Salvador and one on the border with Mexico
Number of Pleistocene volcanoes with M≥4 eruptions	3 currently listed in LaMEVE: Fuego, Pacaya and Ayarza. There is also evidence of M≥4 eruptions at Tacaná, Santa Maria, Siete Orejas, Sabana Grande, Atitlan, Amatitlan and Tecuamburro.
Number of volcanoes generating pyroclastic flows	7
Number of volcanoes generating lahars	5*
Number of volcanoes generating lava flows	6*
Number of fatalities caused by volcanic eruptions	?>11,555
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M7.8 Los Chocoyos Ash (H) eruption of Atitlán at 84 ka.
Largest recorded Holocene eruption	The M6.3 eruption of Santa María in 1902 AD.
Number of Holocene eruptions	128 confirmed eruptions. 28 uncertain and 4 discredited eruptions.
Recorded Holocene VEI range	1 – 6 and unknown

Number of historically active volcanoes	7
Number of historic eruptions	104

*The number of volcanoes with Holocene age lahars and lava flows recorded in VOTW4.22 is thought to be an underestimate, with most Guatemala volcanoes suspected of producing lavas and lahars due to intense rainfall outside of eruptive activity.

Number of volcanoes	Primary volcano type	Dominant rock type
17	Large cone(s)	Andesitic (9), Basaltic (5), Dacitic (3)
1	Lava dome(s)	Rhyolitic (1)
6	Small cone(s)	Basaltic (6)

Table 14.13 The number of volcanoes in Guatemala, their volcano type classification and dominant rock type according to VOTW4.0.

The volcano types described here are the classifications in VOTW4.0. Lava domes are present at several volcanoes. For example Almolonga is listed as a stratovolcano, however much of the Holocene volcanism has been dominated by dome formation and destruction. The same applies to Santa Maria, which is listed as a stratovolcano, but has been dominated by dome forming activity for about a century and it is this lava dome activity which is the main cause of hazard.

Socio-Economic Facts

Total population (2012)	15,135,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	4,351
Gross National Income (GNI) per capita (2005 PPP $)	4,325
Human Development Index (HDI) (2012)	0.581 (Medium)

Population Exposure

Capital city	Guatemala City
Distance from capital city to nearest Holocene volcano	29.0 km*
Total population (2011)	13,824,463
Number (percentage) of people living within 10 km of a Holocene volcano	1,423,044 (10.3%)
Number (percentage) of people living within 30 km of a Holocene volcano	7,922,171 (57.3%)
Number (percentage) of people living within 100 km of a Holocene volcano	13,081,892 (94.6%)

*Villa Nueva and southern parts of Guatemala City lie within 15 to 20 km of the nearest volcano, Pacaya.

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

Guatemala City	1,022,001 (UNDP data, 2001)
Mixco	452,134 (UNDP data, 2001)
Villa Nueva	390,329 (UNDP data, 2001)
Quetzaltenango	152,223 (UNDP data, 2001)
Escuintla	114,626 (UNDP data, 2001)
Chimaltenango	82,370
Huehuetenango	79,426
Totonicapan	69,734
Puerto Barrios	56,605
Coban	53,375

Infrastructure Exposure

Number of airports within 100 km of a volcano	4
Number of ports within 100 km of a volcano	1
Total length of roads within 100 km of a volcano (km)	2,921
Total length of railroads within 100 km of a volcano (km)	0

The numerous volcanoes in Guatemala are distributed through the south of the country, from the border with El Salvador to that with Mexico. With so many volcanoes in a relatively narrow stretch of land, the 100 km radii extends to encompass much of southern Guatemala, and also extend into El Salvador, Mexico and Honduras exposing infrastructure here. The 100 km radii of about 10 volcanoes in El Salvador also extend into Guatemala. Many of Guatemala's largest cities are located in the south of the country, and hence fall within 100 km of the Holocene volcanoes. Indeed eight of the most populous cities lie here in addition to the capital, Guatemala City. Much of the critical infrastructure in the country is therefore exposed to the volcanic hazard, including airports, ports and an extensive road network. Guatemala City lies within 70 km of several historically active volcanoes, including Atitlan, Acatenango, Fuego, Agua and Pacaya.

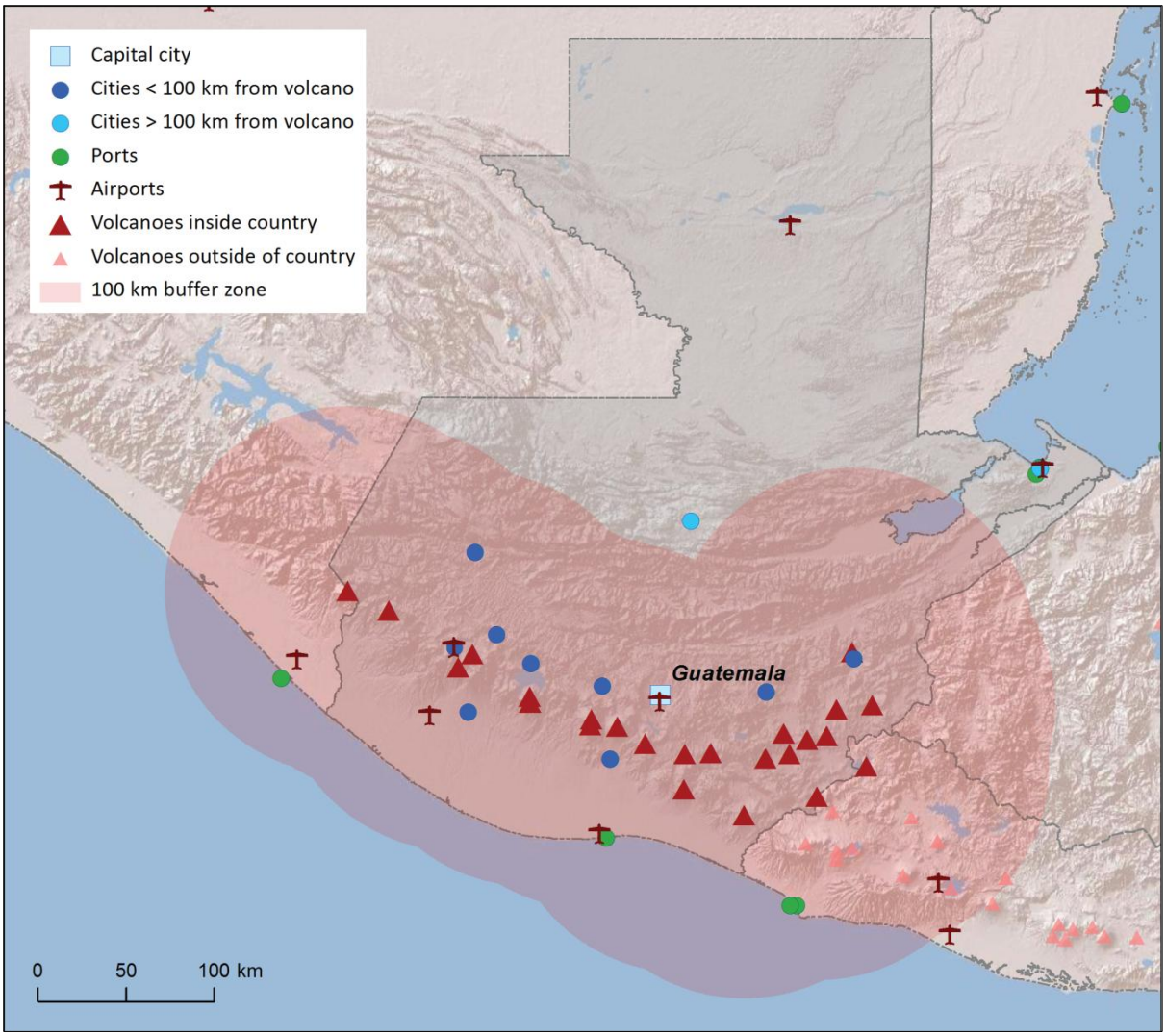

Figure 14.14 The location of Guatemala's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of Guatemala's volcanoes. Just four volcanoes out of 24 have sufficient detail to define the hazard through the calculation of the VHI. Three of these, Fuego, Santa Maria and Pacaya are classified at Hazard Level III, with records of explosive activity and pyroclastic flows and Holocene records of VEI ≥3 eruptions. Atitlan is classified as Hazard Level II, with a smaller percentage of eruptions with pyroclastic flows. All four of these volcanoes have high proximal populations, and PEIs of 5 and 6. These are therefore classified at Risk Level III.

Of the unclassified volcanoes, 16 have no recorded confirmed Holocene eruptions. Four have Holocene records, including historical events at Tacana, Almolonga and Acatenango. Eruptions since 1900 AD are recorded at the latter. With no classification of hazard, the risk levels cannot be

determined, however these all have large local populations, with PEIs of 5 – 7, suggesting risk levels of II to III.

CLASSIFIED	**Hazard III**					Fuego	Santa María; Pacaya	
	Hazard II						Atitlán	
	Hazard I							
UNCLASSIFIED	**U – HHR**					Tacaná	**Acatenango**	Almolonga
	U- HR					Tecuamburro		
	U-NHHR					Moyuta; Tahual; Suchitán; Ipala; Quezaltepeque	Tajumulco; Tolimán; Agua; Cuilapa-Barbarena; Jumaytepeque; Flores; Santiago, Cerro; Ixtepeque; Chiquimula Volcanic Field; San Diego	Chingo
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 14.14 Identity of Guatemala's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Pacaya	6	III
Santa María	6	III
Atitlán	6	III
Fuego	5	III

Table 14.15 Classified volcanoes of Guatemala ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 0 volcanoes; Risk Level III – 4 volcanoes.

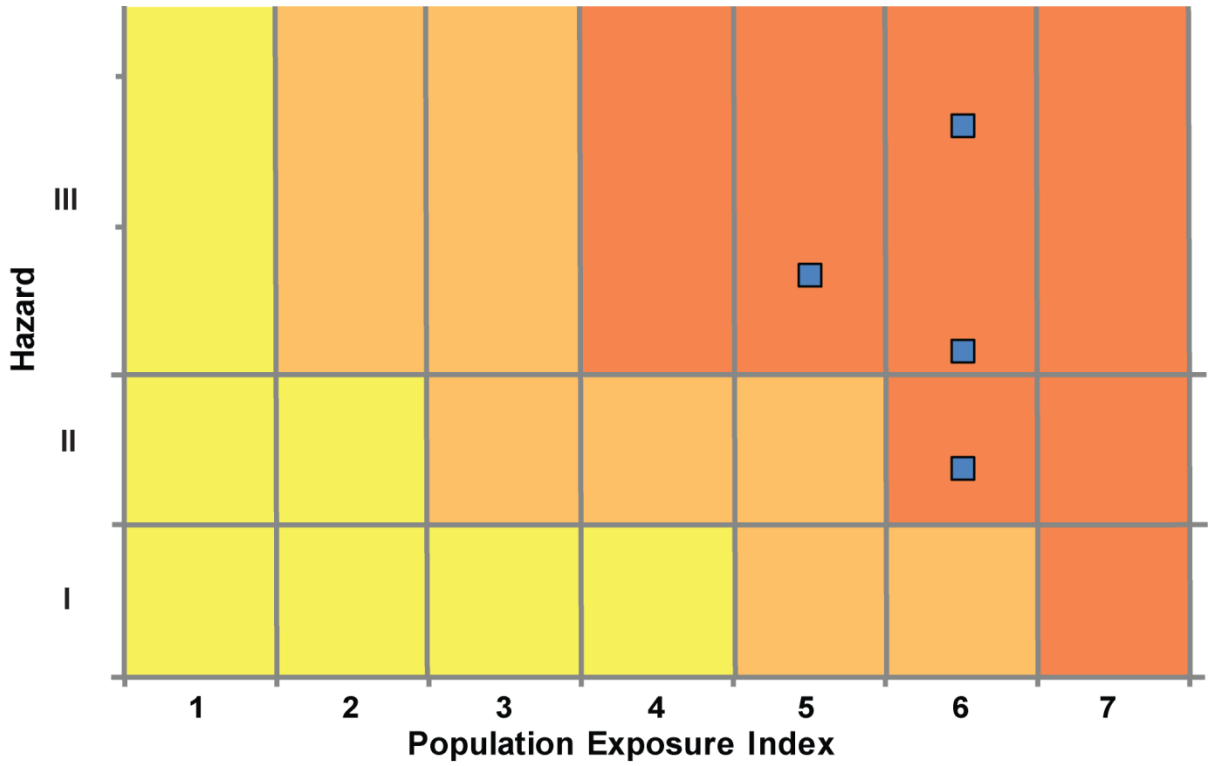

Figure 14.15 Distribution of Guatemala's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I – III.

National Capacity for Coping with Volcanic Risk

Seven volcanoes in Guatemala have recorded historical eruptions. These are classified as Risk Levels III (Atitlán, Fuego, Pacaya and Santa María) and Unclassified (Almolonga, Acatenango and Tacaná). The Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH) is responsible for monitoring these volcanoes. Monitoring is focussed on the Risk Level III volcano Santa Maria where seismic networks and geochemical monitoring is undertaken. Seismic monitoring is also undertaken at Fuego and Pacaya. A national seismic network is in place which may detect seismic activity at those volcanoes with no dedicated systems, if the seismic activity is very strong.

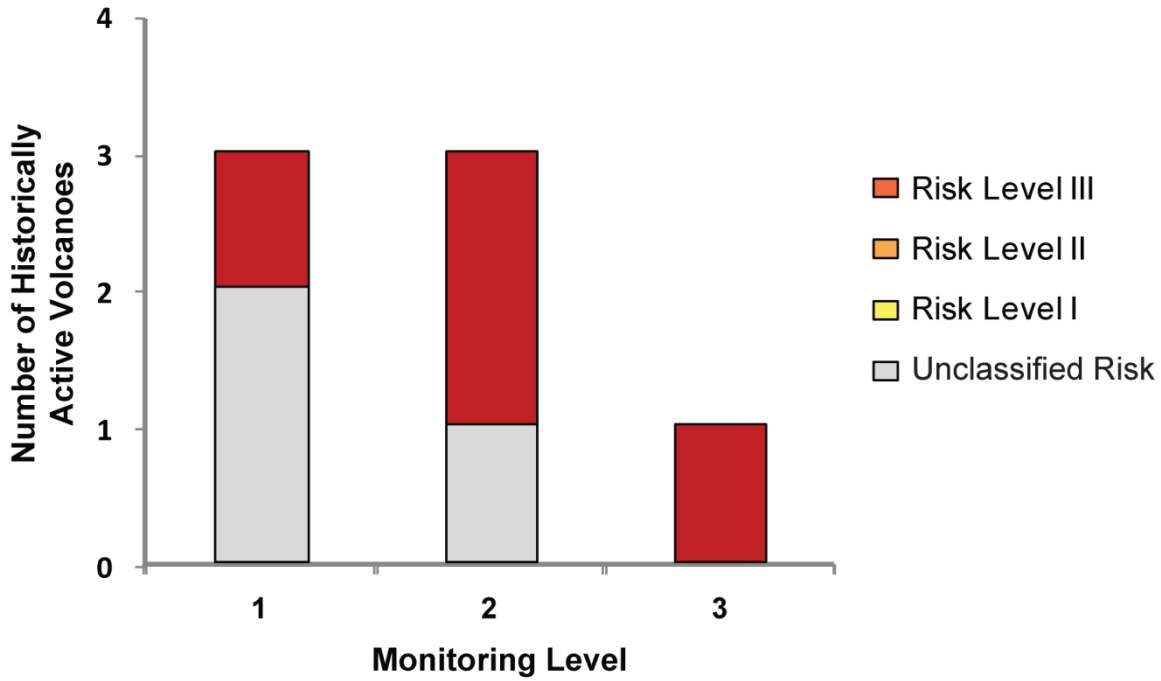

Figure 14.16 The monitoring and risk levels of the historically active volcanoes in Guatemala. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Honduras

Description

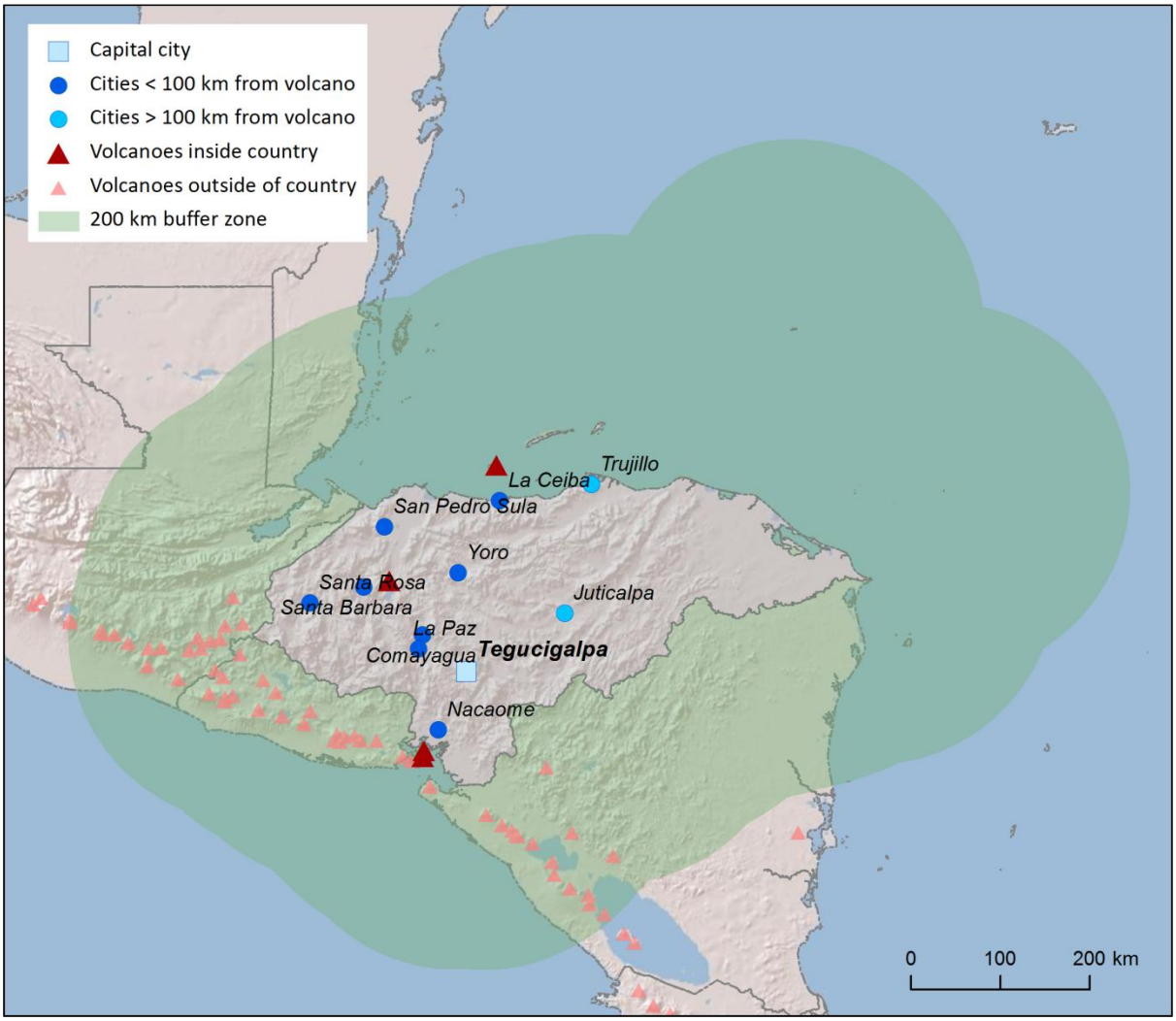

Figure 14.17 Location of Honduras' volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Honduras.

Four Holocene volcanoes are located in Honduras, of these, only Lake Yojoa is situated on the mainland, in north-central Honduras. Utila Island volcano is situated in the Caribbean Sea of the northern coast of Honduras, whilst Isla el Tigre and Isla Zacate Grande lie off the southern coast in the Gulf of Fonseca. The country lies on the Caribbean plate, with the Cocos Plate subduction zone lying to the south.

No eruptions are recorded in the Holocene, however Holocene activity is suspected at Utila Island, Isla Zacate Grande and Isla el Tigre due to deposits of lavas and a satellite vent of this age. With deposits of suspected Holocene age, these volcanoes would benefit from further research to date the eruptions and develop an eruptive history. There is no Pleistocene record of large explosive eruptions or a historical record of unrest.

The volcanoes in Honduras are dominantly basaltic. Those in the Gulf of Fonseca are stratovolcanoes, whilst the more northerly volcanoes are small cones comprising a volcanic field and pyroclastic cones. Being basaltic centres, with suspected Holocene lavas, effusive and localised moderately explosive activity may be a feature of the volcanism here.

Despite the small number of the volcanoes, over 80% of the population in Honduras lives within 100 km of one or more Holocene volcanoes. This is due to the widespread distribution of the Honduran volcanoes and the proximity of volcanoes in neighbouring countries, with some southern Guatemalan and northern Nicaraguan volcanoes and many of the volcanoes in El Salvador having 100 km radii extending into Honduras. Similarly, the radii of the Honduran volcanoes extend into these countries. The extent of population exposure is also due to the location of many of the country's largest cities in these 100 km radii, including the capital, Tegucigalpa.

The Honduran volcanoes are unclassified in both hazard and risk due to the lack of a comprehensive eruptive history, meaning the understanding of the hazard at these volcanoes is limited and the Hazard Level assignment would be associated with considerable uncertainty.

At the time of the writing of this report there was no information available to suggest that ground-based monitoring is undertaken at the volcanoes in Honduras. With no historical activity or constrained Holocene activity, the hazard from neighbouring volcanoes may be greater than that within the borders of Honduras.

Volcano Facts

Number of Holocene volcanoes	4
Number of Pleistocene volcanoes with M≥4 eruptions	-
Number of volcanoes generating pyroclastic flows	-
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	-
Largest recorded Holocene eruption	-
Number of Holocene eruptions	0 confirmed. Suspected activity.
Recorded Holocene VEI range	-
Number of historically active volcanoes	-
Number of historic eruptions	-

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

Table 14.16 The number of volcanoes in Honduras, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	7,960,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	3,566
Gross National Income (GNI) per capita (2005 PPP $)	3,426
Human Development Index (HDI) (2012)	0.632 (Medium)

Population Exposure

Capital city	Tegucigalpa
Distance from capital city to nearest Holocene volcano	96.4 km
Total population (2011)	8,143,564
Number (percentage) of people living within 10 km of a Holocene volcano	41,037 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	423,747 (5.2%)
Number (percentage) of people living within 100 km of a Holocene volcano	6,650,766 (81.7%)

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

Tegucigalpa	850,848
San Pedro Sula	489,466
La Ceiba	130,218
Comayagua	58,784
Juticalpa	33,686
Santa Rosa	27,753
La Paz	17,555
Yoro	15,774
Santa Barbara	15,119
Nacaome	13,929

Infrastructure Exposure

Number of airports within 100 km of a volcano	5
Number of ports within 100 km of a volcano	7
Total length of roads within 100 km of a volcano (km)	3,924
Total length of railroads within 100 km of a volcano (km)	0

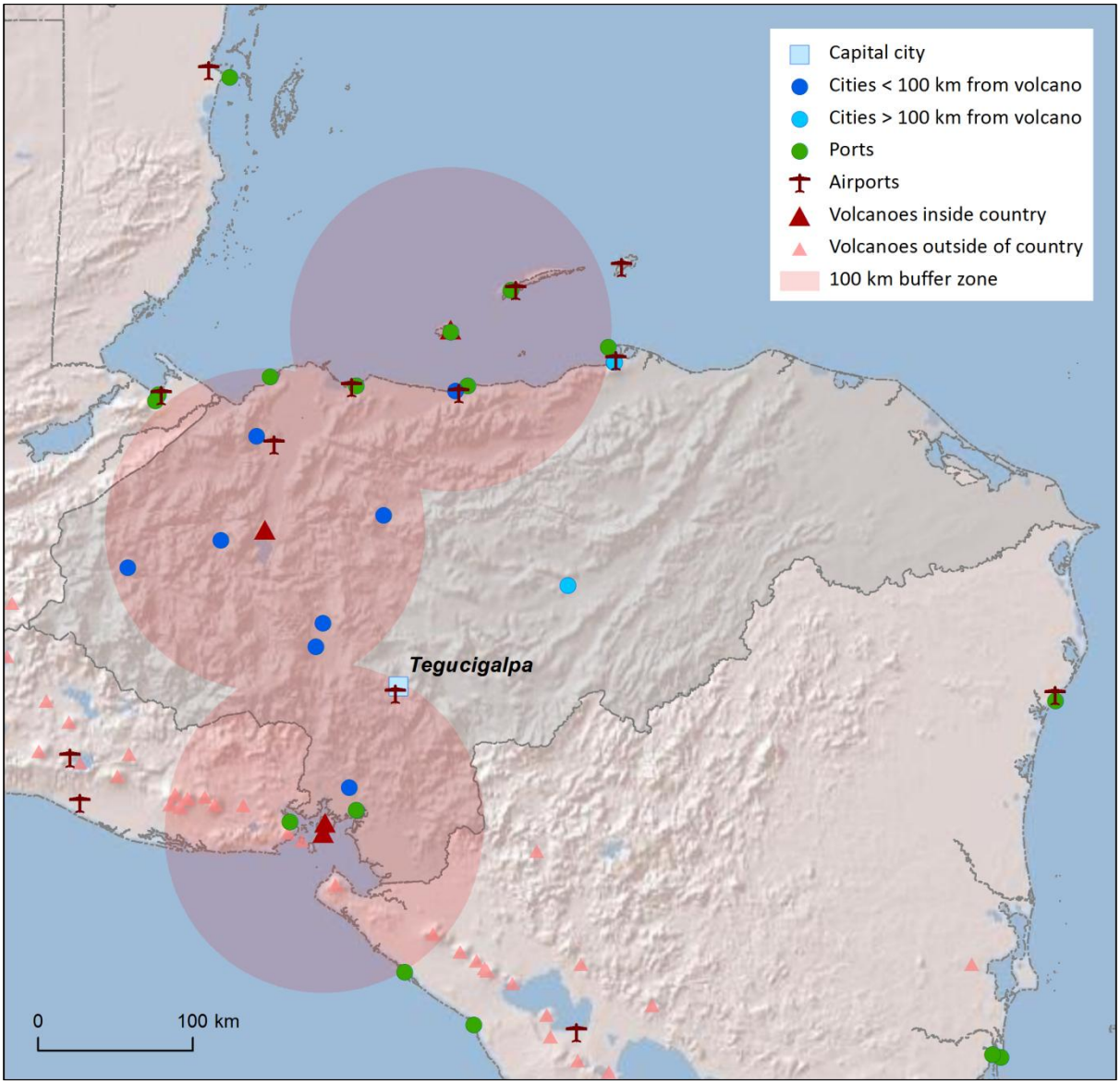

Figure 14.18 The location of Honduras' volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

The volcanoes of Honduras are widely distributed, from the Gulf of Fonseca in the Pacific Ocean, to a volcano in central mainland Honduras, to Utila Island in the Caribbean Sea. The 100 km radii of these volcanoes cover an extensive section of Honduras and extend into Guatemala, El Salvador and Nicaragua. Eight of the largest cities in Honduras lie within the 100 km radii of the Holocene volcanoes, as does the capital, Tegucigalpa. Much of the country's critical infrastructure is therefore

exposed, including ports on the Caribbean Sea and Pacific Ocean, airports and an extensive road network. Tegucigalpa is not situated within 100 km of any historically active volcanoes.

Hazard, Uncertainty and Exposure Assessments

No volcanoes in Honduras have a record of confirmed Holocene eruptions. The absence of an extensive eruption record prevents assessment of hazard through the calculation of the VHI, and as such these volcanoes are unclassified.

The PEI ranges from moderate to high in Honduras, with Lake Yojoa having the highest PEI with over 120,000 living with 10 km. Without a hazard classification, the risk levels for Honduran volcanoes cannot be determined.

CLASSIFIED	**Hazard III**							
	Hazard II							
	Hazard I							
UNCLASSIFIED	**U – HHR**							
	U- HR							
	U- NHHR			Utila Island	Tigre, Isla el; Zacate Grande, Isla		Yojoa, Lake	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 14.17 Identity of Honduras' volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 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 Honduras have recorded historical eruptions and no information is available at the time of the writing of this report to indicate that regular ground-based monitoring is undertaken at any Holocene volcanoes in Honduras.

Mexico

Description

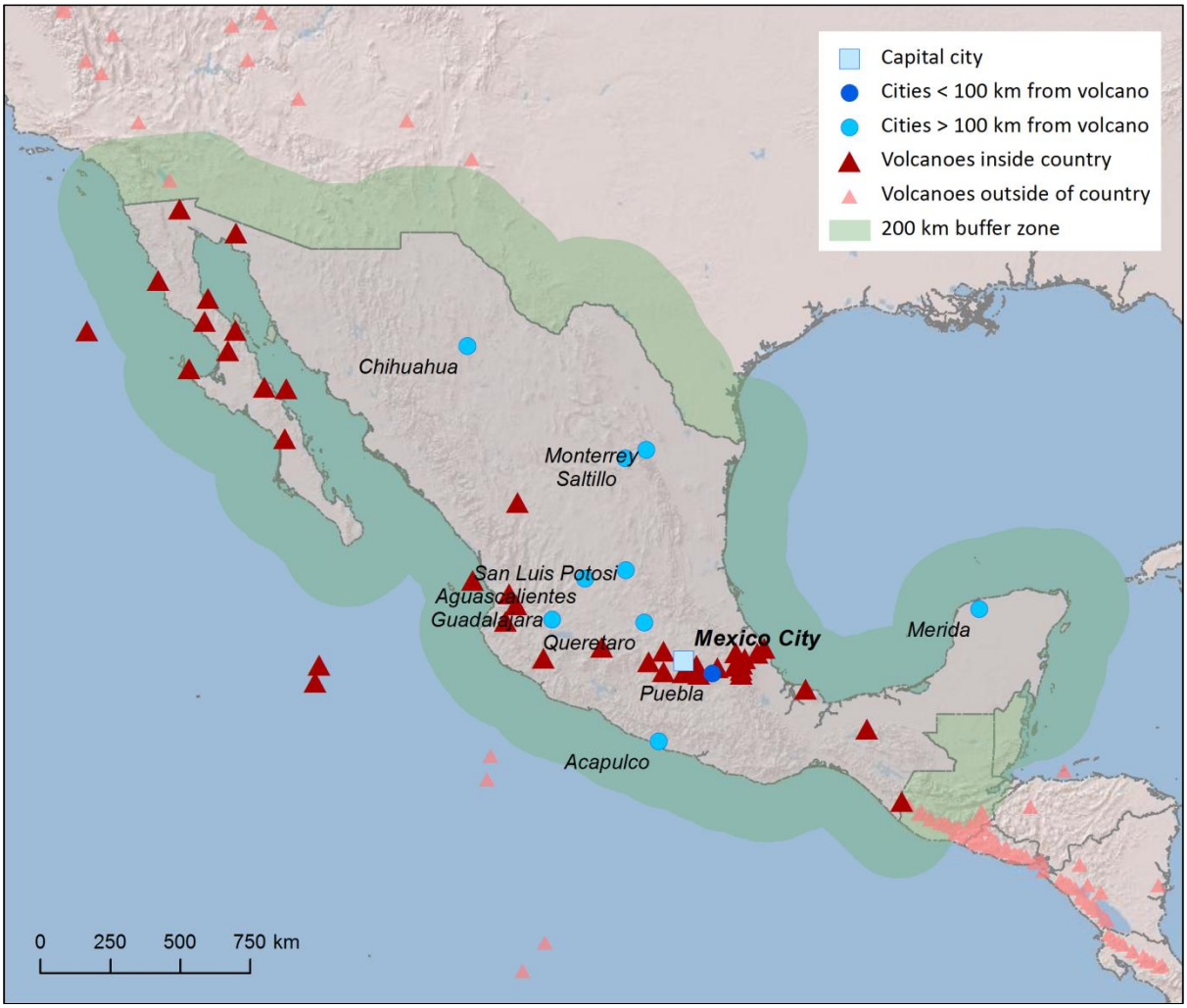

Figure 14.19 Location of Mexico's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Mexico.

Forty Holocene volcanoes are located in Mexico, including one on the border with Guatemala. Volcanoes are concentrated on the Baja California peninsula and across central Mexico, around the capital, Mexico City. Volcanism here is primarily due to the subduction of the Pacific and Cocos Plates beneath the North American Plate. This has given rise to the formation of dominantly andesitic volcanic centres, primarily comprising groups of cinder or tuff cones and stratovolcanoes, though a range of volcano types are present.

Mexico has an extensive Pleistocene record of large explosive eruptions, with 20 volcanoes recorded in LaMEVE with eruptions of VEI/M≥4. The largest recorded Pleistocene eruption was the M7.4 Xáltipan Ignimbrite from Los Humeros about 460,000 years ago. This ignimbrite covered about 3,500 square kilometres and formed the 15 by 21 km caldera.

Eighteen volcanoes have records of Holocene activity, with the remaining volcanoes having activity of suspected though unconfirmed Holocene age. VOTW4.22 records 214 Holocene eruptions here, from VEI 0 to 6. This size range demonstrates the range in activity in Mexico, from small events to

very large explosive eruptions. About 12% of eruptions here are recorded at VEI ≥4. About 46% of all eruptions have records of producing pyroclastic flows. The largest Holocene eruption was that of the Jala Pumice from Ceboruco in about 930 AD. This produced voluminous rhyolitic pumice and formed a 4 km wide caldera. Most commonly, small eruptions of VEI 0 – 2 are recorded, with about 35% of the Holocene record comprising such events. About 20% of Holocene eruptions were VEI 3, being moderately explosive.

Of the Holocene record, about 50% of the eruptions have been recorded post-1500 AD, with 103 historic eruptions of VEI 0 – 5 from 10 volcanoes. About 10% of these (10 eruptions) were of VEI ≥4. Two VEI 5 eruptions have occurred historically, at Colima in 1913 and El Chichón in 1982. Pyroclastic flows and surges during the 1982 eruption devastated an area extending about 8 km around the volcano.

In total, throughout Mexico, about 50% of the population live within 100 km of one or more Holocene volcanoes. The size of the local population varies at each volcano, with 13 volcanoes having a low PEI. However, 50% of the volcanoes have high local populations. Fatalities are recorded in about 8% of historical eruptions, with none recorded since 1996.

Monitoring of the historically active volcanoes in Mexico is undertaken by CENAPRED (National Center for Disaster Prevention), UNAM (Universidad Nacional Autónoma de México) and UCOL (Universidad de Colima).

CENAPRED creates, manages and evaluates public policies for risk reduction, coordinating risk information and early warning systems. CENAPRED and UNAM collaborate with joint research projects and shared expertise and also collaborate with the U.S. Geological Survey. CENAPRED and UNAM's main monitoring focus is on Popocatepetl, one of the most frequently active volcanoes in Mexico, located just 70 km from Mexico City. Popocatepetl has a complex monitoring system of visual, seismic, geodetic and geochemical instruments installed, with telemetered data CENAPRED for data processing. Upon detection of seismic unrest an alarm system is activated and duty staff are notified. The Scientific Technical Advisory Committee undertakes analysis of the data and makes recommendations based on the activity level. Government officials and civil protections are regularly updated and the public is informed. Hazard maps are available for flow and fall hazards.

Volcán de Colima, Mexico's most frequently active volcano, is monitored by the University of Colima. The University of Colima uses seismic, deformation, visual and geochemical, thermal and acoustic monitoring. All staff members have experience of responding to volcanic eruptions. Resources are limited with little current funding available to this institution. The Sub-committee for Geological Hazards of Colima informs civil protection about the level of volcanic activity, however no formal alert system is currently in use at Volcán de Colima. The Protección Civil de Jalisco (Jalisco state) control the alert system there and the State of Colima are currently developing an official alert system. Advice is provided to the public for what to do before, during and after eruptions, and hazard maps and evacuation routes are provided.

See also:

CENAPRED: www.cenapred.unam.mx/es/

University of Colima, Centro Universitario de Estudios e Investigaciones de Vulcanologia: portal.ucol.mx/cueiv/

Volcano Facts

Number of Holocene volcanoes	40, inclusive of one on the border with Guatemala
Number of Pleistocene volcanoes with M≥4 eruptions	20
Number of volcanoes generating pyroclastic flows	12
Number of volcanoes generating lahars	8
Number of volcanoes generating lava flows	13
Number of fatalities caused by volcanic eruptions	?>2,197
Tectonic setting	27 Subduction zone, 13 Rift zone
Largest recorded Pleistocene eruption	The M7.4 eruption of the Xáltipan Ignimbrite from Los Humeros at 460 ka.
Largest recorded Holocene eruption	The VEI 6 eruption of the Jala Pumice from Ceboruco in 930AD.
Number of Holocene eruptions	214 confirmed eruptions. 30 uncertain and 1 discredited eruptions.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	10
Number of historic eruptions	103

Number of volcanoes	**Primary volcano type**	**Dominant rock type**
2	Caldera(s)	Dacitic (1), Rhyolitic (1)
13	Large cone(s)	Andesitic (11), Dacitic (1), Unknown (1)
3	Lava dome(s)	Andesitic (1), Dacitic (2)
6	Shield(s)	Andesitic (2), Basaltic (3), Trachytic / Andesitic (1)
15	Small cone(s)	Andesitic (7), Basaltic (5), Rhyolitic (2), Trachytic / Andesitic (1)
1	Submarine	Unknown (1)

Table 14.18 The number of volcanoes in Mexico, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	121,073,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	12,776
Gross National Income (GNI) per capita (2005 PPP $)	12,947
Human Development Index (HDI) (2012)	0.775 (High)

Population Exposure

Capital city	Mexico City
Distance from capital city to nearest Holocene volcano	46.7 km
Total population (2011)	113,724,226
Number (percentage) of people living within 10 km of a Holocene volcano	394,678 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	15,418,740 (13.6%)
Number (percentage) of people living within 100 km of a Holocene volcano	57,764,870 (50.8%)

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

Mexico City	11,285,654
Guadalajara	1,640,589
Puebla	1,392,099
Monterrey	1,122,874
Merida	717,175
Chihuahua	708,267
San Luis Potosi	677,704
Aguascalientes	658,179
Acapulco	652,136
Saltillo	621,250

Infrastructure Exposure

Number of airports within 100 km of a volcano	13
Number of ports within 100 km of a volcano	10
Total length of roads within 100 km of a volcano (km)	17,530
Total length of railroads within 100 km of a volcano (km)	2,233

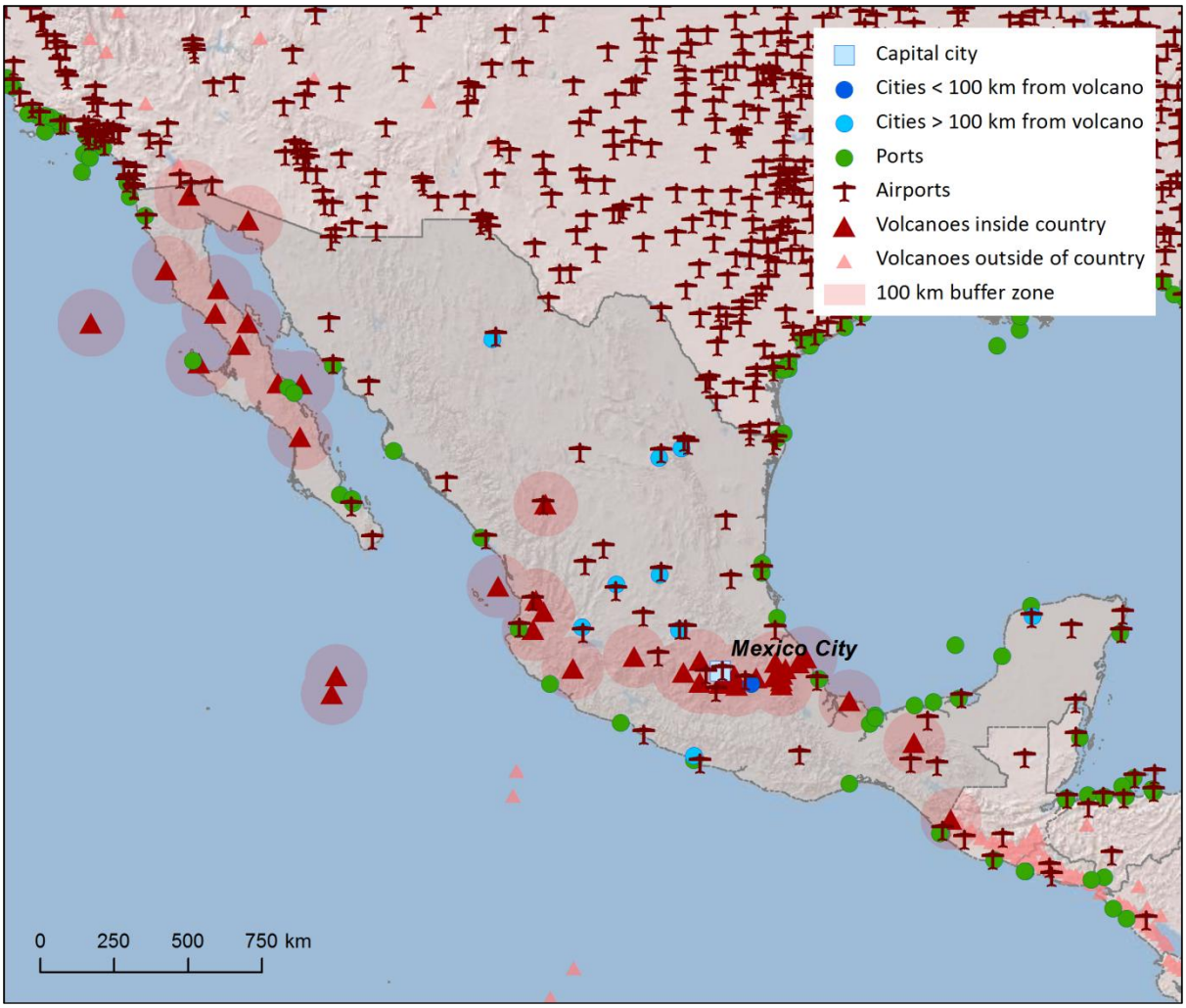

Figure 14.20 The location of Mexico's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

The volcanoes in Mexico are distributed throughout the Baja California peninsula, across central Mexico and to the border with Guatemala. The 100 km radius of Tacaná, on the Mexico-Guatemala border extends into both countries, while the radius surrounding Pinacate in the north extends into Arizona in the USA. Four volcanoes in Guatemala and Salton Buttes in California, USA have 100 km radii that extend into southern and northern Mexico respectively, exposing infrastructure here. Two of the largest cities in Mexico lie within 100 km of the Holocene volcanoes, including Puebla and the capital, Mexico City, hence exposing significant critical infrastructure here. Mexico City lies within 100 km of the historically and frequently active Popocatépetl volcano. The distribution of the volcanoes throughout the country places numerous ports and airports under threat as well as a very extensive road and rail network.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of data in the eruption records of Mexico's volcanoes. Out of 40, just four have sufficient detail to define the hazard through the calculation of the VHI. These volcanoes are classified at Hazard Level II and III, with Holocene records of large explosive eruptions of VEI ≥4 and a

particularly strong record of explosive eruptions accompanied by pyroclastic flows at Colima and Pico de Orizaba.

Of the unclassified volcanoes, 22 have no records of confirmed Holocene age eruptions. The remaining have a Holocene record, including historical events at seven volcanoes, with eruptions recorded since 1900 AD at five of these volcanoes. Five unclassified volcanoes have records of Holocene age large explosive VEI ≥4 eruptions.

The PEI ranges from low to very high in Mexico. The classified volcanoes all have moderate to very high PEIs and these are therefore classed at Risk Levels II and III. The risk levels for the unclassified volcanoes cannot be determined due to the absence of hazard data.

CLASSIFIED	**Hazard III**				Colima	Orizaba, Pico de		
	Hazard II					Popocatépetl		Chichinautzin
	Hazard I							
UNCLASSIFIED	**U – HHR**	**Bárcena; Socorro**			San Martín; **El Chichón**	Ceboruco; **Tacaná**		**Michoacán-Guanajuato**
	U- HR				Cumbres, Las	Malinche, La; Cofre de Perote	Zitácuaro -Valle de Bravo; Jocotitlán ; Toluca, Nevado de; Naolinco Volcanic Field	
	U-NHHR	Guadalupe ; Isabel, Isla	Pinacate; San Luis, Isla; Jaraguay Volcanic Field; Coronado ; San Borja Volcanic Field; Unnamed ; Tres Vírgenes; Tortuga, Isla; Comondú -La Purísima		San Quintín Volcanic Field; Sangangüey; Mascota Volcanic Field; Atlixcos, Los	Prieto, Cerro; Iztaccíhuatl; Humeros, Los	Papayo; Serdán-Oriental; Gloria, La	Durango Volcanic Field
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 14.19 Identity of Mexico's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Chichinautzin	7	III
Orizaba, Pico de	5	III
Popocatépetl	5	II
Colima	4	III

Table 14.20 Classified volcanoes of Mexico ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 0 volcanoes; Risk Level II – 1 volcano; Risk Level III – 3 volcanoes.

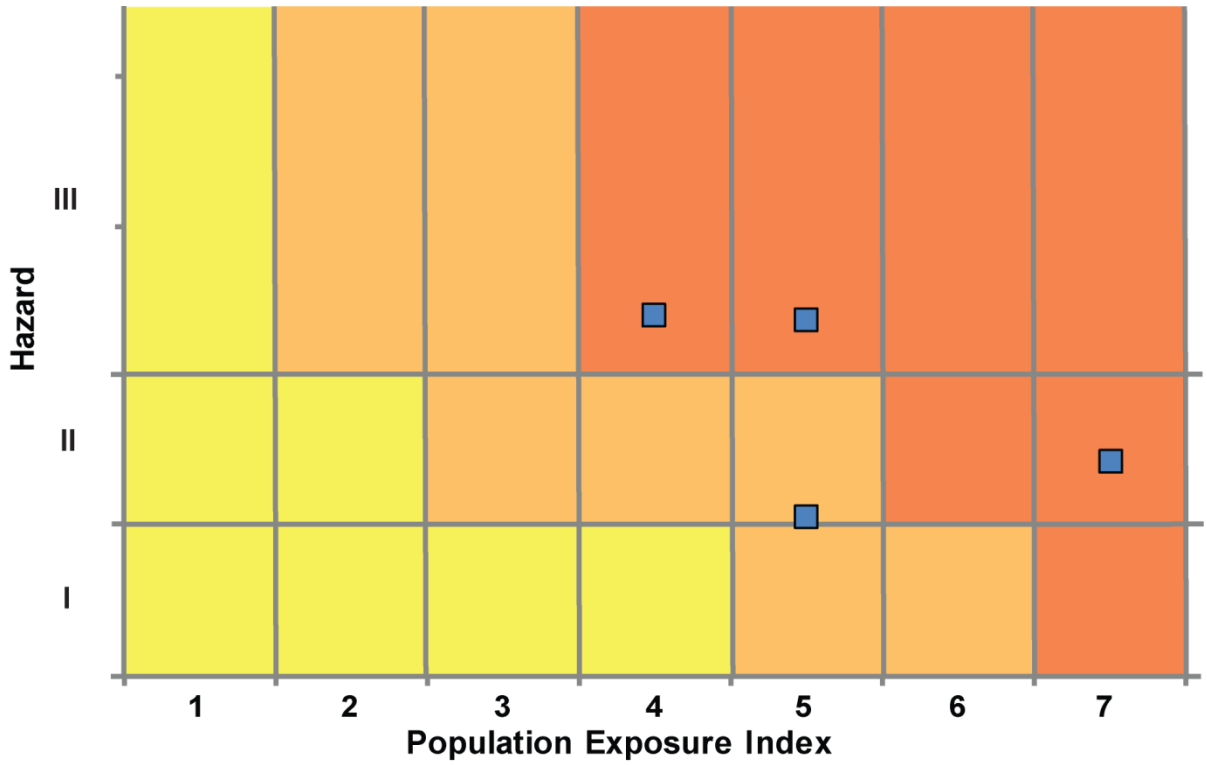

Figure 14.21 Distribution of Mexico's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels from Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Ten volcanoes in Mexico have records of historical activity. Seven of these are unclassified whilst three are at Risk Levels II and III. At the time of the writing of this report, no information available indicated dedicated ground-based monitoring at three volcanoes here (Bárcena, Socorro, Michoacán-Guanajuato). However, a national seismic network is in place. At seven historically active volcanoes, dedicated seismic monitoring and additional deformation and sometimes gas monitoring is used.

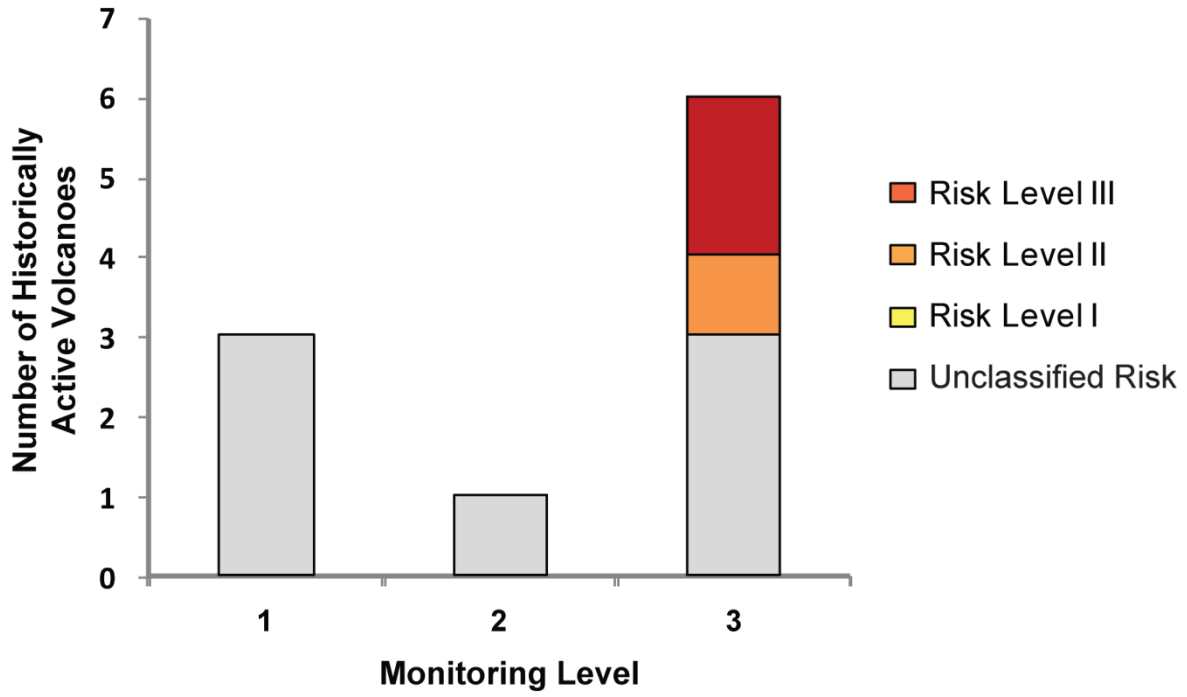

Figure 14.22 The monitoring and risk levels of the historically active volcanoes in Mexico. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Nicaragua

Description

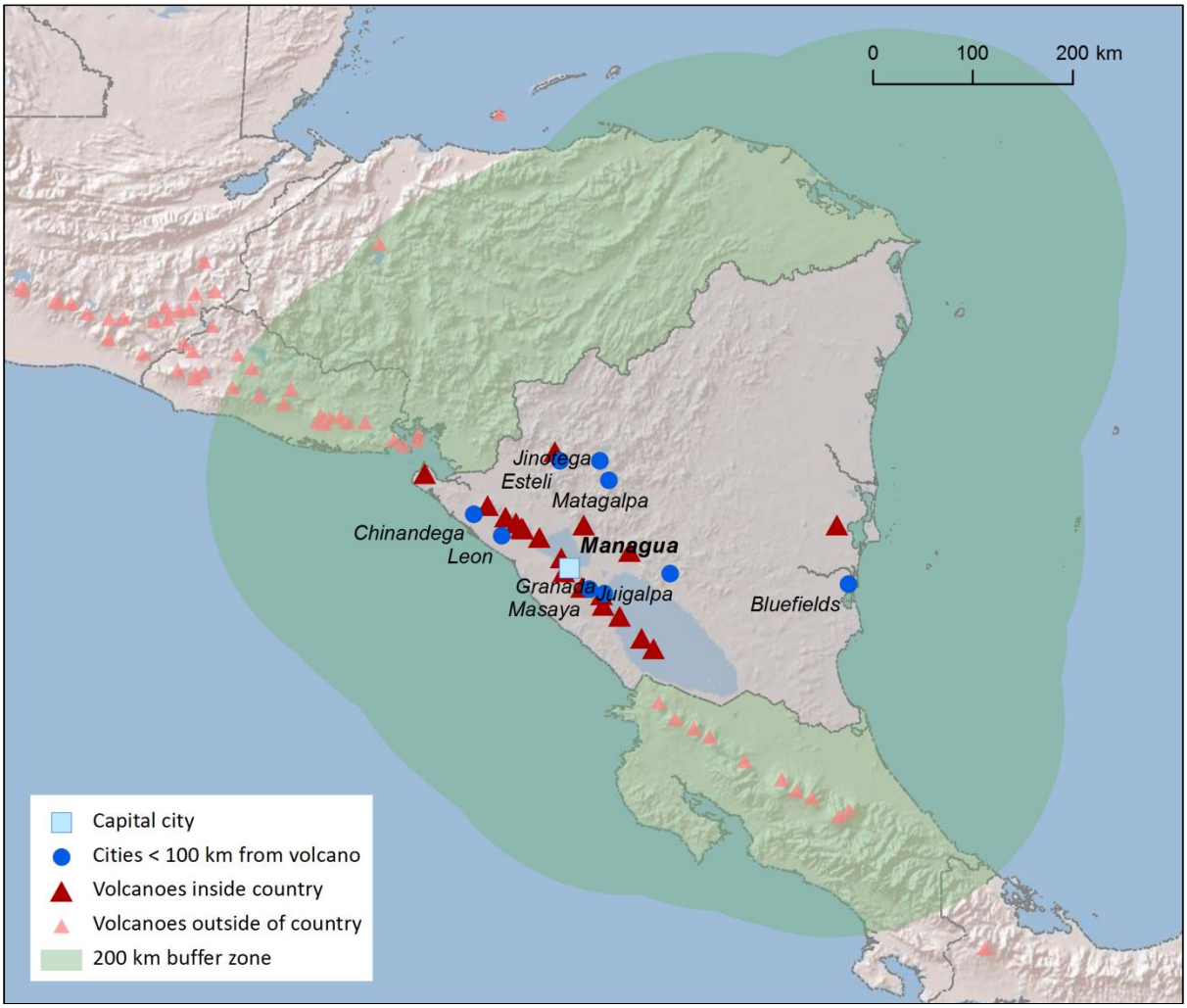

Figure 14.23 Location of Nicaragua's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Nicaragua.

Nineteen Holocene volcanoes are located in Nicaragua, dominantly in a chain near the west coast, from the border with Costa Rica in the south and the Gulf of Fonseca in the north. One, Volcán Azul (Blue volcano), lies near the Caribbean Sea coast. Volcanism in Nicaragua is due to the subduction of the Cocos Plate beneath the Caribbean Plate. A range of volcano types have developed throughout Nicaragua, though most volcanoes are dominantly basaltic and andesitic stratovolcanoes. A number of basaltic volcano fields comprising multiple cinder cones have also formed, and large calderas are also present.

VOTW4.22 records 191 confirmed eruptions here during the Holocene, ranging in size from VEI 0 – 6 indicating a range in activity styles from mild events to very large explosive eruptions. Seven volcanoes have records of producing pyroclastic flows. The largest recorded Holocene eruption was the VEI 6 eruption of Masaya at about 6,000 years ago. This basaltic Plinian eruption produced ash fall and pyroclastic flows. Masaya has been one of the most frequently active volcanoes in Nicaragua

in the Holocene, with 34 recorded eruptions, but these have mainly been small to moderate events. The capital of Nicaragua, Managua, lies only about 20 km from this volcano and a large explosive eruption here could have devastating consequences.

Most of the eruptions recorded during the Holocene were recorded in historical times, since 1500 AD, with 172 eruptions recorded in this time from eight volcanoes. With a scarce eruption record prior to 1500 AD, the assessment of hazard at many of Nicaragua's volcanoes is difficult and associated with significant uncertainties. Further research documenting the Holocene eruption record would be beneficial in understanding volcanism here.

Despite high proximal populations surrounding most volcanoes in Nicaragua, with over 1.5 million people living within 10 km of one or more Holocene volcanoes throughout the country and most of the population living within 100 km of one or more Holocene volcanoes, just five eruptions have recorded about 2,000 fatalities. In 1992, a VEI 3 eruption of Cerro Negro produced widespread damage due to voluminous ash fall. Despite the evacuation of over 20,000 people, many roofs collapsed resulting in loss of life. In 1998 Volcán Casita, a cone of San Cristóbal, suffered a catastrophic landslide and lahar following Hurricane Mitch. Several villages were buried and several thousand lost their lives. Lahars in the tropics are relatively common-place with the high rainfall, and lahars can occur for many years after eruptions due to the remobilisation of ash.

The Instituto Nicaragüense de Estudios Territriales (INETER) is responsible for volcano monitoring in Nicaragua. All historically active volcanoes are seismically monitored, with additional deformation monitoring at five volcanoes. INETER analyse the data in near real-time and release monthly bulletins of volcanic activity and status online. INETER is a member of WOVO.

See also:

Instituto Nicaragüense de Estudios Territriales (INETER): www.ineter.gob.ni/

Volcano Facts

Number of Holocene volcanoes	19
Number of Pleistocene volcanoes with M≥4 eruptions	6
Number of volcanoes generating pyroclastic flows	7
Number of volcanoes generating lahars	5
Number of volcanoes generating lava flows	6-7
Number of fatalities caused by volcanic eruptions	?
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The M6.4 eruption of the Upper Apoyo Tephra (UAT) from Apoyo at 29,468 BP.

Largest recorded Holocene eruption	The M6.3 San Antonio Tephra eruption from Masaya at 6 ka.
Number of Holocene eruptions	191 confirmed eruptions. 23 uncertain.
Recorded Holocene VEI range	0 – 6 and unknown
Number of historically active volcanoes	8
Number of historic eruptions	172

Number of volcanoes	Primary volcano type	Dominant rock type
2	Caldera(s)	Basaltic (1), Dacitic (1)
10	Large cone(s)	Andesitic (6), Basaltic (4)
2	Shield(s)	Andesitic (1), Basaltic (1)
5	Small cone(s)	Basaltic (5)

Table 14.21 The number of volcanoes in Nicaragua, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	6,009,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	2,579
Gross National Income (GNI) per capita (2005 PPP $)	2,551
Human Development Index (HDI) (2012)	0.599 (Medium)

Population Exposure

Capital city	Managua
Distance from capital city to nearest Holocene volcano	6.4 km
Total population (2011)	5,666,301
Number (percentage) of people living within 10 km of a Holocene volcano	1,521,967 (26.9%)
Number (percentage) of people living within 30 km of a Holocene volcano	3,371,558 (59.5%)
Number (percentage) of people living within 100 km of a Holocene volcano	5,314,523 (93.8%)

Ten of the largest cities, as measured by population and their population size (2005 Census, www.inide.gob.ni/):

Managua	937,489
León	174,051
Masaya	138,582
Matagalpa	133,416
Chinandega	121,793
Esteli	112,084
Granada	105,171
Tipitapa	101,685
Jinotega	99,382
El Viejo	76,775

Infrastructure Exposure

Number of airports within 100 km of a volcano	1
Number of ports within 100 km of a volcano	5
Total length of roads within 100 km of a volcano (km)	3,333
Total length of railroads within 100 km of a volcano (km)	0

With the exception of Volcán Azul in the east of the country, all volcanoes in Nicaragua are situated in the west, largely in a chain paralleling the coastline. With numerous volcanoes located here, a large expanse of the country lies within the 100 km radii of these volcanoes. These radii also extend into Costa Rica, Honduras and El Salvador. All ten of Nicaragua's largest cities, including the capital, Managua, lie within 100 km of Holocene volcanoes, and hence much of the country's critical infrastructure is exposed including ports, airports and an extensive road network. Managua lies within 100 km of seven historically active volcanoes.

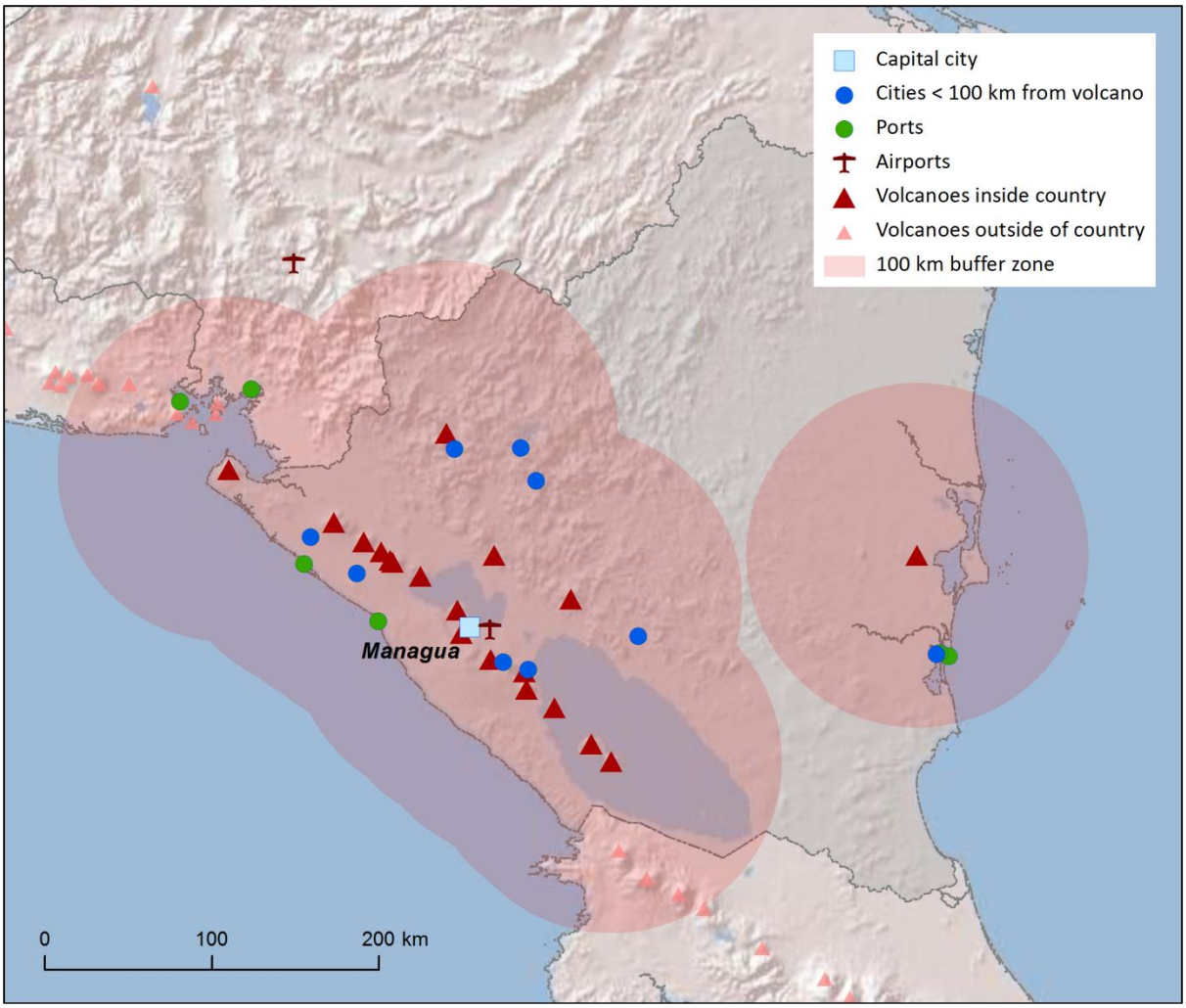

Figure 14.24 The location of Nicaragua's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

Hazard, Uncertainty and Exposure Assessments

There are varying levels of information available in the eruption records of Nicaragua's volcanoes. About 40% of volcanoes have sufficient detail to define the hazard through the calculation of the VHI. These are classified across the hazard levels, with just one at Hazard Level III: Apoyeque. This volcano has a Holocene record of a VEI 6 eruption and all Holocene eruptions recorded here are large, explosive VEI ≥4 events.

Of the unclassified volcanoes, nine have no recorded confirmed Holocene eruptions. Three have Holocene records, including historical events at Cosigüina and Las Pílas. Eruptions since 1900 AD are recorded at the latter, and seismic unrest has been detected at the former. Unrest is also described at Nejapa-Miraflores, Rota and Mombacho.

The PEI ranges from moderate to very high in Nicaragua, with over half of the volcanoes here classed with a high local population and PEI of 5 to 7. The classified volcanoes are classed across all three Risk levels, with just Apoyeque and Masaya being Risk Level III. Although unclassified in hazard, the very high PEI at Nejapa-Miraflores indicates that this would class as a Risk Level III.

CLASSIFIED	**Hazard III**						Apoyeque	
	Hazard II				San Cristóbal; Momotombo	Telica; Concepción		Masaya
	Hazard I				Negro, Cerro			
UNCLASSIFIED	**U – HHR**			**Cosigüina**	**Las Pilas**			
	U- HR							**Nejapa-Miraflores**
	U-NHHR			Maderas; Azul, Volcán	Zapatera; Ciguatepe, Cerro el; Lajas, Las	**Rota; Mombacho**	Granada; Estelí	
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

*Table 14.22 Identity of Nicaragua's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.*

Volcano	Population Exposure Index	Risk Level
Masaya	7	III
Apoyeque	6	III
Concepción	5	II
Telica	5	II
Momotombo	4	II
San Cristóbal	4	II
Negro, Cerro	4	I

Table 14.23 Classified volcanoes of Nicaragua ordered by descending Population Exposure Index (PEI). Risk levels determined through the combination of the Hazard Level and PEI are given. Risk Level I – 1 volcano; Risk Level II – 4 volcanoes; Risk Level III – 2 volcanoes.

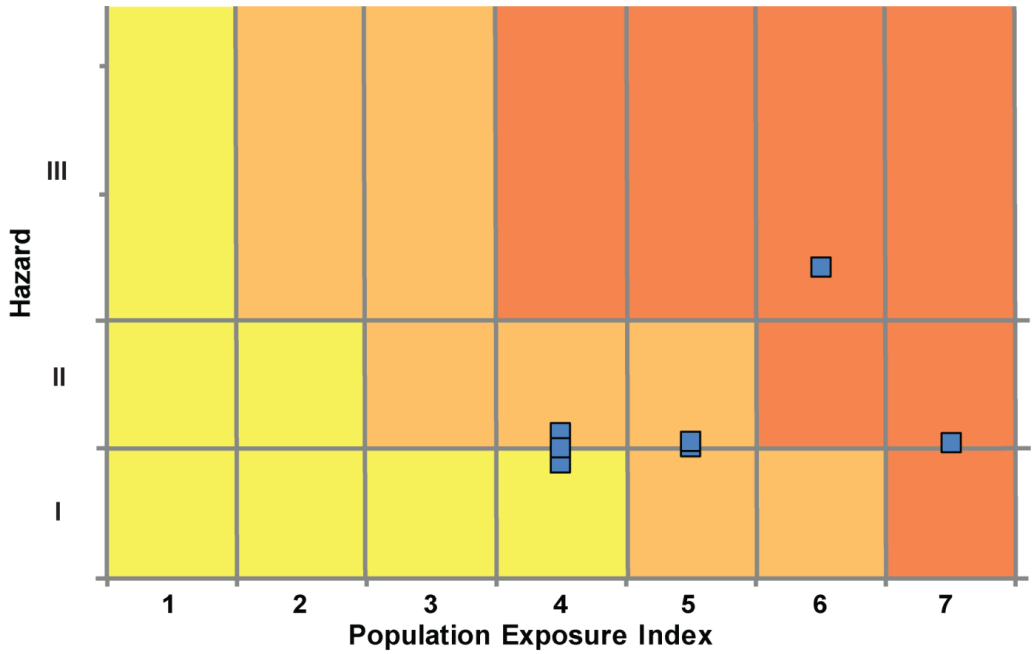

Figure 14.25 Distribution of Nicaragua's classified volcanoes across Hazard and Population Exposure Index levels. The warming of the background colours illustrates increasing Risk levels: Risk Level I - III.

National Capacity for Coping with Volcanic Risk

Eight volcanoes have recorded historical activity. The Instituto Nicaragüense de Estudios Territriales (INETER) is responsible for volcano monitoring. All historically active volcanoes have continuous seismic monitoring, with near real-time analysis. In addition to this, deformation monitoring is undertaken at San Cristóbal, Cerro Negro, Concepción, Cosigüina and the Risk Level III Masaya.

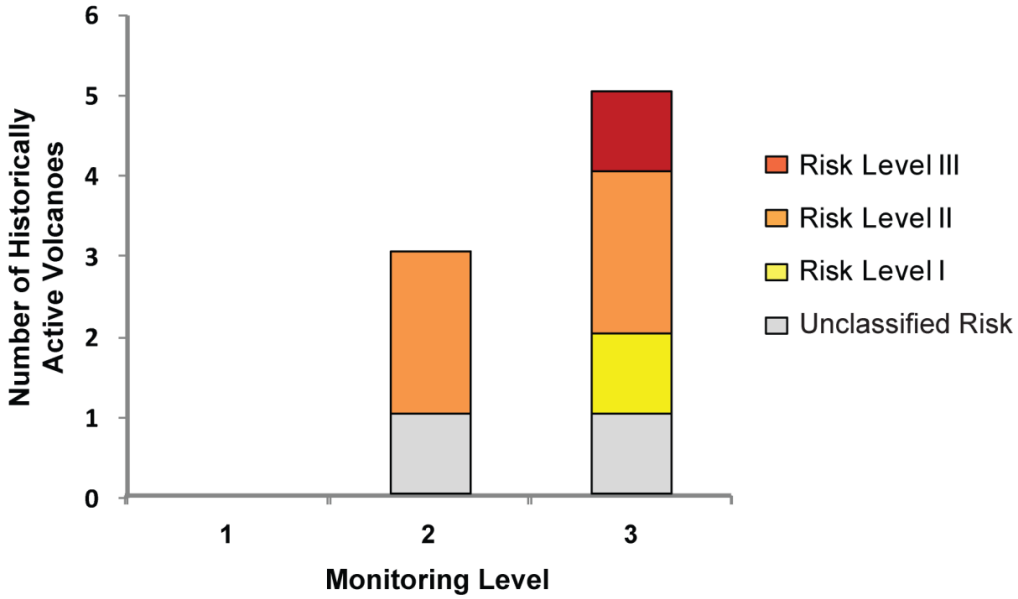

Figure 14.26 The monitoring and risk levels of the historically active volcanoes in Nicaragua. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.

Panama

Description

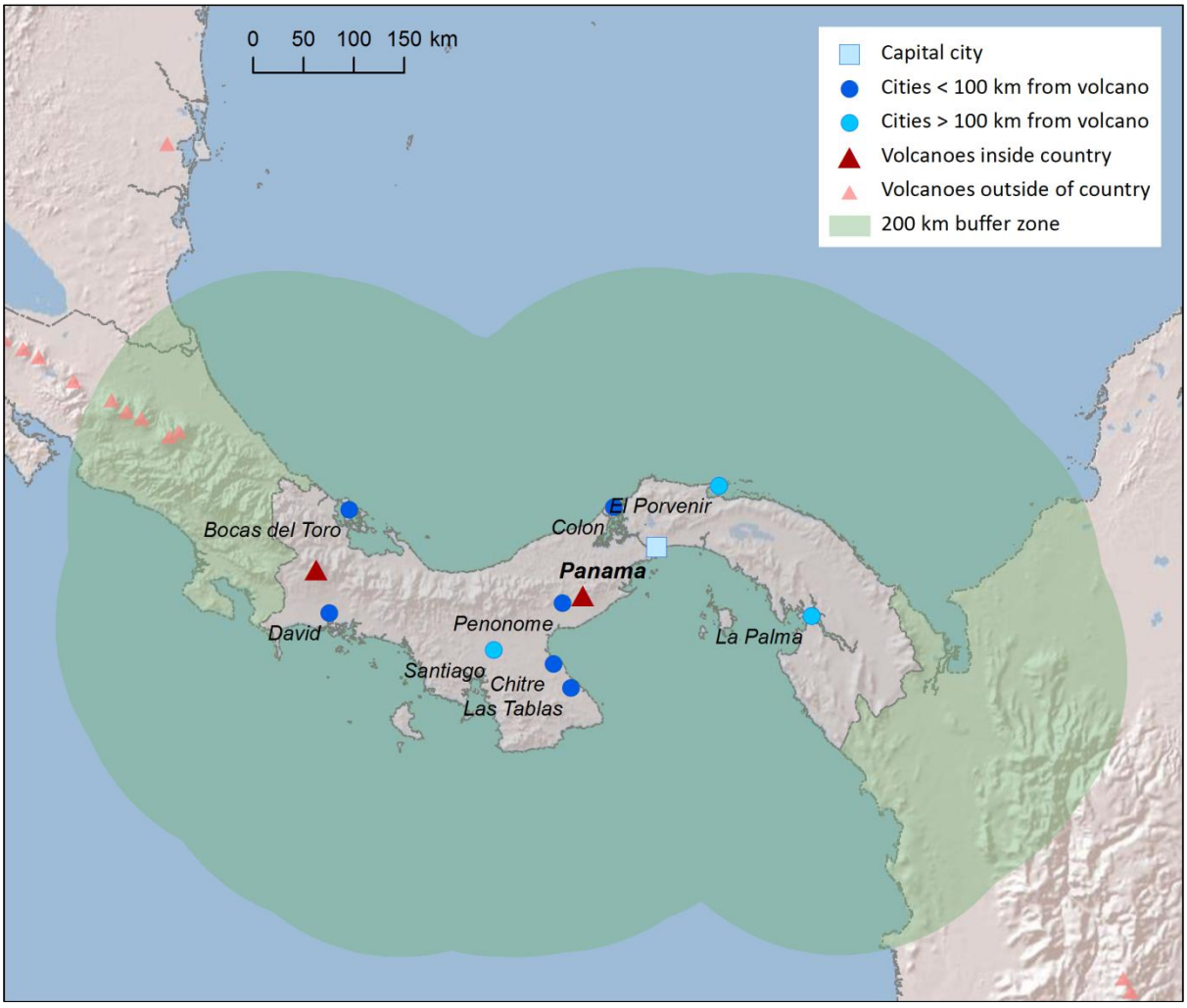

Figure 14.27 Location of Panama's volcanoes, the capital and largest cities. A zone extending 200 km beyond the country's borders shows other volcanoes whose eruptions may directly affect Panama.

Two Holocene volcanoes are situated in Panama. Barú lies in the west, close to the border with Costa Rica. El Valle lies in central Panama, around 80 km from the Panama Canal.

The volcanoes in Panama lie at the southern end of the Central American volcanic arc. Located on the Caribbean plate, several plates converge in this region with both the Caribbean and Nazca plates undergoing subduction.

Of the two Holocene volcanoes, neither has recorded historical activity, and only Barú has confirmed Holocene eruptions, with the most recent occurring in 710 AD. The size of the eruptions are unknown, however multiple pyroclastic surge deposits are identified suggesting a history of explosive eruptions at Barú. A record of Pleistocene activity at El Valle shows the occurrence of large magnitude explosive eruptions, with a magnitude 4 eruption here 56,000 years ago. Both volcanoes are large dominantly andesitic and dacitic Stratovolcanoes. This rock chemistry coupled with the explosive deposits suggests dominantly explosive activity in Panama with the potential for future eruptions of a similar style, producing pyroclastic density currents, ash fall and lahars.

Nearly 93% of the population of Panama lives within 100 km of the Holocene volcanoes, as many of the largest cities in the country lie within this distance. Indeed, the capital, Panama City lies at around 80 km from El Valle. Despite the large proportion of the population being exposed, the population within 10 km is moderate, and the volcanoes here are classed at PEI 4. A Holocene record of property damage exists at Barú. Barú has the potential to affect neighbouring Costa Rica, whilst some of the southernmost volcanoes in Costa Rica lie within 200 km of Panama.

Ash fall has been deposited more than 100 km downwind in prehistoric eruptions of Barú and dome collapses and subsequent hot PDCs have been channelled westwards. The town of Volcán is built on the deposits of these flows. Sherrod et al. (2008) describes these flows as constrained to 15 km from the summit dome. Large lahar plains extend to the south, and the city of David, the second most populous in Panama is located on this plain.

Barú is monitored by a seismic network maintained by the Institute of Geosciences at the University of Panama.

See also:

Sherrod, D.R., Vallance, J.W., Tabia Espinosa, A., and McGeehin, J.P. (2008) Volcan Baru; eruptive history and volcano-hazards assessment: US Geological Survey Open-File Report 2007-1401. 33p pubs.usgs.gov/of/2007/1401/

Volcano Facts

Number of Holocene volcanoes	2
Number of Pleistocene volcanoes with M≥4 eruptions	1
Number of volcanoes generating pyroclastic flows	1
Number of volcanoes generating lahars	-
Number of volcanoes generating lava flows	-
Number of fatalities caused by volcanic eruptions	-
Tectonic setting	Subduction zone
Largest recorded Pleistocene eruption	The 56 ka M4.0 El Hato Ignimbrite and El Valle de Antón caldera formation of El Valle.
Largest recorded Holocene eruption	All Holocene eruptions are of unknown VEI.
Number of Holocene eruptions	5 confirmed eruptions.
Recorded Holocene VEI range	Unknown
Number of historically active volcanoes	-
Number of historic eruptions	-

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

Table 14.24 The number of volcanoes in Panama, their volcano type classification and dominant rock type according to VOTW4.0.

Socio-Economic Facts

Total population (2012)	3,808,000
Gross Domestic Product (GDP) per capita (2005 PPP $)	13,766
Gross National Income (GNI) per capita (2005 PPP $)	13,519
Human Development Index (HDI) (2012)	0.780 (High)

Population Exposure

Capital city	Panama City
Distance from capital city to nearest Holocene volcano	82.6 km
Total population (2011)	3,460,462
Number (percentage) of people living within 10 km of a Holocene volcano	18,189 (<1%)
Number (percentage) of people living within 30 km of a Holocene volcano	266,966 (7.7%)
Number (percentage) of people living within 100 km of a Holocene volcano	3,203,311 (92.6%)

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

Panama	408,168
David	82,859
Colon	76,643
Santiago	45,355
Chitre	43,966
Penonome	12,394
Las Tablas	8,570
La Palma	1,845
Bocas del Toro	<50,000

Infrastructure Exposure

Number of airports within 100 km of a volcano	4
Number of ports within 100 km of a volcano	12

Total length of roads within 100 km of a volcano (km)	1,394
Total length of railroads within 100 km of a volcano (km)	75

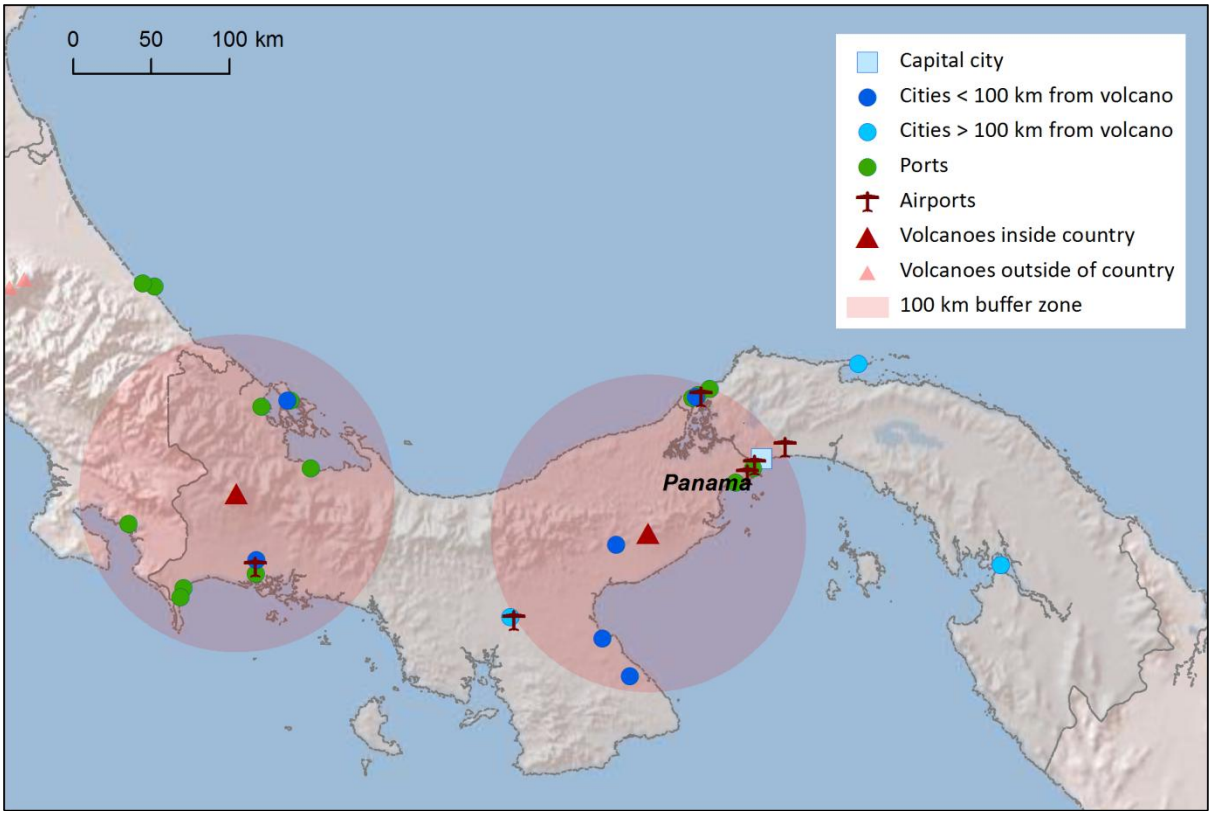

Figure 14.28 The location of Panama's volcanoes and the extent of the 100 km zone surrounding them. Ports, airports and the major cities are just some of the infrastructure that may be exposed to volcanic hazards.

The two volcanoes in Panama are located in the centre and west of the country. The 100 km radius of the western volcano, Barú, extends across the border into Costa Rica, exposing infrastructure here as well as encompassing a number of ports and two of Panama's largest cities. The 100 km radius of El Valle volcano, encompasses several of Panama's largest cities, including the capital, Panama City, and crucially the Panama Canal, hence considerable critical infrastructure is exposed here.

Hazard, Uncertainty and Exposure Assessments

Neither volcano in Panama have a sufficiently extensive record for assessment of the hazard through the calculation of the VHI. Indeed, El Valle has no confirmed Holocene eruptions. Five Holocene eruptions are known at Barú, however the VEI is unknown. These volcanoes are therefore unclassified.

Both volcanoes in Panama have a moderate proximal population and are classed at PEI 4.

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

*Table 14.25 Identity of Panama's volcanoes in each Hazard-PEI group. Those volcanoes with a sufficient record for determining a hazard score are deemed 'Classified' (top). Those without sufficient data are 'Unclassified' (bottom). The unclassified volcanoes are divided into groups: U-NHHR is Unclassified No Historic or Holocene Record: that is there are no confirmed eruptions recorded in the Holocene. U-HR is Unclassified with Holocene Record: that is there are confirmed eruptions recorded during the Holocene, but no historical (post-1500) events. U-HHR is Unclassified with Historic and Holocene record. The unclassified volcanoes in **bold** have experienced unrest or eruptions since 1900 AD, and those in red have records of at least one Holocene VEI ≥4 eruption.National Capacity for Coping with Volcanic Risk*

A network of seismometers dedicated to the monitoring of Barú volcano has been installed and is managed by the University of Panama. El Valle has no historical eruption record and no dedicated ground-based monitoring.

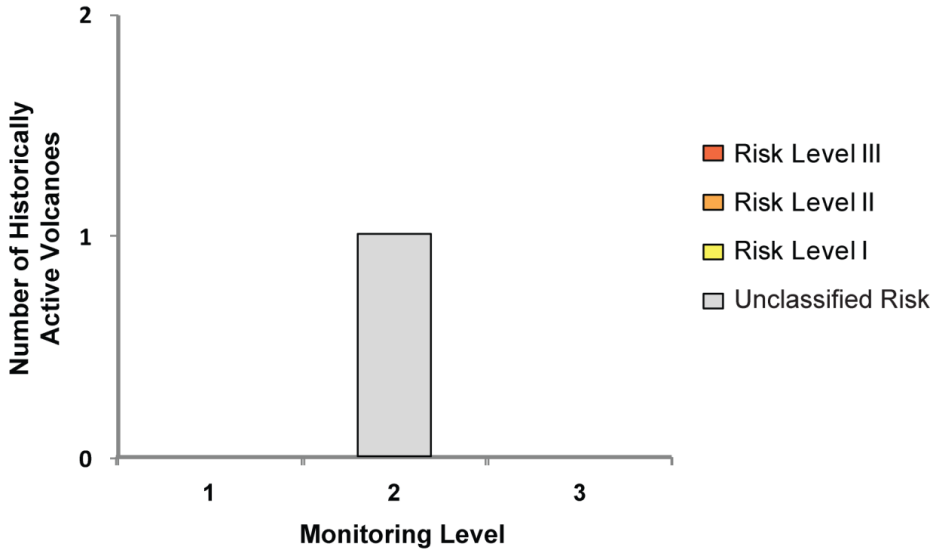

Figure 14.29 The monitoring and risk levels of the historically active volcanoes in Panama. Monitoring Level 1 indicates no known dedicated ground-based monitoring; Monitoring Level 2 indicates that some ground-based monitoring systems are in place including ≤3 seismic stations; Monitoring Level 3 indicates the presence of a dedicated ground-based monitoring network, including ≥4 seismometers.