Volcanic Threat in Central America: Assessment and Comparison of Volcanic Hazards and Associate Vulnerability in Guatemala, El Salvador, Nicaragua and Costa Rica

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Michigan Technological University
Department of Geological/Mining Engineering & Sciences

José Luis Palma, William I. Rose and Rüdiger Escobar Wolf

Figure 1. Map of Population Density and Volcanoes in Central America

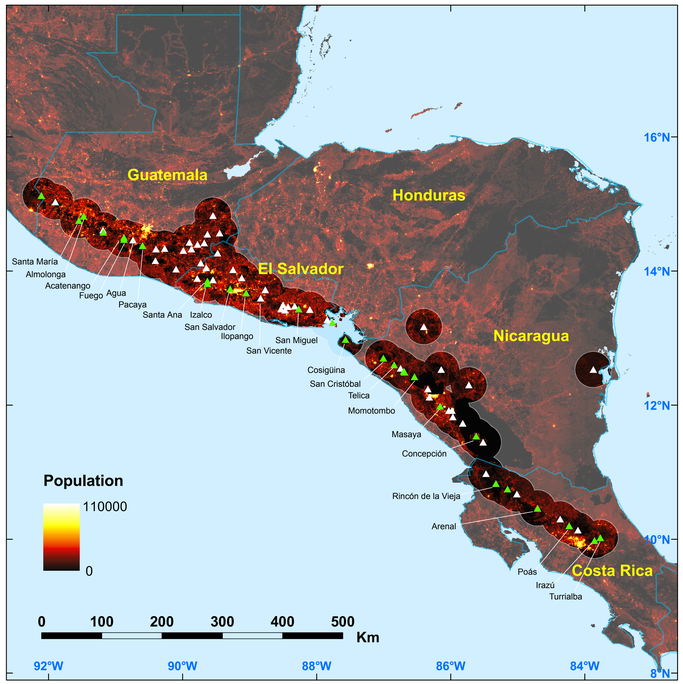

Figure 1. This map shows all volcanoes active in the Holocene (white triangles) and historically (green triangles). The colors in the map represent the logarithm of the population obtained from the LandScan database (LandScan 2007). On each volcano a circle of 30 km radius enhance the area and population most likely to be affected by volcanic events. In total, more than 20 million people live within 30 km from volcanic centers in Central America, which is roughly 50% of the total population.

Table 1. Volcanic hazard, exposure and threat scores of the 23 most active and best documented volcanoes in Central America.

Volcano name	Status	Type	Past eruptions	Potential hazards	Historical unrest	HAZARD SCORE	Log VPI30km	Historical impact	Development	EXPOSURE SCORE	THREAT SCORE
Santa María	Historical	Stratovolcano	12	1	3	16	6.1	2	5	13.1	209.1
Santa Ana	Historical	Stratovolcano	10	3	3	16	6.1	2	4	12.1	193.3
Fuego	Historical	Stratovolcano	11	1	2	14	6.0	2	5	13.0	181.8
San Salvador	Historical	Stratovolcano	10	1	2	13	6.4	2	5	13.4	174.6
Pacaya	Historical	Complex volcano	9	1	3	13	6.4	2	5	13.4	174.0
Irazú	Historical	Stratovolcano	9	2	2	13	6.2	2	5	13.2	172.0
Almolonga	Historical	Stratovolcano	11	2	1	14	6.0	1	5	12.0	168.3
Arenal	Historical	Stratovolcano	10	1	3	14	5.0	2	4	11.0	153.7
Rincón de la Vieja	Historical	Complex volcano	10	2	2	14	4.9	1	4	9.9	138.3
Turrialba	Historical	Stratovolcano	10	1	2	13	5.8	0	4	9.8	127.6
Telica	Historical	Stratovolcano	9	1	2	12	5.6	1	4	10.6	126.7
San Cristóbal	Historical	Stratovolcano	8	2	2	12	5.5	1	4	10.5	126.2
Poás	Historical	Stratovolcano	6	2	2	10	5.9	1	5	11.9	119.5
Cosigüina	Historical	Stratovolcano	10	1	2	13	4.2	2	3	9.2	119.2
Ilopango	Historical	Caldera	9	0	1	10	6.4	0	5	11.4	114.4
Masaya	Historical	Caldera	8	1	2	11	6.3	0	4	10.3	113.0
Concepción	Historical	Stratovolcano	8	1	2	11	5.0	1	4	10.0	109.7
San Miguel	Historical	Stratovolcano	6	2	2	10	5.9	1	4	10.9	108.9
Izalco	Historical	Stratovolcano	9	0	0	9	6.1	2	4	12.1	108.8
Momotombo	Historical	Stratovolcano	10	0	2	12	5.0	0	4	9.0	107.7
Acatenango	Historical	Stratovolcano	8	2	1	11	6.0	0	3	9.0	99.1
San Vicente	Holocene	Stratovolcano	5	2	1	8	5.9	1	4	10.9	87.4
Agua	Holocene	Stratovolcano	3	2	0	5	6.4	0	5	11.4	56.9

Figure 2. Volcanic Threat in Central America

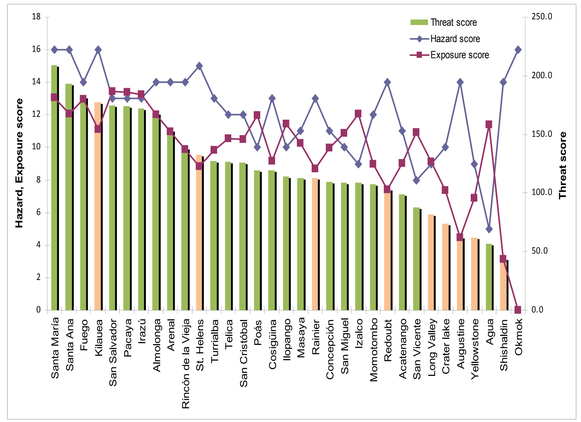

Figure 2. Volcanic threat scores of 23 volcanoes in Central America (Guatemala, El Salvador, Nicaragua y Costa Rica) and, for comparison, 10 U.S. volcanoes categorized as high or very high threat volcanoes by Ewert et al. (2005, 2007). The plot also shows the Hazard and Exposure scores for the same volcanoes. In this analysis the factors that quantify the population living downstream and the regional aviation exposure were not considered.

The Volcanic Threat score is calculated by multiplying a **Hazard Score** with an **Exposure Score** associated to each volcano. Both the Hazard and Exposure scores are subdivided in groups of scores that are related to specific type of information. The **Hazard score** is obtained by adding the Past Hazards, Potential Hazards and Historical Unrest scores. The **Exposure score** is obtained by adding the logarithm of the population within 30 kilometres of the summit (Log VPI30km), the Historical Impact and Development scores.

Past Eruptions score: it includes factors related to the VEI of eruptions within the past 500 and 5000 years, recurrence interval of eruptions, and the occurrence of hazards in the Holocene: pyroclastic flows, lava flows that reached populated areas, lahars and tsunamis.

Potential Hazards score: it includes information about potential sector collapses, hydrothermal explosions and source of permanent water/ice on the edifice.

Historical unrest score: it considers observations of seismicity associated with volcanic activity, ground deformation and evidence of magma degassing.

Historical Impact score: it concerns about historical evacuations and fatalities.

Development score: it groups indices related to the exposure of local aviation, power and transportation infrastructure, major development around the volcano, and whether it constitutes a significant part of a populated island.

Individual scores are shown in Table 1.

Figure 3. Volcanic Threat in Guatemala

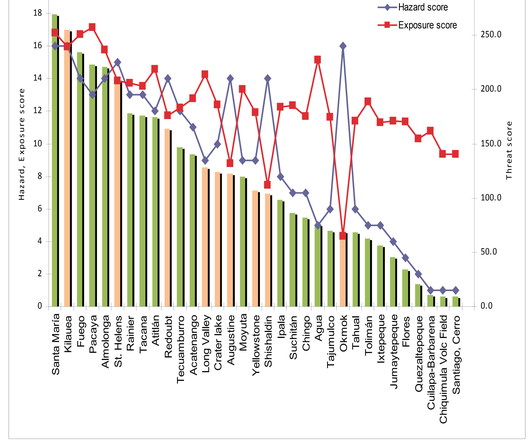

Figure 3. Volcanic threat scores for 23 volcanoes in Guatemala and 10 volcanoes in the United States (Ewert et al. 2005, 2007). The plot also shows the Hazard and Exposure scores for the same volcanoes. In these results the exposure factor that quantifies population living downstream was not considered.

The dataset for Guatemala was completed using all published information available as well as personal knowledge and inferences on the past and current activity of each volcano. Owing to the sparse or non-existent data on the characteristics and age of the deposits, insufficient monitoring, and low number of geophysical studies on non-erupting volcanoes, the completion of the hazard score was difficult. Some information could only be obtained from indirect sources of data such as the predominant composition of the products, morphology of the volcanic edifice, comparison with similar volcanoes, and photographs. Hazard factors that couldn't be inferred from indirect sources were left blank (or with a zero), so the final score can be still considered a minimum. The Regional aviation exposure factor was estimated from the number of people arriving and leaving every year to and from the Aurora International airport in Guatemala city (DGACG 2008), and set equal to all volcanoes in Guatemala (3.76).

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Remote Sensing for Hazard Mitigation and Resource Protection in Pacific Latin America.
http://www.geo.mtu.edu/rs4hazards

Summary

This presentation shows an assessment of the volcanic threat posed by the 23 most active and best documented volcanoes in Central America (Figures 1 & 2). It also includes a preliminary evaluation for all volcanoes in Guatemala (Figure 3). The results are compared to the threat posed by 10 high and very high threat volcanoes of the United States. The methodology used for the quantification of volcanic threat is based on the score system developed by Ewert et al. (2005, 2007) as part of the Framework for a National Volcano Early Warning System (NVEWS) in the United States.

Volcanic Threat results:
1) Based on the threat groups defined in NVEWS, in Central America at least 22 volcanoes classify as Very High Threat volcanoes (Figure 2, Table 1).
2) Among volcanoes with similar threat score, the exposure score in Central American volcanoes is generally higher than in U.S. volcanoes (Figure 2).
3) One of the main difficulties in completing the dataset is the lack of information about past activity and volcanic unrest for Central American volcanoes. Using indirect sources of information the dataset was completed for all volcanoes in Guatemala (Figure 3).

Comparison of the vulnerabilities to volcanic hazards between countries has been analyzed in terms of the Human Development Index (HDI) and population density around volcanoes (Table 2). The vulnerability to volcanic events of El Salvador, Nicaragua and Guatemala is greater than that of Costa Rica, and much greater than the vulnerability in the United States.

Table 2. Vulnerability and the Human Development Index (HDI)

The HDI is one of the development indicators contained in the Human Development Report, published annually since 1990, commissioned by the United Nations Developing Programme (UNDP) for countries worldwide. It is based on three indicators:
1. life expectancy at birth, as a measure of population health and longevity,
2. education index, measured by adult literacy rate and the combined enrolment ratio for primary, secondary and tertiary schools, and
3. standard of living, measured by the Gross Domestic Product (GDP) per capita.

Countries are categorized with High Human Development (70 countries) with an HDI between 0.968-0.8, Medium Human Development (85 countries) with HDI between 0.798-0.502, and Low Human Development (22 countries) with HDI between 0.499-0.336 (Human Development Report, HDR, 2007/2008).

Table 2. Comparison of the Human Development Index (HDI) between countries in Central America and the United States for 2005 (HDR 2007/2008).

HDI rank	Country	Life expectancy[a] (years)	Life expectancy[a] (index)	Literacy rate[b] (%)	School enrolment[c] (%)	Education[d] (index)	GDP per capita[e] (PPP US$)	GDP per capita[e] (index)	HDI (index)
12	United States	77.9	0.881	99.0	93.3	0.971	41,890	1.000	**0.951**
48	Costa Rica	78.5	0.891	94.9	73.0	0.876	10,180	0.772	**0.846**
103	El Salvador	71.3	0.772	80.6	70.4	0.772	5,255	0.661	**0.735**
110	Nicaragua	71.9	0.782	76.7	70.6	0.747	3,674	0.601	**0.710**
118	Guatemala	69.7	0.746	69.1	67.3	0.685	4,568	0.638	**0.689**

(a) life expectancy at birth; (b) % aged 15 and above 1995-2005, in the case of the U.S. this value was estimated differently; (c) combined gross enrolment ratio for primary, secondary and tertiary school; (d) literacy rate and school enrolment combined; (e) PPP= purchasing power parity, income.

El Salvador, Nicaragua and Guatemala exhibit a much lower GDP and HDI compared to the U.S. and Costa Rica. These three countries are also characterized by a high population density around volcanic centers, in many cases with houses or 'fincas' built on the flanks of historically active volcanoes (Figure 4, below). Indeed, many people are obliged to inhabit hazardous areas because of the socio-economical environment they live in, and they become more vulnerable to natural disasters. Education and access to quality information influence people's awareness of the threat that communities face living or working near active volcanoes. Furthermore, volcano monitoring and disaster mitigation plans in Central America are improving but they are still at a basic level.

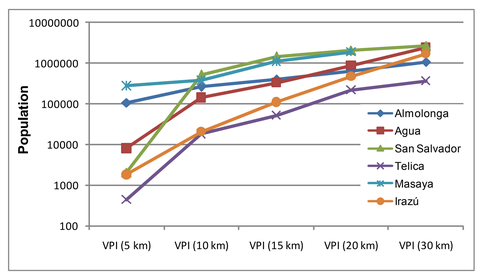

Figure 4. Population density around selected volcanic centers expressed by the Volcano Population Index (people living within the specified distance).