Chapter 19

Global monitoring capacity: development of the Global Volcano Research and Monitoring Institutions Database and analysis of monitoring in Latin America

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19.1 Background

Volcanic eruptions can cause loss of life and livelihoods, damage critical infrastructure and have long-term impacts, including displaced populations and long-lasting economic implications. Many factors contribute to disasters from natural hazards. One of these is the institutional capacity to enable hazard assessment for pre-emergency planning to protect populations and environments, provide early warning when volcanoes threaten to erupt, to provide forecasts and scientific advice during volcanic emergencies, and to support post-eruption recovery and remediation. Volcano observatories play a critical role in supporting communities to reduce the adverse effects of eruptions [Chapter 15]. Their capacity to monitor volcanoes is thus a central component of disaster risk reduction.

The resources are not available for extensive monitoring of all 596 historically active volcanoes. The availability of resources varies on local, national, regional and global scales, resulting in highly variable monitoring levels from volcano to volcano. Some countries have observatories dedicated to volcano monitoring, others monitor from within larger organisations, and still others have no permanent monitoring group. Individual volcanoes may have large comprehensive monitoring networks of multiple monitoring systems whilst a neighbouring volcano is unmonitored.

It is therefore vital to understand the monitoring capacity at local, national, regional and global scales to establish how well volcanoes are monitored, the distribution of monitoring equipment, the human resources, experience and education and the instrumental and laboratory capabilities. To this end a database has been developed: Global Volcano Research and Monitoring Institutions Database (GLOVOREMID).

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19.2 GLOVOREMID

In 2011 IAVCEI funded the development of VOMODA (Volcano Monitoring Database), whose main purpose was to obtain a realistic diagnosis of volcano monitoring and training of the human resources working on volcanological research and monitoring institutions (VRMI) in Latin America. In 2013, VOMODA was adopted and adapted for worldwide use as GLOVOREMID. The Global Volcano Model (GVM) supports this work. It is currently in both Spanish and English. This database will contribute to improving communication and cooperation between scientists and technicians responsible for volcano monitoring and may help to reduce the effects of volcanic crises. GLOVOREMID can be accessed online via http://132.248.182.158/glovoremid/.

19.2.1 Database development

The structure of GLOVOREMID was designed using a relational model. This consists of a set of tables and links that maintain information related to: volcanoes, VRMI, instrumentation and human resources responsible for volcanic surveillance. The development of the tables and relations in GLOVOREMID was completed under the normalisation method, which is a process of organizing data to minimise redundancy (Kendall & Kendall, 2010).

In order to achieve compatibility of GLOVOREMID with other existing volcanological databases, principally the Volcanoes of the World database of the Smithsonian Institution (VOTW4.0, Siebert et al. (2010)) and the Large Magnitude Explosive Volcanic Eruptions database (LaMEVE, Crosweller et al. (2012)) of the Volcano Global Risk Identification and Analysis Project (VOGRIPA), the same volcano identification codes are used and relevant data were transferred from these databases into GLOVOREMID.

For the development and implementation of GLOVOREMID KumbiaPHP Framework (Comunidad KumbiaPHP, 2012), PHP language and MYSQL engine were used. Model View Controller (MVC) was used for the architectural pattern giving a natural code organisation (De la Torre, 2010). All views were developed with HTML5 and JAVASCRIPT. The system works as follows: a query comes from browser to controller; the controller interacts with the model that is able to make data transactions directly to the engine database. Finally, the controller sends data in order to visualise it using a view (Figure 19.1).

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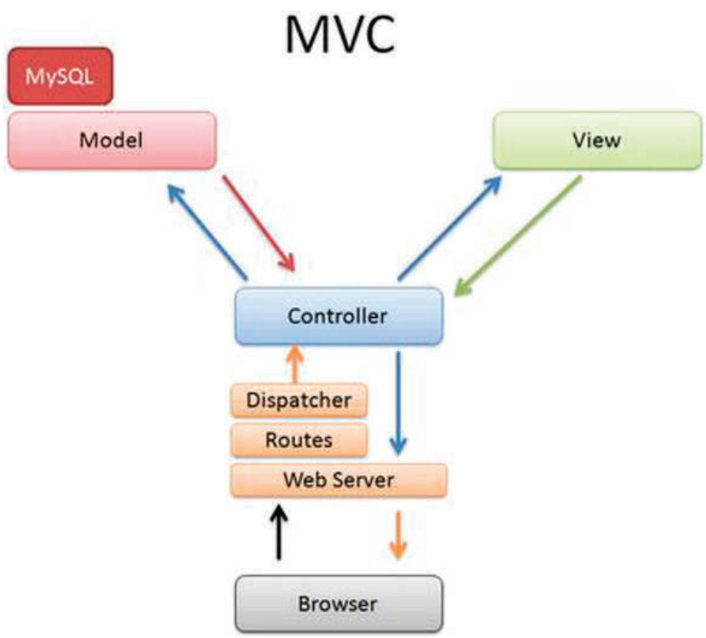

Figure 19.1 Model view controller pattern in GLOVOREMID.

GLOVOREMID is hosted on a server at the Instituto de Geofísica (UNAM). After development, the VRMI data were collected and entered into the database. Multiple users can be authorised and those working within VRMI are being given access. It is these users who are responsible for data updates. GLOVOREMID is anticipated as a global, sustainable database, accessible to and updated by those involved with volcano research and monitoring, to allow better communication and collaboration between scientists, to highlight knowledge gaps and areas where funding, training and equipment should be prioritised and perhaps even facilitate the sharing of equipment with un- or under-monitored regions as activity develops. GLOVOREMID is in the early stages of population globally, but, as it is expanding from VOMODA, is well populated for Latin America.

19.3 Monitoring in Latin America

VOMODA was developed as part of the IAVCEI project “Weaknesses and strengths in Latin America facing volcanic crises: a research for improvement of national capabilities”, and hence focussed on countries of Latin America.

Figure 19.2 Representation of the Latin American VRMI that populate VOMODA.

Volcanoes with known or suspected Holocene activity, as recorded in VOTW4.0, are included in the database. Additional as yet unidentified volcanoes, or volcanoes with few studies or infrequent activity may also require further research or monitoring. Where volcanoes lie on the border between two countries some may be monitored by one or more VRMI. The VRMI responsible for the volcanoes are identified and were contacted to join the database and provide monitoring information.

There are many methods for monitoring volcanoes, many of which are widespread. On local scales institutions may favour particular monitoring methods or derive their own methods using the resources available to them. The database allows the recording of many types of instrumentations and methods, and can be expanded to include new methods.

To determine the monitoring level for each volcano three main lines of monitoring were chosen: seismology, deformation and gas. Monitoring levels were chosen of 0-5 based on the use of these three methods. A volcano with no seismic, deformation or gas monitoring is classed at Level 0. Level 1 is assigned when using only seismic stations. Level 2 is assigned when the volcano is monitored with seismic stations and at least one deformation station, and increasing levels represent increasing deformation and gas stations. A very well monitored volcano is that of Level 5, indicative of seismology, deformation and gas monitoring through multiple stations

(Figure 19.3). For example, Level 5 could represent a volcano with a seismic network, GPS station, EDM line, SO_2 and CO_2 monitoring.

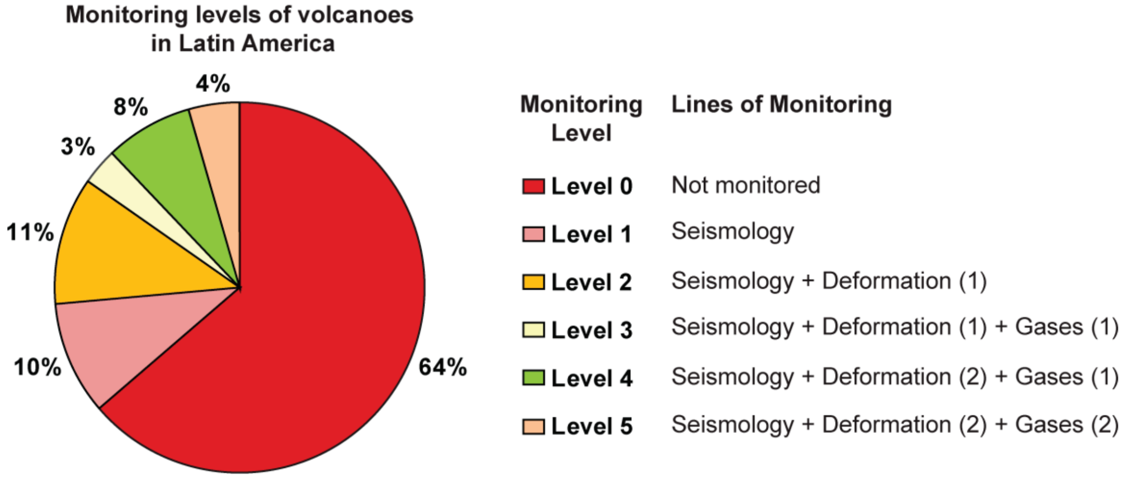

Figure 19.3 Monitoring levels for 314 Holocene volcanoes in Latin America and assignment of monitoring levels.

There are 314 Holocene volcanoes in Latin America (across the regions of Mexico and Central America and South America). Of these, 159 have confirmed eruptions recorded during the Holocene in VOTW4.0, 113 of which have confirmed historical activity. It is intuitive that a correlation between the age of eruptions and the monitoring level may exist.

Table 19.1 The number of volcanoes across Latin America that classify with each level of monitoring.

Monitoring level	Number of Latin American volcanoes	% of total Latin American volcanoes	% of monitored Latin American volcanoes
0	202	64%	-
1	30	10%	27%
2	35	11%	31%
3	10	3%	9%
4	24	8%	21%
5	13	4%	12%

There are 202 Latin American volcanoes that classify as Level 0 (i.e. unmonitored; Table 19.1). Mexico and Chile have the largest number of unmonitored volcanoes (32 and 50, respectively). These countries host the largest number of volcanoes in Latin America. 64% of Chilean volcanoes and 82% of Mexican volcanoes are unmonitored. Three countries have no *on-site* monitoring at any of their volcanoes: Argentina, Bolivia and Honduras, however, volcanoes on the Chile-Bolivia and Chile-Argentina borders are monitored. Neither Bolivia nor Honduras has recorded Holocene eruptions, with the exception of volcanoes along the Bolivia and Chile border. Four volcanoes in Argentina, excluding those on the border with Chile, have confirmed eruptions as recently as 1988.

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In Latin America, 86% of unmonitored volcanoes have no recorded historic eruptions. However, 30 unmonitored volcanoes have 95 eruptions recorded between 1505 and 2008 AD (Table 19.2). These eruptions ranged in magnitude from VEI 0-5, with four volcanoes producing five large explosive VEI ≥4 eruptions in this time (Cerro Azul in Ecuador, VEI 5 eruption of 1916; Michoacán-Guanajuato in Mexico with two VEI 4 eruptions in 1759 and 1943; Carrán-Los Venados in Chile with the VEI 4 eruption of 1955; Chaitén in Chile with the VEI 4 eruption of 2008). There are populations living within 100 km distance of these four volcanoes, with Population Exposure Indices (PEI) of 2-7 [see Chapter 4]. Over 5.7 million people live within 10 km of Michoacán-Guanajuato volcanic field, ranking this as the most populous volcano (10 km) worldwide, however this is due to the wide distribution of vents in the ~50,000 square kilometre volcanic field. This volcanic field currently has no ground-based monitoring systems specifically designed for volcano monitoring, however regional monitoring networks are available. A further four Latin American volcanoes are Monitoring Level 0 with historical activity and high PEI levels of 5 to 7. Most of the unmonitored historical volcanoes have no hazard classification [see Chapter 22], with just three Hazard Level I and two Hazard Level II volcanoes; risk levels are unclassified for those 25 unmonitored historically active volcanoes with no hazard classification, whilst the majority of classified volcanoes in this group fall in the Risk Level I category (Table 19.2).

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*Table 19.2 Latin American volcanoes with Monitoring Levels of 0 (unmonitored) shown with their hazard level (see CS19) and PEI (see CS1). The top section shows those volcanoes with a classified hazard level; the historically active volcanoes are shown in **bold** and the warming of the background colours indicates increasing risk levels. Those volcanoes with no hazard classification are shown in the lower section, where historically active volcanoes are shown in section U-HHR; volcanoes with a Holocene record but no historical activity are shown in U-HR; the number of volcanoes with no confirmed Holocene records are shown under U-NHHR.*

CLASSIFIED	**Hazard III**							
	Hazard II		**Yucamane**				**Atitlán**	Chichinautzin
	Hazard I		**Cerro Azul; Lautaro; Wolf**					
UNCLASSIFIED	**U – HHR**	Robinson Crusoe; Bárcena; Socorro	Huanquihue Group; Putana; Olca-Paruma; Pinta; Viedma; Fueguino; Sumaco; Burney, Monte; Arenales; Darwin; Marchena; Irruputuncu; Tromen; Llullaillaco; Reclus; Santiago	Chaitén; Carrán-Los Venados		Chacana	Acatenango	Almolonga; Michoacán-Guanajuato
	U-HR	Aliso	Aguilera; Antillanca Group; Cayutué-La Viguería; Ecuador; Infiernillo; Longaví, Nevado de; Palei-Aike Volcanic Field; Yanteles	Caburgua-Huelemolle; Huambo; Soche; Sollipulli	Andahua-Orcopampa; Cumbres, Las; Quimsachata; Romeral	Cofre de Perote; Malinche, La; Tecuamburro	Jocotitlán; Naolinco Volcanic Field; Zitácuaro-Valle de Bravo	Nejapa-Miraflores
	U-NHHR	5 volcanoes	80 volcanoes	8 volcanoes	12 volcanoes	14 volcanoes	24 volcanoes	4 volcanoes
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

There are 112 Latin American volcanoes that are monitored using seismic, gas or deformation stations. Thirty volcanoes (10% of Latin American volcanoes, Table 19.1) classify as Monitoring Level 1, including 11 with no recorded historical activity (Table 19.3). About half of these are in well populated regions and 11 classify at Hazard Levels II-III. Of the monitored volcanoes, 35 classify as Monitoring Level 2 making a combination of seismic and deformation monitoring the most popular choice. Further detail is available in the database regarding the type of deformation studies being used (e.g. INSAR, GPS, EDM). Forty-seven volcanoes are classified at Monitoring Levels 3 – 5, indicating that all three monitoring methods are used at 15% of the Latin American volcanoes. Just three countries have monitoring levels of 3-5 at over 50% of their *monitored* volcanoes: Mexico (86% of monitored volcanoes here – 6 out of 7), Costa Rica (75% - 6 out of 8) and Colombia (62% - 8 out of 13), indicating that several lines of monitoring are used here and that where monitoring is used in these countries, it is comprehensively undertaken.

Table 19.3 The number of volcanoes with and without historic activity in Latin America. Percentage is percentage of each age group.

Monitoring level	**Number and % of Latin American volcanoes with historical activity**		**Number and % of Latin American volcanoes with no historical activity**	
	Number	**%**	**Number**	**%**
0	30	27%	172	86%
1	19	17%	11	5%
2	25	22%	10	5%
3	10	9%	0	0%
4	18	16%	6	3%
5	11	10%	2	1%

Just 13 volcanoes throughout Latin America are at the highest monitoring level (Level 5) with seismic stations and two or more deformation and gas analysis techniques. All but Cuicocha in Ecuador and Cerro Machín in Colombia have recorded historical activity, but both have recent signs of unrest including elevating lake temperatures at Cuicocha (Gunkel et al., 2008) and seismic activity at Cerro Machín. Well-monitored Latin American volcanoes (Monitoring Levels (ML) 3-5) have low to high PEI levels and hazard and risk levels of I to III; however, most ML5 volcanoes have high levels of hazard and risk, and fatalities in the historic record (Table 19.4).

The largest numbers of monitored volcanoes are located in Chile, representing just 36% of volcanoes in this country. Countries with high proportions of monitored volcanoes are Colombia (87%), Costa Rica (80%) and Ecuador (53%), with monitoring levels ≥1 (Figure 19.4). Colombia and Ecuador also have the highest number and highest proportion of volcanoes at Monitoring Level 5; however, only about half of the historically active volcanoes of Ecuador are monitored (Figure 19.5). Four Latin American countries have monitoring at all historically active volcanoes: Colombia, Costa Rica, El Salvador and Nicaragua.

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Table 19.4 Well-monitored Latin American volcanoes (Monitoring Levels 3-5; ML3 in green, ML4 in purple, ML5 in black) shown with their hazard level and PEI. The top section shows those volcanoes with a classified hazard level; the warming of the background colours indicates increasing risk levels. Those volcanoes with no hazard classification are shown in the lower section, where historically active volcanoes are shown in section U-HHR; volcanoes with a Holocene record but no historical activity are shown in U-HR; the number of volcanoes with no confirmed Holocene records are shown under U-NHHR.

CLASSIFIED	**Hazard III**			Reventador	Cerro Bravo; Colima; Cotopaxi; Tungurahua	Irazú; Turrialba; Guagua Pichincha; Nevado del Ruiz	Galeras	
CLASSIFIED	**Hazard II**		Fernandina; Planchón-Peteroa; Antuco; Chillán, Nevados de; Copahue; Láscar;	Rincón de la Vieja; Ubinas		Santa Ana; Popocatépetl		
CLASSIFIED	**Hazard I**		Sierra Negra, San Pedro	Maipo	Arenal; Puracé; El Misti	Poás		
UNCLASSIFIED	**U – HHR**		Callaqui; Descabezado Grande; Cerro Hudson; Mentolat; Ticsani; Tinguiririca		Chichón, El; Cumbal; Miravalles; Nevado del Huila; San Martín	Ceboruco		
UNCLASSIFIED	**U- HR**		Corcovado; Maca; Melimoyu			Azufral; Machín	Nevado de Toluca; Cuicocha	
UNCLASSIFIED	**U-NHHR**		1 volcano					
		PEI 1	**PEI 2**	**PEI 3**	**PEI 4**	**PEI 5**	**PEI 6**	**PEI 7**

Analysis of the data provided for VOMODA in 2012 shows that with just 13% and 20%, respectively, of Colombian and Costa Rican volcanoes being unmonitored and 100% of their historically active volcanoes having some monitoring, these countries are proportionally top for having at least minimal monitoring standards at their recognised Holocene volcanoes. Coupled with the monitoring of over 50% of their volcanoes at Levels 3-5, these countries show the most

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comprehensive monitoring regimes. With 200 unmonitored volcanoes throughout Latin America, including 30 unmonitored historically active volcanoes, resources may be required to better equip the region for anticipation and monitoring of volcanic activity.

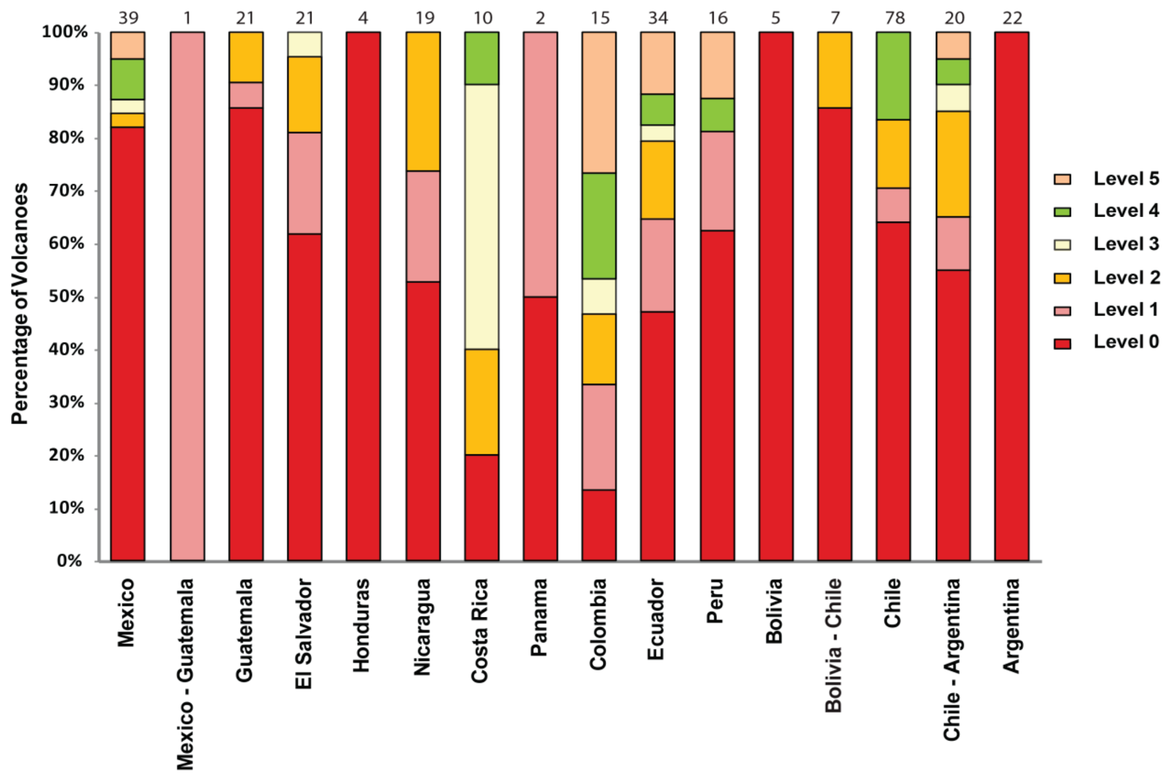

Figure 19.4 The percentage of all volcanoes in each Latin American country classified at Monitoring Levels 0-5. Data provided in 2012.

19.4 Conclusions

Efforts are underway to populate GLOVOREMID for a global dataset of VRMI and instrumentation. Further work and international cooperation with the global volcanological community is required to expand this database and the analysis of the data contained within it. Ultimately, an aim is to allow continuous data updates and to embed GLOVOREMID in other global volcanic databases in order to perform ongoing analyses of volcanic activity and monitoring.

GLOVOREMID allows a comparison between the number of active volcanoes and the investment in monitoring resources for each country. In combination with the Hazard Levels and Population Exposure Index it can be used to investigate the monitoring of high-risk volcanoes as global data are collated. The database will encourage cooperation between volcano monitoring institutions by facilitating the exchange of expertise in monitoring techniques as well as lessons learned from managing previous volcanic crises.

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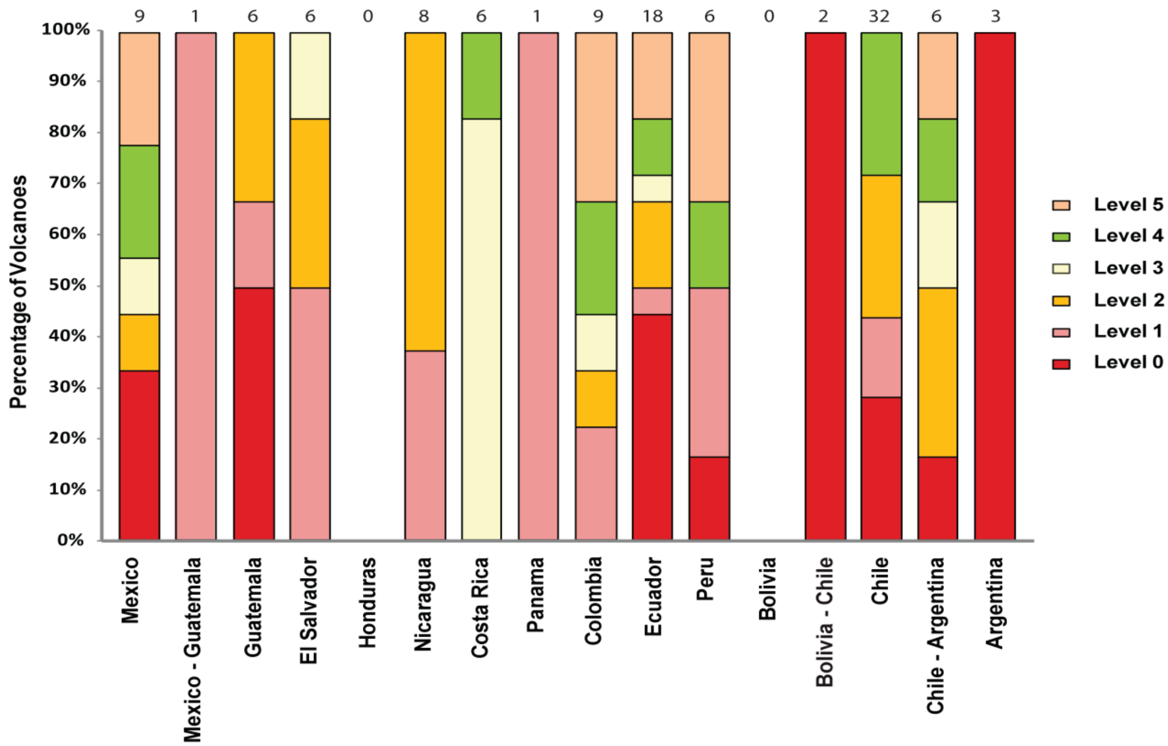

Figure 19.5 Monitoring levels of historically active volcanoes through Latin America.

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