Volcanic risk management in Spain

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1. Introduction: Volcanism in the Canary Islands, hazards and eruption history

Although volcanic activity in Spain is not only present in the Canary Islands, the Directriz Básica de Planificación de Protección Civil ante el Riesgo Volcánico en España [*Basic Civil Protection Planning Guidelines and Volcanic Risk in Spain*] approved by the Council of Ministers on 19 January 1996 (BOE [*Official Spanish Government Gazette*], 1996) describes the Autonomous Region of the Canary Islands as the only region in the territory of Spain that is exposed to volcanic risk.

The origin of volcanism in the Canary Islands has been the source of intense debate over the past 50 years, but the theory most widely accepted by the scientific community is that Canary Island volcanic activity is linked to the presence of a deep thermal anomaly inside the Earth (lower mantle) capable of building and continuing to build these island volcanic systems. Simple spatial analysis of the age of the oldest subaerial rocks making up each of the island volcanic systems reveals a declining trend in the age of these rocks from the easternmost to the westernmost islands, with the older subaerial rock that is youngest in age located on the islands of La Palma and El Hierro (Carracedo J.C. *et al*., 1998). Furthermore, current emission levels of helium-3, the best indicator of underground magmatic activity volcanologists have, also exhibit a clear spatial distribution in the Canary Island volcanic systems, rising from the easternmost to the westernmost islands, with the highest helium-3 emission levels on the islands of La Palma and El Hierro (Pérez N. M. *et al*., 1994). The combination of these two trends or progressions, one downward (rock age), the other upward (helium-3 emissions), from the easternmost to the westernmost islands suggests that the western part of the island chain is the part of the Canary Islands with the strongest connection to the deep thermal anomaly (Figure 1) and hence that it is the region in the archipelago most likely to experience future volcanic eruptions.

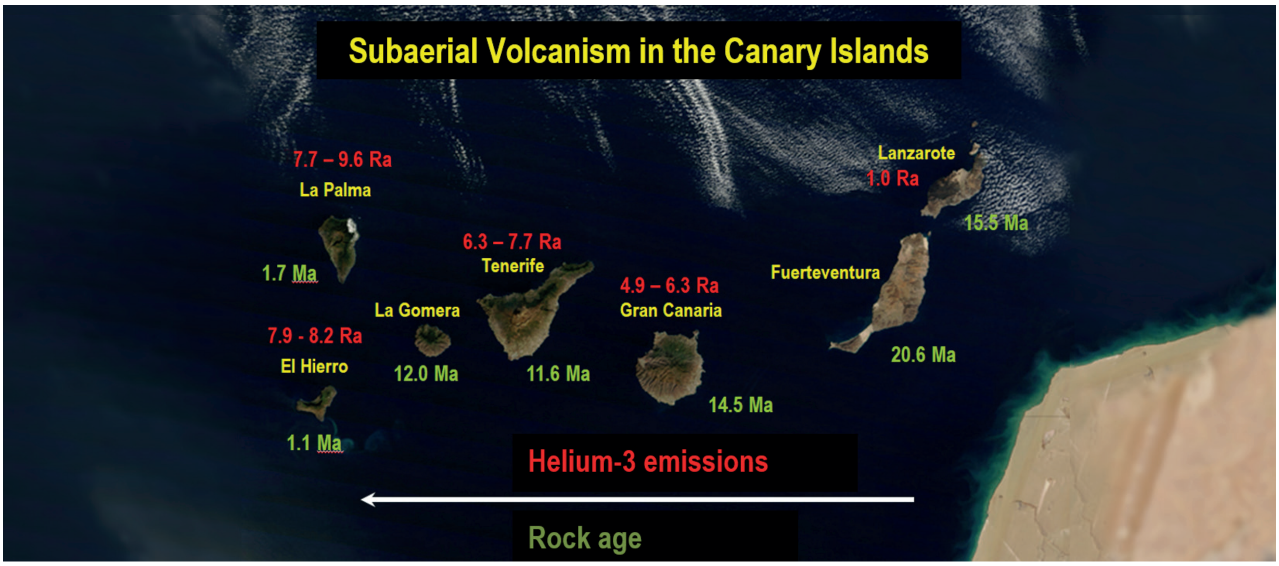

Figure 1. Spatial distribution of the oldest subaerial rock age and helium-3 emission levels in the volcanic systems in the Canary Islands.

Although volcanic activity in Spain is not only present in the Canary Islands, the Directriz Básica de Planificación de Protección Civil ante el Riesgo Volcánico en España [*Basic Civil Protection Planning Guidelines and Volcanic Risk in Spain*] approved by the Council of Ministers on 19 January 1996 (BOE [*Official Spanish Government Gazette*], 1996) describes the Autonomous Region of the Canary Islands as the only region in the territory of Spain that is exposed to volcanic risk. This assertion is clearly borne out by the 16 recorded eruptions that have taken place in the Canary Islands since the fifteenth century (Table 1) in four of the seven principal island volcanic systems located there (Figure 2), the most recent being the one that took place on the submarine slope of the El Hierro island volcanic system, the Tagoro eruption of 2011-12 (Romero C., 1990; Romero C., 2000; Romero C. *et al*., 2009; Pérez N.M., 2015). Therefore, while the Canary Islands are exposed to a number of different natural hazards, the volcanic hazard is the central natural hazard faced by that Autonomous Region and the risk that sets it apart from the rest of Spain (Sansón Cerrato, 1995).

#	Eruption	Island system	Date	Duration (days)
1	Tacande	La Palma	1430-1447	?
2	Christopher Columbus*	Tenerife	1492	?
3	Boca Cangrejo	Tenerife	S. XVI	?
4	Tehuya	La Palma	1585	84
5	Tigalate	La Palma	1646	82
6	San Antonio	La Palma	1677-1678	66
7	Siete Fuentes-Fasnia-Arafo	Tenerife	1704-1705	71
8	Arenas Negras	Tenerife	1706	40
9	Charco	La Palma	1712	56
10	Timanfaya	Lanzarote	1730-1736	2,055
11	Chahorra o Narices del Teide	Tenerife	1798	99
12	Tao-Nuevo del Fuego-Tinguatón	Lanzarote	1824	86
13	Chinyero	Tenerife	1909	10
14	San Juan	La Palma	1949	47
15	Teneguía	La Palma	1971	24
16	Tagoro	El Hierro	2011-2012	145

* The volcanic eruption on the island of Tenerife described by Christopher Columbus (actual location unknown).

Table 1. List of the 16 recorded historical eruptions in the Canary Islands.

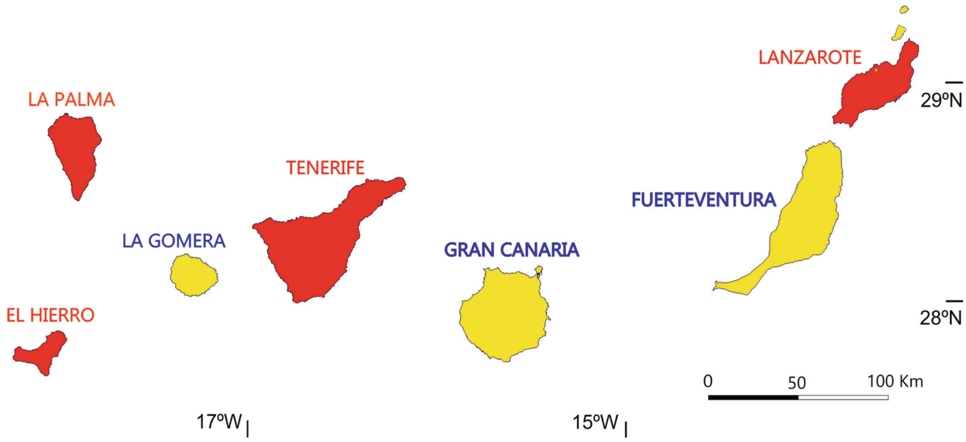

Figure 2. Eruptions in the Canary Islands have been recorded in the island volcanic systems of La Palma, Tenerife, Lanzarote, and El Hierro.

Some publications have made reference to other historical eruptions in the Canary Islands, such as the eruption of Lomo Negro on the island of El Hierro, which may have occurred in 1783. However, that eruption, like some others that have sometimes also been included as historical, is not supported by any documentary records. For an eruption anywhere in the world to be classified as historical, the volcanic event must be recorded by some sort of documentary reference, either written and/or graphic reports attesting to the incident.

Historically, eruptions in the Canary Islands have mainly been basaltic fissure eruptions with low volcanic explosivity index (VEI) values. Therefore, the volcanic hazards associated with eruptions of this kind have mainly been lava flows, pyroclastic falls, both ballistic projectiles and ash cloud dispersion, volcanic gases, volcanic earthquakes, and lahars or mudflows. On the other hand, in the geological past the Canary Islands have also been witness to eruptions with higher volcanic explosivity index values and catastrophic processes that have left traces of more extreme volcanic hazards on the land, for instance, pyroclastic flows, pyroclastic falls associated with explosive eruptions, landslides, and volcanic tsunamis. These larger-scale, more catastrophic phenomena have longer return periods than smaller-scale events (Figure 3).

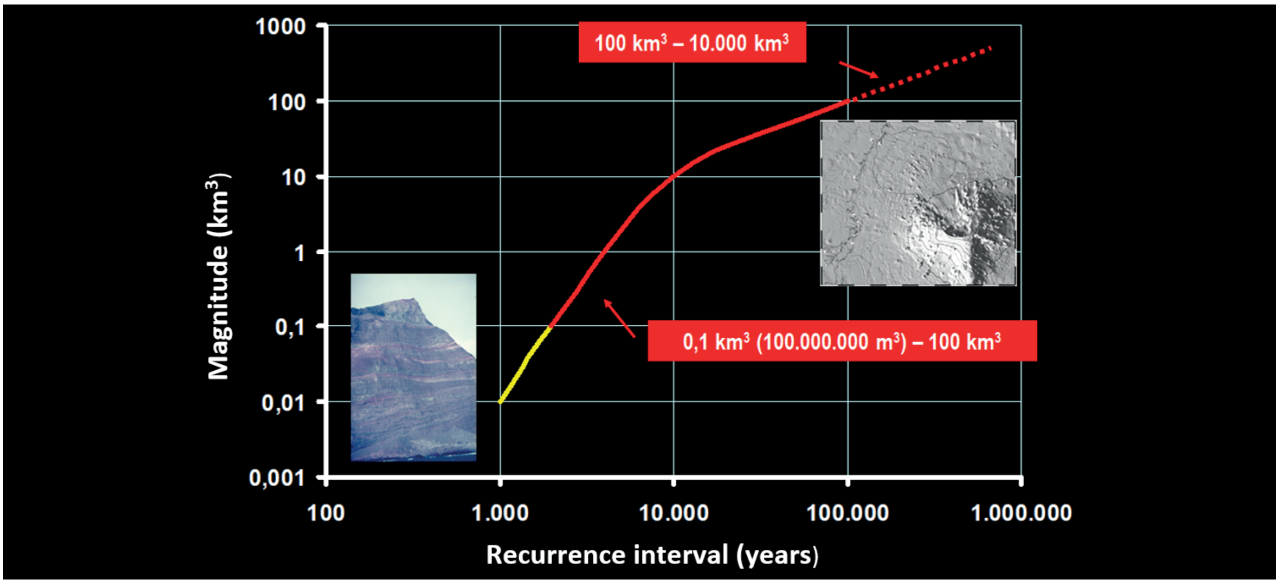

Figure 3. Magnitude and recurrence interval for volcanic hazards associated with landslides.

2. Probability of future eruptions in the Canary Islands

Volcanism is inherently complex because of the geological characteristics of planet Earth. Concatenation of deep magma generating processes, the rise of magma to the surface, its accumulation in magma chambers, and eruptions are highly complex. One obvious expression of that complexity is the great range of different volcanic phenomena across our planet, more specifically, the high variability in the frequency of volcanic eruptions. Some volcanoes are in a virtually non-stop process of eruption, like Mount Stromboli in Italy, and conversely some volcanoes may lie dormant for centuries before erupting again, like Mount Pinatubo in the Philippines, which awakened in 1991 after a centuries-long period of calm, resulting in one of the most catastrophic eruptions of the twentieth century. Because of this complexity, at the present time long-term deterministic prediction of volcanic eruptions is unfeasible. For this reason, statistical analysis is the only valid scientific tool. From a physical and mathematical standpoint, the complexity of volcanism finds expression in its pronounced non-linearity. In other words, small variations in the interior of the Earth are capable of bringing about relevant changes in volcanic activity at the surface. As a result, eruptions in most volcanoes are marked not by regularity but by the converse, and a volcano may experience eruptions in the span of just a few years and then lie dormant for scores of years. It has been possible to develop statistics that fit the special characteristics of certain individual volcanoes. However, for most volcanoes detailed statistical analysis is not possible because of the small number of eruptions that have been able to be precisely dated. In this respect, studies performed on a worldwide scale have indicated that, on average, for the approximately 1,500 volcanoes on planet Earth, the interval between one eruption of a volcano and the next by that same volcano follows a Poisson distribution. That is to say, according to this model, a volcano has no memory of its history after an eruption, and the interval to the next eruption depends only on one specific factor, the mean interval between one eruption and the next. For volcanoes with a historical record like those in the Canary Islands, that factor can be calculated directly. The probability of occurrence of an eruption for an interval ΔT, where T is the mean interval, can be calculated using the formula:

$$P(\Delta \mathrm{T}) = 1 - e^{-\frac{\Delta T}{T}}$$

For example, according to the historical record, the Cumbre Vieja volcano on La Palma has erupted seven times in the past 600 years, which yields a mean interval of 85.7 years between eruptions. According to the preceding formula, the probability that the Cumbre Vieja volcano will erupt in a time window of 50 years is 44.2%. Table 2 lists the probabilities that an eruption will take place in the Canary Islands as a whole and on some of the islands in the group over different time intervals. In addition to giving the probabilities for the volcanic systems on the islands of La Palma and Tenerife, which have undergone an appreciable number of recorded eruptions, the Table also gives the probability for systems like that of Grand Canary Island, which has not experienced any eruption during the historical period but has been the site of twenty-odd eruptions over the past 10,000 years.

	5 years	10 years	50 years	100 years	500 years
Canary Islands	12.5%	23.4%	73.6%	93.1%	100.0%
La Palma	5.7%	11.0%	44.2%	68.9%	99.7%
Tenerife	4.9%	9.5%	39.4%	63.2%	99.3%
Grand Canary	1.1%	2.2%	10.3%	19.6%	66.4%
Fogo	25.1%	43.8%	94.4%	99.7%	100.0%

Table 2. Probability of future eruptions in the Canary Islands and Fogo (Cape Verde) over different time windows.

The probabilities of a future eruption of the Pico do Fogo volcano, an island volcanic system in the Cape Verde islands quite similar to those in the Canary Islands geologically but with more frequent eruptions, have also been listed for comparison.

3. Is volcanic risk increasing in the Canary Islands?

Volcanic risk is a sensitive area of civil defence that compromises, or may very well compromise, calamitously people's lives and personal safety and the welfare of their property and the collective heritage. Regarding that risk, the recent geological history of the Canary Islands has demonstrated that these islands have been the site not only of volcanic eruptions with low explosivity index values but also of eruptions with moderate to high explosivity index values.

Distinguishing between the concepts of danger and volcanic risk, it is to be noted in this respect that at the present time, volcanic risk in the Canary Islands is greater than several decades ago because currently there are more people and greater economic development exposed to volcanic events (Figure 4).

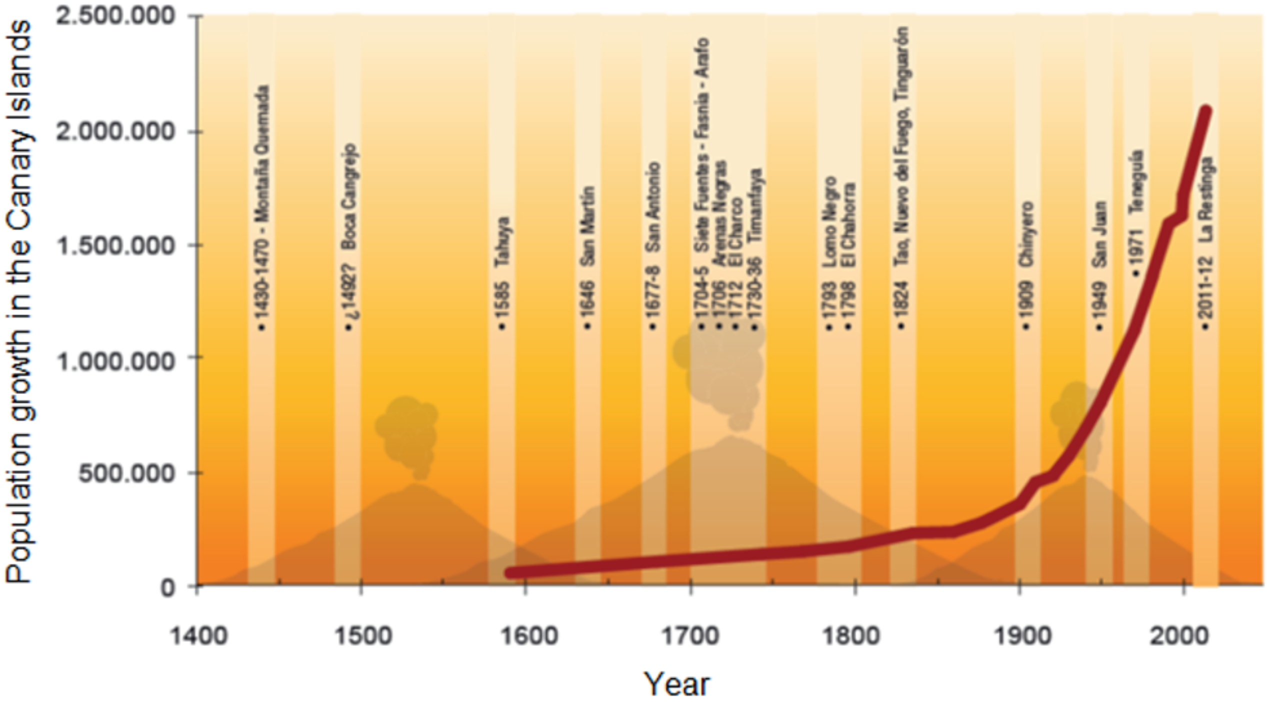

Figure 4. Population growth in the Canary Islands and historic eruptions since the fourteenth century.

Figure 5 depicts an image of the extent of lava flows from the Arafo eruption in 1705 projected onto an aerial photograph of the Güimar Valley in the present day. That eruption lasted 54 days (2 February 1705 – 27 March 1705) and was part of the triple eruption of the Siete Fuentes-Fasnia-Arafo volcanoes that took place at the end of 1704 and beginning of 1705. Had this eruption taken place not in 1705 but today, the lava flows would have devastated the entire main population centre of Güimar. This hypothetical scenario clearly shows why volcanic risk is on the rise in the Canary Islands, namely, because population growth in the Canary Islands has resulted in expansion over more territory.

The property damage caused by historic eruptions in the Canary Islands depended on the impact of the different volcanic hazards associated with those eruptions. Homes, infrastructure, and farmland were destroyed by the effects of the lava flows. Plant cover and farmland were damaged and destroyed by pyroclastic falls. There were landslides, flows in watercourses decreased, rooftops caved in, and buildings collapsed from the seismic activity linked to the eruptions.

Turning to the loss of human life, historic eruptions in the Canary Islands have caused the deaths of at least 24 people; certain historical documents mention the loss of human lives but do not give a number (Table 3). It is noteworthy that 16 of the 24 lives lost were associated with volcanic earthquakes that took place during the Siete Fuentes-Fasnia-Arafo eruption in 1704-05. The rest of the fatalities were caused by volcanic gases, posteruptive lahars, and even volcanic ash falls.

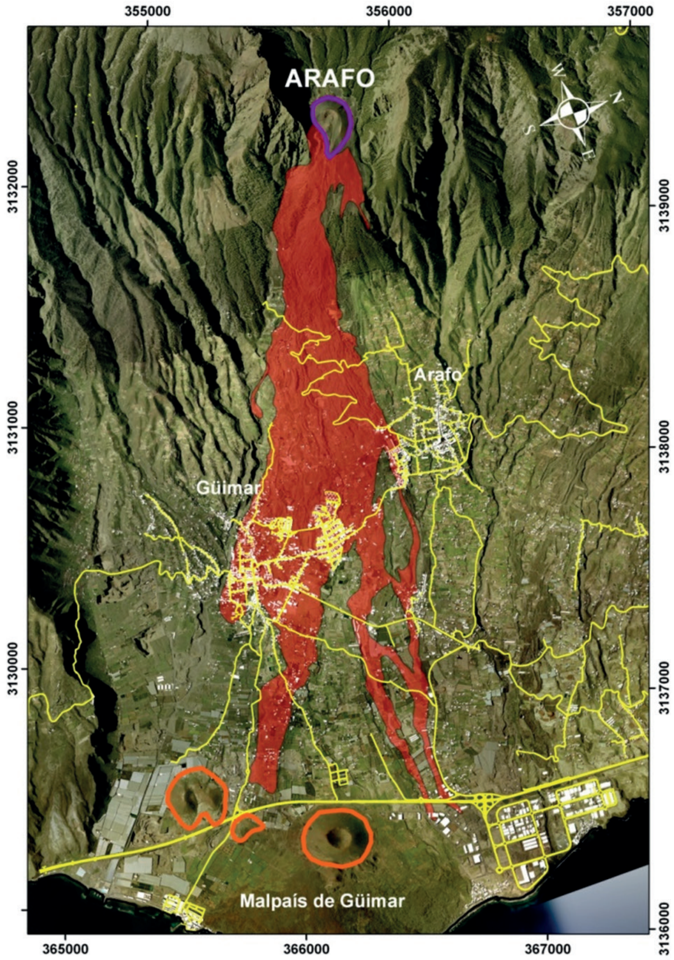

Figure 5. Map illustrating the extent of lava flows from the Arafo eruption in 1705.

Eruption	Year	No. of victims	Cause
Tehuya	1585	Multiple	Noxious gases
		Number not reported	Associated with falling ash
San Antonio	1677-78	3	Cause not reported
		1	Noxious gases
Arafo-Fasnia-Siete Fuentes	1704-05	16	Volcanic earthquakes
Timanfaya	1730-36	1	Cause not reported
San Juan	1949	1	Missing
		Number not reported	Posteruptive lahars
Teneguía	1971	2	Noxious gases
TOTAL		**24**	

Table 3. Number of victims caused by historical eruptions in the Canary Islands.

The "GeoMEP – Modelo de Evaluación de Pérdidas por Peligros Geológicos. Aplicación al Caso de las Islas Canarias [*Model for Assessing Losses from Geological Hazards. Application to the Canary Islands*]" study, prepared by the Spanish Geological Survey [*Instituto Geológico y Minero de España* (IGME)] and published by the Consorcio de Compensación de Seguros (CCS), shows that the volcanic hazard is unquestionably the risk that could have the greatest economic impact on the Canary Islands, as compared to such other natural hazards as floods and earthquakes. Looking specifically at the case of Tenerife, with a probability less than or equal to 0.2% per year, the sums insured against damage from lava flows could come to some 5.5 billion euros. Another 2.5 billion euros in further losses would lack insurance coverage (Llorente Isidro M., 2015).

4. Awareness of volcanic risk by Canary Island society

Even though Basic Civil Protection Planning Guidelines and Volcanic Risk in Spain have been in place since 1996, awareness of the volcanic hazard and of the steps to be taken to reduce or mitigate volcanic risk by the citizens of Spain is low and insufficient. There is much and varied evidence to that effect.

There may be a range of causes for the low awareness of the volcanic hazard in Spain, chief among which could be (a) Spanish society's short memory concerning natural phenomena of this kind because of the relatively low frequency of volcanic eruptions during the past 600 years; (b) disinformation that historic eruptions in the Canary Islands have caused no loss of human life spread in society by certain sectors; (c) the idea that the most likely volcanic scenario in the Canary Islands (basaltic fissure eruptions) does not pose a substantial risk to inhabitants, because in the past (the last 600 years) natural events of this type have not caused large numbers of human fatalities, overlooking the fact that population density and land use today are much greater than before; (d) the belief by some scientists, and communication of that belief to society, that volcanic eruptions in the Canary Islands are and will be quiet, ignoring the fact that that term should never be used to describe any deleterious natural phenomenon, however small in size it may be and however minor its potential effects may be; (e) the belief that future volcanic eruptions in the Canary Islands will only be like the ones that have occurred in the past 600 years, overlooking the fact that more dangerous eruptions have taken place in the islands in the recent geological past (the last 10,000 years); and (f) conflation of the concepts of danger and volcanic risk and the probability of occurrence of an eruption event.

5. Future challenges to reduce volcanic risk in the Canary Islands

Society faces a number of challenges to lower the volcanic risk in the Canary Islands. Based on the preceding discussion, these include: (1) fulfilling unanimous calls by the legislature for the Instituto Volcanológico de Canarias (INVOLCAN) [*Volcanology Institute of the Canary Islands*] to bring together all public efforts to optimise scientific volcanic risk management; (2) putting in place the necessary legislative mechanisms to provide ongoing funding to strengthen research for lowering volcanic risk in the Canary Islands; (3) improving assessments of the economic costs posed by volcanic risk in the Canary Islands in the next 50 years; (4) carrying out regular information and educational campaigns concerning volcanoes and management of volcanic risk in the Canary Islands for both residents and tourists to help break the equivalence volcano = alarm and instead reinforce the message volcano = alert + opportunities; and lastly, most probably one of the most important challenges, designing and strengthening a solid programme of communications regarding volcanic risk management.

5.1. Communication and volcanic risk management

Suitable communication among all organisations, institutions, and private parties interested in volcanic risk management is vital to be able to reduce disaster risk. The importance of this type of communication has been gaining recognition over the past 20 years, and it is an integral part of volcanic emergency response planning in the advanced countries (Solana C. *et al*., 2017).

Our understanding of what comprises suitable communication has changed from its merely being a one-way flow of information to its being a participatory process with room for the opinions of all stakeholders and interested individuals and for listening to and considering their points of view.

From a scientific standpoint, this communication includes preparing all parties affected by volcanic risk, from the authorities in charge, to responders and the media (including social networks), and to other stakeholders like non-governmental organisations (NGOs), companies and businesses, educators, and the general public, in advance of an emergency. Proper handling of communication and information expectations ahead of an emergency is crucial to the successful handling of a volcanic crisis.

Planning and scientific information management during an emergency should include not only a consensus among all the parties making up the scientific committee concerning the information to be released to key groups (e.g., the people in charge of the emergency, the mass media, and the general public). It should also specify the most suitable format for each of those groups and methods to ensure that the message and its consequences have been understood. This entails arranging, in parallel to the response plan, a specific information plan for each key group in the emergency, at least one for the group in charge and the action group and another for the media. It is critically important for that information plan to have been agreed to by all the groups in advance and for it to comprise the information of interest to each group, the amount and the frequency of release of the information, the information format, and a verification and response mechanism. The globalised nature of the population and information today further requires taking into account the languages of the permanent local residents and the transient population (tourists) and issuing announcements to the international press.

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