Probabilistic E-tools for Hazard Assessment and Risk Management

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Abstract

The impact of a natural event can significantly affect human life and the environment. Although fascinating, a volcanic eruption creates similar or even greater problems than more frequent natural events due to its multi-hazard nature and the intensity and extent of its potential impact. It is possible to live near a volcanic area and take advantage of the benefits that volcanoes offer, but it is also important to be aware of the existing threats and to know how to minimise risks. In this chapter, we present an integrated approach using e-tools for assessing volcanic hazard and risk management. These tools have been especially designed to assess and manage volcanic risk, to evaluate long- and short-term volcanic hazards, to conduct vulnerability analysis, and to assist decision-makers during the management of a volcanic crisis. The methodology proposed here can be implemented before an emergency in order to identify optimum mitigating actions and how these may have to be adapted as new information is obtained. These tools also allow us identifying the most appropriate probabilistic and statistical techniques for volcanological data analysis and treatment in the context of quantitative hazard and risk assessments. Understanding volcanic unrest, forecasting volcanic eruptions, and predicting the most probable scenarios, all imply a high degree of inherent uncertainty, which needs to be quantified and clearly explained when transmitting scientific information to decision-makers.

Resumen

El impacto de un evento natural puede afectar significativamente la vida humana y el medio ambiente. Aunque fascinante, una erupción volcánica

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puede generar problemas parecidos o incluso mayores que otros eventos naturales más frecuentes, ya que se trata de un fenómeno multipeligro y con un impacto potencial de gran intensidad y magnitud. Vivir cerca de una zona volcánica es posible considerando sus innumerables beneficios, pero sin embargo debemos ser conscientes de la amenaza existente y tomar las medidas oportunas para minimizar el riesgo. En este capítulo, se presenta un enfoque integrado que utiliza herramientas para la evaluación de la peligrosidad y del riesgo volcánico, el análisis de vulnerabilidad, y para ayudar en la gestión de una crisis volcánica. La metodología aquí propuesta puede ser implementada antes de una emergencia con el fin de determinar las medidas óptimas de mitigación y como pueden adaptarse a medida que se obtiene nueva información. Además, estas herramientas se basan en las técnicas probabilísticas y estadísticas más adecuadas para el análisis de datos vulcanológicos y su implementación en el contexto de las evaluaciones cuantitativas del peligro y riesgo. La interpretación del *unrest*, la predicción de las erupciones volcánicas, y la identificación de los escenarios más probables, implican un alto grado de incertidumbre, que debe ser cuantificado y claramente explicado para transmitir correctamente la información científica a los gestores de las crisis volcánicas.

Keywords

Volcanic risk · Volcanic hazard · Vulnerability · Risk management · Decision-making · E-tools

Introduction

One of the most important tasks in modern volcanology is to manage volcanic risk and, consequently, to minimise it. Forecasting volcanic eruptions and predicting the most probable scenarios are tasks that are subject to high degrees of uncertainty but which need to be quantified and clearly explained when transmitting scientific information to decision-makers. Assessing eruption risk scenarios in probabilistic ways has become one of the main challenges tackled by modern volcanology (Newhall and Hoblitt 2002; Marzocchi et al. 2004; Aspinall 2006; Neri et al. 2008; Sobradelo et al. 2014).

The volcanic management cycle consists of four phases (Sobradelo et al. 2015): (i) the pre-unrest phase that includes long-term assessment, hazard and risk mapping, and estimation regarding expected scenarios, volcano monitoring, and emergency planning; (ii) the unrest phase, which includes short-term assessment, alert, communication, and information procedures, the implementation of emergency measures, and the interpretation of eruption precursors; (iii) the volcanic event itself, represented by a major change in the state of the volcano; decisions can be revised as new information is obtained and the evolution of the volcanic event is updated; (iv) the post-event phase characterized by rescue and recovery.

Previous studies, focusing attention on the first phase of volcanic crisis management, have developed different methodologies for evaluating

hazards. Most of these studies are based on the use of simulation models and Geographic Information Systems (GIS) that enable volcanic hazards such as lava flows, pyroclastic density currents (PDCs), and ash fallout to be modeled and visualised (Felpeto et al. 2007; Toyos et al. 2007; Cappello et al. 2012; Martí et al. 2012; Becerril et al. 2014; Bartolini et al. 2014a, b). The use of spatio-temporal data and GIS has now become an essential part of integrated approaches to disaster risk management in light of the development of new analysis/modelling techniques. These spatial information systems are used for storage, situation analysis, modelling, and visualisation (Twigg 2004). Normally, these studies present a systematic approach based on the estimation of spatial probability, that is, a susceptibility analysis (Martí and Felpeto 2010), a temporal analysis based on Bayesian inference (Marzocchi et al. 2004; Sobradelo et al. 2014), or the evaluation of hazards (Felpeto et al. 2007; Bartolini et al. 2014a, b; Becerril et al. 2014) and vulnerability (Marti et al. 2008; Scaini et al. 2014). These studies have been applied in a number of volcanic areas such as Etna, Sicily (Cappello et al. 2013), Tenerife, Spain (Martí et al. 2012), Peru (Sandri et al. 2014), the island of El Hierro, Spain (Becerril et al. 2014), and Deception Island, Antarctica (Bartolini et al. 2014a). Other procedures have been employed to assess volcanic hazards in Campi Flegrei, Italy (Lirer et al. 2001), Furnas (São Miguel, Azores), Vesuvius, Italy (Chester et al. 2002), and Auckland, New Zealand (Sandri et al. 2012).

These studies underline the fact that scientists are aware of the relationship between volcanic hazards and socio-economic impacts and are in the process of developing new approaches and models to assess its importance. One positive aspect is that, as a result, there is now a choice of freely available models; on the other hand, these models are not integrated into a single platform and have been developed in a variety of different programming languages.

Despite the fact that these tools have been created for application in real situations and have been successfully tested in different volcanic areas and retrospectively for a number of volcanic crisis (Martí et al. 2012; Sobradelo et al. 2014; Bartolini et al. 2014a, b; Becerril et al. 2014; Scaini et al. 2014), to date they only exist as academic exercises. To convert them into practical tools ready to be used by Civil Protection managers and decision-makers, they must be checked and tested, and then adapted to the real needs of end users.

Probabilities are still the best outcome of scientific forecasting. However, they are not easily understood. Understanding the potential evolution of a volcanic crisis is crucial for designing effective mitigation strategies. One of the main issues when managing a volcanic crisis is how to make scientific information understandable for decision-makers and Civil Protection managers. Thus, we need quantitative risk-based methods for decision-making under conditions of uncertainty that can be developed and applied to volcanology. In order to resolve this problem and to take a step forward in minimising risks, we have defined an integrated approach using user-friendly e-tools, which can be run on personal computers. They are specifically useful for long- and short-term hazard assessment, vulnerability analysis, decision-making, and volcanic risk management. In this chapter, we describe the e-tools designed to manage and to minimise volcanic risk.

Volcanic Risk: Hazard, Vulnerability, and Value

In general, risk is defined as the probability or likely magnitude of a loss (Blong 2000). In volcanic risk assessment, risk depends on the adverse effects of volcanic hazards and can be defined as the product of three main factors: volcanic hazard, vulnerability to those hazards, and the value of what is at risk.

Volcanic hazard is defined as the probability of any particular area being affected by a destructive volcanic event within a given period of time (Blong 2000). The quantification and evaluation of the volcanic hazard allow us determining which areas will be affected by a

given volcanic event, and to design appropriate emergency plans and territorial planning.

A vulnerability assessment uses indicators to quantify the physical vulnerability of the elements of each sub-system (buildings, transportation system, urban services, and population) and is a measurement of the proportion of the value likely to be lost as a result of a given event (Blong 2000). In fact, the values of elements-at-risk that can be directly or indirectly damaged by a given hazard will vary. Each hazardous phenomenon affects elements and infrastructures in different ways in terms of their specific physical vulnerability; this in turn will be depend on their number (of buildings, people, etc.), monetary value, surface area, and the importance of the elements-at-risk. Indicators are used to determine the specific physical vulnerability of each hazardous phenomenon and sub-system (Scaini et al. 2014).

The value is the number of human lives at stake, together with the capital value (land,

buildings, etc.) and productive capacity (factories, power plants, highways, etc.) exposed to the destructive events (Blong 2000).

Risk management is a complex process (Fig. 1) since different steps are necessary for evaluating and minimising risk. It can be thought of as the sum of risk assessment—which includes risk analysis and risk evaluation—and risk control. Risk analysis aims to improve prevention tools through the collection and acquisition of data on hazards and risks, and then to disseminate it in the form of maps and scenarios (Thierry et al. 2015). This phase is characterised by five different steps: hazard identification, hazard assessment, elements-at-risk/exposure analysis, vulnerability assessment, and risk estimation (Van Westen 2013). In particular, it is important to distinguish between long- and short-term hazard assessments, which will vary according to the expected period of time over which the process will display significant variations.
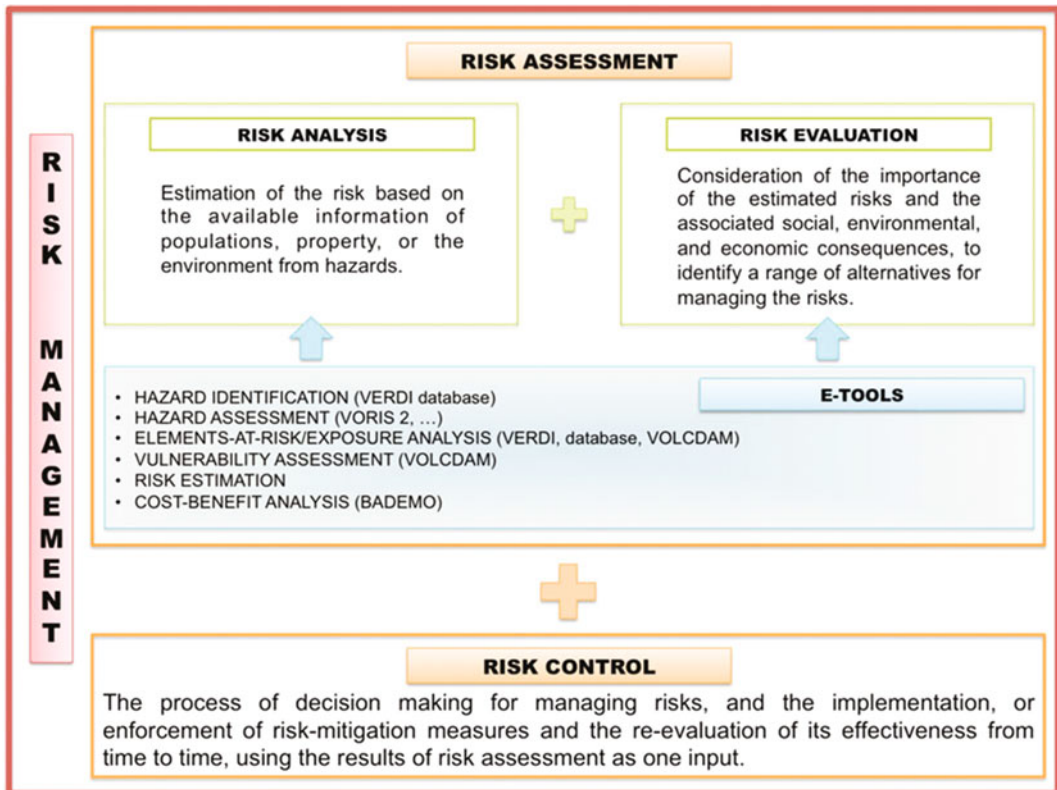

Fig. 1 Risk management schematic: steps for evaluating and minimising risk

Long-term assessment is based on historical and geological data, as well as theoretical models, and refers to the time window available—during which time the volcanic system shows no signs of unrest—before an unrest episode occurs. On the other hand, short-term assessment refers to the unrest phase, and complementary information derived from the combination of a long-term analysis with real-time monitoring data is needed to update the status of the volcanic hazard (Blong 2000). Short-term evaluation helps forecast where and when the eruption may take place and the most likely eruptive scenarios.

Once the long-term risk analysis is computed, it is then possible to adopt mitigation measures such as land-use planning and emergency preparations to reduce the risk. In addition, this long-term analysis will help manage the volcanic crisis as it will constitute the basis for the short-term analysis and, combined with a cost-benefit analysis, will assist in correct decision-making (Sobradelo et al. 2015). To evaluate the total risk related to a particular volcanic eruption we have to repeat the evaluation of the vulnerability and the cost-benefit analysis (risk evaluation) for each possible hazard scenario and then sum the results. This will allow us to estimate the impact and the economic losses that will affect society and the environment, and to identify a range of risk management alternatives.

Finally, the second part of risk management is risk control, which consists of the decision-making process involved in managing risks whose aim is to improve crisis management capabilities and implement risk-mitigation measures using the results of risk assessment as an input (Western 2013). During this phase measures must be adopted for reducing vulnerability (people and infrastructure) and developing recovery and resilience capacities after an event has taken place.

E-tools for Volcanic Hazard and Risk Management

In this section, we present different e-tools that have been specifically designed to assess and manage volcanic risk (Fig. 2). The objective is to combine freely available models to produce a new approach for minimising and managing volcanic risk. These e-tools are based on the assumption that the best way to show how probabilities work is to use the possible scenarios and outcomes of volcanic unrest (an increase in volcanic activity that may or may not precede a volcanic eruption) to design an integrated model that can act as a descriptor of scenarios. The effectiveness of these e-tools has been analysed
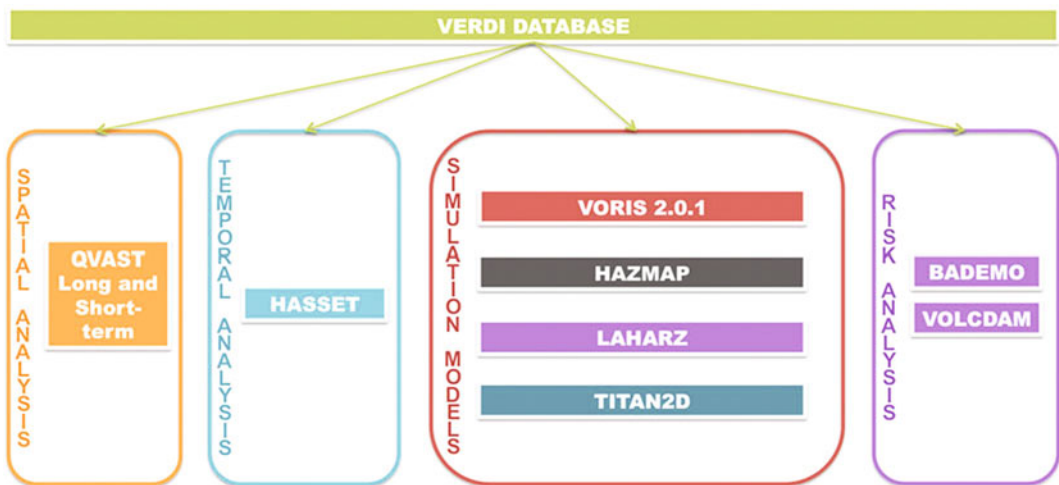

Fig. 2 E-tools for assessing and managing volcanic risk that allow to evaluate the possible hazards that could affect a volcanic area and develop appropriate hazard and risk maps

in different volcanic areas showing pros and contras of these approaches, such as in the case of El Hierro Island in Canary Islands (Becerril et al. 2014; Sobradelo et al. 2015), Tenerife in Canary Islands (Scaini et al. 2014), Deception Island in Antarctica (Bartolini et al. 2014a), and La Garrotxa Volcanic Field in Spain (Bartolini et al. 2014b). User manuals are available at https://volcanbox.wordpress.com/ and http://www.vetools.eu.

These e-tools are designed to be implemented before an emergency in order to identify (i) the optimum mitigating actions and (ii) the most appropriate probabilistic and statistical techniques for volcanological data analysis and treatment in the context of quantitative hazard and risk assessment, and (iii) how appropriate responses may change as new information is obtained. They constitute different steps, as shown in Fig. 3, in hazard assessment and risk management.

Storing Data

The results of our analyses are as important as the input parameters that are used. Given the nature, variety, and availability of the data we need to handle, one of the most important aspects of risk assessment is the management and exchange of information (De la Cruz-Reyna 1996). The quality of the data will determine the evaluation of the volcanic risk, which is an essential part of risk-based decision-making in land-use planning and emergency management. Some of the most relevant issues include how and where to store the data, in which format should they be made available, and how to facilitate its use and exchange. Thus, it is essential to have an appropriate database that is specifically adapted to the task of evaluating and managing volcanic risk. For that reason, we designed VERDI (Volcanic managEment Risk Database desIgn) (Bartolini et al. 2014c), a
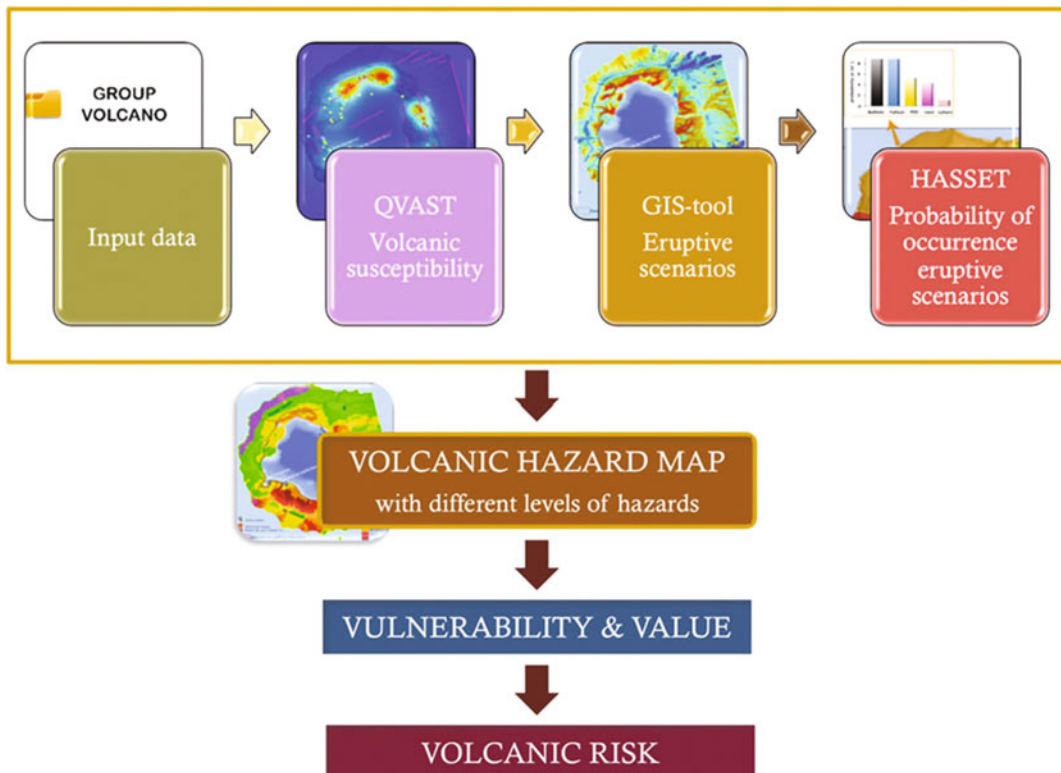

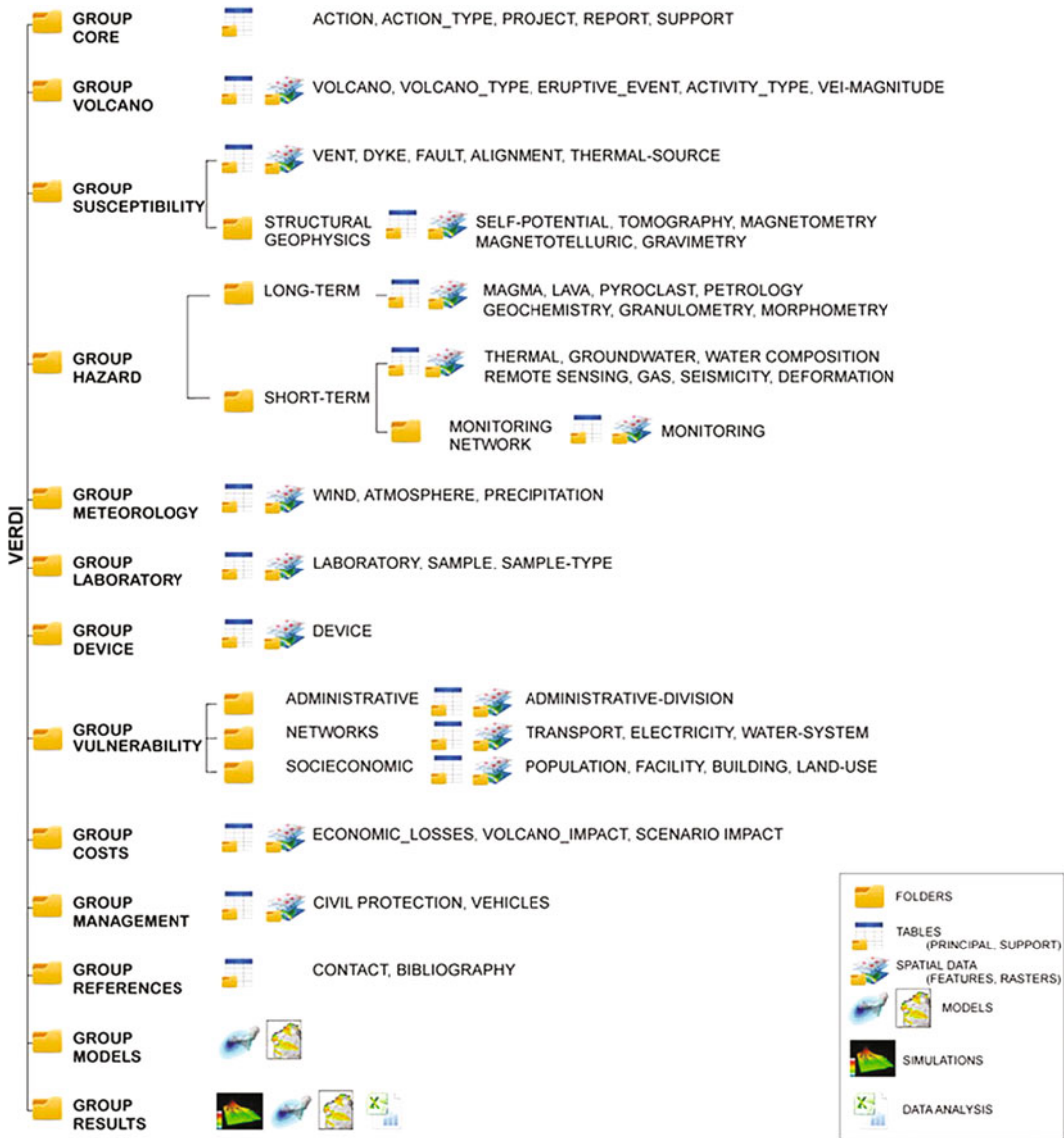**Fig. 3** Steps in volcanic risk assessment applying e-tools to be implemented before an emergency

Fig. 4 The design of the VERDI database (after Bartolini et al. 2014c)

geodatabase with an appropriate architecture for volcanic risk assessment and management that stores the data from which we will extract the input parameters to run our e-tools. VERDI is a spatial database structure (Fig. 4) that allows different types of data, including geological, volcanological, meteorological, monitoring, and socio-economic information, to be manipulated, organised, and managed. The data contained in this database are the basis for applying the probabilistic models that are the first step in our risk analysis.

Hazard E-tools

Volcanic hazard assessment consists of simulating eruptive scenarios for use in risk-based decision-making, land-use planning, and emergency management. They must necessarily be

based on a good knowledge of the past eruptive history of the volcano or volcanic area, and will reveal how volcanoes erupted in the past, thereby providing clues to *how* they will erupt in the future. The first step in the quantitative assessment of volcanic hazards is the spatial probability of occurrence of a hazard, i.e. *where* the next eruption may take place and its extent. This analysis is based on the development of susceptibility maps (Martí and Felpeto 2010), that is, the spatial probability of a future vent opening given the past eruptive activity of a volcano and the simulation of possible eruptive scenarios. Another important task is to investigate the temporal probability, in other words, *when* the next eruption will occur in the future and the type of scenarios that are most likely to be involved. Thus, an evaluation of volcanic hazard enables us to infer where and when the next eruption may take place and its magnitude.

Spatial Analysis

Susceptibility analysis is the evaluation of the spatial distribution of future vent openings (Fig. 5a). This challenging issue is generally tackled using probabilistic methods that use the calculation of a kernel function at each data location to estimate probability density functions (PDFs). Commonly, a Gaussian kernel, describing a normal distribution, is used to estimate local event densities in volcanic fields, which will give the intensity of a new vent opening. This method is based on the distance from nearby volcanic structures and a smoothing parameter, also known as bandwidth. This factor is the most important parameter in the kernel function and represents the degree of randomness in the distribution of past events.

QVAST (QGIS for VolcAnic SuscepTibility), developed by Bartolini et al. (2013), is a new tool designed to generate user-friendly quantitative assessments of volcanic susceptibility (e.g. the probability of hosting a new eruptive vent). QVAST allows an appropriate method for evaluating the bandwidth for the kernel function to be selected on the basis of input parameters and the shapefile geometry, and can also evaluate the PDF with the Gaussian kernel. When different

input data sets are available for the area, the total susceptibility map is obtained by assigning different weights to each of the PDFs, which are then combined via a weighted sum and modeled in a non-homogeneous Poisson process. This e-tool has been used to evaluate susceptibility on the island of El Hierro (Canary Islands) (Becerril et al. 2014) and on Deception Island (Antarctica) (Bartolini et al. 2014a).

When monitoring data generated during an unrest phase are available, the QVAST e-tool can also be used to update the susceptibility map. In fact, seismicity and surface deformation are good indicators of magma movement and during volcanic unrest variations in shallow volcano-tectonic and long-period seismicity, as well as ground deformation, are observed as the magma migrates within the volcanic system (Martí et al. 2013). Thus, QVAST is a highly useful tool that can be applied to both long- and short-term evaluations.

Temporal Analysis

HASSET (Hazard Assessment Event Tree), developed by Sobradelo et al. (2014), is a probability tool built on an event tree structure that uses Bayesian inference to estimate the probability of occurrence of a future volcanic scenario. It also evaluates the most relevant sources of uncertainty in the corresponding volcanic system. Event tree structures (Newhall and Hoblitt 2002) constitute one of the most useful and necessary tools in modern volcanology for assessing the volcanic hazard of future eruptive scenarios. An event tree is a graphic representation of events in the form of nodes and branches. It evaluates the most relevant sources of uncertainty when estimating the probability of occurrence of a future volcanic event.

The objective of this e-tool is to outline all relevant possible outcomes of volcanic unrest at progressively greater detail and to assess the hazard of each scenario by estimating its probability of occurrence within a future time interval. Each node of the event tree represents a step and contains a set of possible branches (the outcomes for that particular category). The nodes are
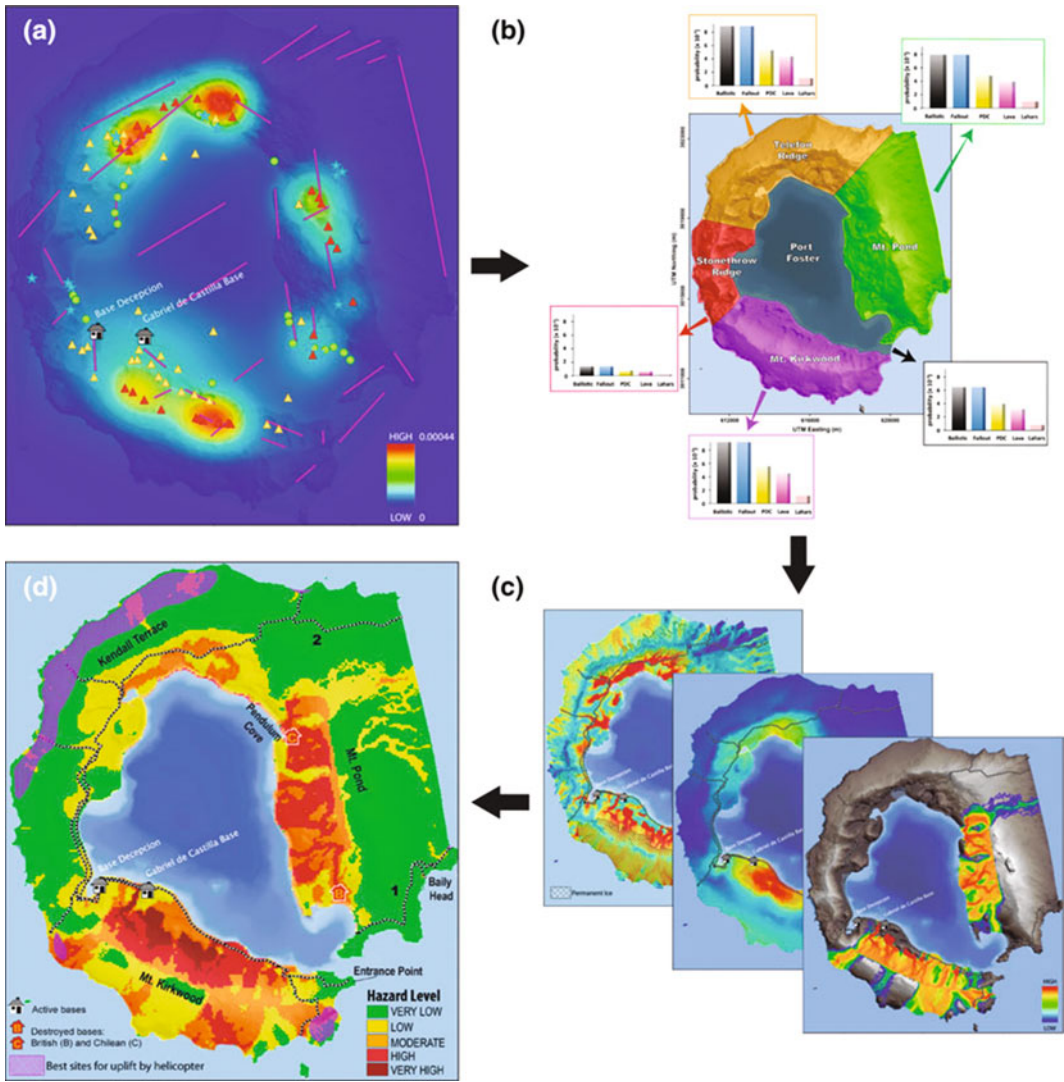
Fig. 5 Methodological approach for obtaining a qualitative hazard map: its application to Deception Island (after Bartolini et al. 2014a)

alternative steps from a general prior event, state, or condition that move towards increasingly specific subsequent events and a final outcome. HASSET (Fig. 5b) uses this event tree structure to make estimations of the probabilities for each possibility (branches and nodes) using a statistical methodology known as Bayesian Inference (Newhall and Hoblitt 2002; Marzocchi et al. 2004; Sobradelo et al. 2014). In particular, and based on comparisons with previous event trees for volcanic eruptions, HASSET accounts for the possibility of (i) flank eruptions (as opposed to

only central eruptions), (ii) geothermal or tectonic unrest (as opposed to only magmatic unrest), and (iii) felsic or mafic lava composition, as well as (iv) certain volcanic hazards as possible outcomes of an eruption, and (v) the distance reached by each hazard.

A user-friendly interface guides the user through all steps and helps

– enter all the data needed for the analysis;
– compute the estimated probability for each branch in the event tree;

– compute the total estimated probability and compare up to five different scenarios.

This tool has been used for determining the eruption probability on El Teide (Tenerife, Spain) (Sobradelo and Martí 2010), El Hierro (Canary Islands) (Becerril et al. 2014), and Deception Island (Antarctica) (Bartolini et al. 2014a).

In both long-term and short-term evaluations HASSET can be useful for determining the occurrence probabilities of eruptive scenarios and can assist decision-makers assess the required mitigation actions associated with each scenario and estimate the corresponding potential risk.

Simulation Models

Simulating eruptive scenarios caused directly (e.g. lava flows, fallout, surges) and indirectly (earthquakes, landslides) by an eruption requires a detailed analysis of the past activity of the volcano or volcanic area, and must take into account all the possible hazards associated with the eruptive activity. Volcanic hazard can be assessed via two different types of approaches: deterministic, which defines a maximum extension area affected by an eruptive episode based on deposits generated by past activity, or probabilistic, based on the probability that a certain area will be affected by an eruptive process. In order to generate hazard maps (Fig. 5d), it is important to understand past eruptive behaviour and to employ physical simulation models that will permit the behaviour of future volcanic activity to be foreseen. In this type of approach, accurate and detailed geographic and cartographic data are required for high-quality analysis with a GIS.

Here, we describe some of the e-tools freely available for download that allow volcanic hazards to be evaluated (Fig. 5c):

– VORIS 2.0.1 is a GIS-based tool, developed by Felpeto et al. (2007) that allows users to simulate lava flows, fallout, and pyroclastic density current scenarios. Lava-flow simulations are based on a probabilistic model that assumes that topography is the most

important factor determining the path of a lava flow. The determination of the probability of each point being invaded by lava is performed by computing several random paths with a Monte Carlo algorithm. Fallout simulation models are advection diffusion models that assume that away from the vent the transport of the particles from a Plinian column is controlled by the advective effect of the wind, by diffusion due to atmospheric turbulence, and by the settling velocity of the particles. The model for simulating pyroclastic density currents is the energy cone model proposed by Sheridan and Malin (1983). The input parameters are the topography, the collapse equivalent height (H), and the collapse equivalent angle (θ). The intersection of the energy cone, originating at the eruptive source, with the ground surface defines the distal limits of the flow.

– HAZMAP is a free program for simulating the sedimentation of volcanic particles at discrete point sources that predicts the corresponding ground deposits (deposit mode) (Macedonio et al. 2005). HAZMAP is also able to evaluate the probability of overcoming a given loading threshold in ground deposits by using a set of different wind profiles recorded on different days (probability mode). Using a statistical set of recorded wind profiles (and/or other input parameters), it can also be used to draw hazard maps for ashfall deposits. In HAZMAP, settling velocities can be calculated using several models as a direct function of particle diameters, densities, and shapes. The advantage of HAZMAP is that it is a simple tool able to predict ashfall during hypothetical or real eruptions of a given magnitude and wind profile.

– LAHARZ is a semi-empirical code for creating hazard-zonation maps that depict estimates of the location and extent of areas inundated by lahars (Schilling 1998). The input parameters for this model are the Digital Elevation Model and the lahar volume, which provide an automated method for mapping areas of potential lahar inundation. These hazard zones can be displayed in a GIS with

other types of volcano hazard information such as the proximal hazard zone, infrastructure, hydrology, and population, as well as contours and shaded relief, to produce volcano hazard-zonation maps. Such maps show the proximity and intersection of potential hazard zones to people and infrastructures.

– TITAN2D is a computer program model developed by the University at Buffalo (Patra et al. 2005) that simulates granular flows over digital elevation models, based on a "thin layer model". The input for the computer code includes simulation time, minimum thickness of the final deposit, internal and bed friction angles, starting coordinates, and the initial speed and direction of the flow. Additionally, this program allows users to define the specific starting pile dimensions or a dynamic flow source. The outputs from the program (represented dynamically) are flow depth and momentum, which yield the deposit limit, run-out path, average flow velocity, inferred deposit thickness, and travel time.

Vulnerability E-tool

Once we have obtained hazard maps, the next step consists of adding population, infrastructures, and land-use data to evaluate the vulnerability associated with the impact of a determined hazard. The data required for generating vulnerability maps are very complex and varied, and depend on the observation scale. Vulnerability is directly dependent on the type of phenomena in question and on the socio-economic characteristics of the environment. VOLCANDAM is a new e-tool based on the methodology developed by Scaini et al. (2014) that generates maps

estimating the expected damage caused by volcanic eruptions. VOLCANDAM (Fig. 6) consists of three main parts: exposure analysis, vulnerability assessment, and the estimation of expected damages. The exposure analysis identifies the elements exposed to the potential hazard and focuses on the relevant assets of the study area (population distribution, social and economic conditions, and productive activities and their role in the regional economy). The vulnerability analysis defines a physical vulnerability indicator for all exposed elements, as well as a corresponding qualitative vulnerability index. Systemic vulnerability considers the possible relevance of each element in the system and their interdependencies by taking into account all exposed and non-exposed elements (people, buildings, transportation network, urban services, and productive activities). Damage assessment is performed by associating a qualitative damage rating to each combination of hazard and vulnerability, bearing in mind their specific contexts and roles in the system. The way one element can be damaged—and thus lose its functionality—depends in fact on the type of hazardous event and the characteristics of the element. The result is damage maps that can be displayed at different levels of detail, depending on user preferences. This tool aims to facilitate territorial planning and risk management in active volcanic areas.

Decision-Making

The evaluation of the "direct costs" and "factors" (indirect costs) that have an impact on the economic growth of an area affected by a volcanic event needs to take into account a number of elements. A cost-benefit analysis may assist the decision-making process by evaluating the economic impact of the different scenarios. The approach used by Sobradelo et al. (2015) (Fig. 7)

Fig. 6 Steps in the vulnerability analysis in the VOLCANDAM approach (after Scaini et al. 2014). See text for details
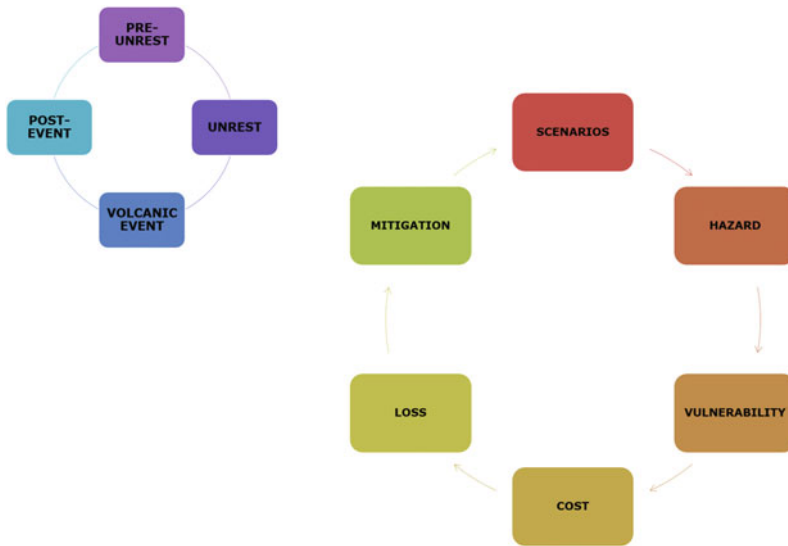
Fig. 7 The volcanic crisis management cycle: stages and phases (after Sobradelo et al. 2015). See text for details

is a Bayesian decision model that applies a general, flexible, probabilistic approach to the management of volcanic crises by combining the hazard and risk factors that decision-makers need for a holistic analysis of a volcanic crisis. These factors include eruption scenarios and their probabilities of occurrence, the vulnerability of populations and their activities, and the costs of false alarms and erroneous forecasts. This model can be implemented before an emergency to (i) pinpoint actions for reducing the vulnerability of a particular area, (ii) identify the optimum mitigating actions during an emergency and how these may change as new information is obtained, (iii) assess after an emergency the effectiveness of a mitigating response and, in light of results, (iv) how to improve strategies before another crisis occurs. BADEMO (BAyesian DEcision MOdel) is part of this integrated approach, and enables the previous analysis of the distribution of local susceptibility and vulnerability to eruptions to be combined with specific costs and potential losses. Indeed, BADEMO should be seen as a tool for improving communication between the monitoring scientists who provide volcanological information and those responsible for deciding which action plans and mitigating strategies should be put into practice.

Discussion and Conclusions

Modern volcanology is a scientific discipline with social and practical applications that derive from its direct involvement in risk reduction. Today, a multidisciplinary approach is required to risk assessment since new methodologies are constantly being developed and explored, and, for example, geo-spatial technologies are becoming extremely helpful in the disaster-risk management. A defined and solid methodology for assessing volcanic hazard and managing risk is fundamental in both long-term evaluations and in unrest phases when monitoring information is available. Furthermore, e-tools can be progressively modified and implemented in light of the outcomes obtained in order to integrate as many models as possible into the assessment and management of volcanic risk.

The possibility of foreseeing an event such as a volcanic eruption is more effective—and guarantees greater economic savings—than acting after a disaster. The potential of simple e-tools such as those presented in this chapter lies in the fact that they are freely available and have been developed on accessible and dynamic graphical user interfaces. The main advantage of

using these e-tools is that new data or new model results can be easily incorporated into the procedures for updating the hazard assessment. By contrast, the use of expensive commercial e-tools hampers the exchange of information and complicates their testing in situ in volcanic fields. Furthermore, non-free tools may hinder effective risk assessment since they are often beyond the means of advisory and management groups with limited financial, technological, and manpower resources (Leidig and Teeuw 2015). However, this does not mean that anybody can use the e-tools discussed here for, on the contrary, they require expertise in volcanic hazards and related issues and their use implies scientific knowledge that will avoid incorrect outcomes.

In this chapter we have presented different statistical methodologies and e-tools for interpreting volcanic data and assessing long- and short-term volcanic hazards and vulnerability, and for carrying out cost-benefit analyses. Statistical analysis enables us to extract information about the future behaviour of a volcano by looking at the geological and historical activity of the volcanic system (VERDI database, Bartolini et al. 2014c). The QVAST tool (Bartolini et al. 2013) can be used to analyse past activity and to calculate the possibility that new vents will open (volcanic susceptibility), while the Bayesian event tree statistical method HASSET (Sobradelo et al. 2014) can be applied to calculate eruption recurrence. Using these calculations, we can identify a number of significant scenarios using GIS-based e-tools (i.e. VORIS 2.0.1, HAZMAP, …) and evaluate the potential extent of the main volcanic hazards expected to occur in volcanic areas. The results obtained allow us to generate volcanic hazard maps for different levels of hazards, evaluate vulnerability (VOLCANDAM e-tools, Scaini et al. 2014), conduct cost-benefit analysis (BADEMO e-tools, Sobradelo et al. 2015), and, finally, manage volcanic risk.

During a volcanic crisis, emergency plans must be put into practice and so different government departments need to be prepared in advance. Therefore, it is important to have conducted previous long-term hazard assessment —among many other tasks—to properly manage a volcanic crisis. They allow scientists and managers to understand the characteristics of the volcano or volcanic area and its past eruptive history, and to infer the possible eruptive scenarios that may occur in the future. With this previous information, short-term hazard assessment can be conducted when volcanic unrest starts and hazard maps can be drawn up and alert levels be defined; nevertheless, it is important to always bear in mind that the best form of protection is the evacuation of the population at risk. Volcanic monitoring is an essential part of short-term assessment and so should be performed by experts and based on a good understanding of volcanic processes. Despite the possibility of conducting cost-benefit analysis, which can help maintain the economic order, the security and health of the population should always be the main concern.

One of the purposes in the near future is to create a new software platform (VolcanBox, see VETOOLS European Project—www.vetools.eu) with a user-friendly interface. This platform will contain different e-tools that, via a homogeneous and systematic methodology, will help minimise risk. However, the feasibility and applicability of each tool will have to be analysed by different groups of experts with experience in regions possessing different volcanological and socio-economic scenarios. This evaluation must also bear in mind potential end users (i.e. Civil Protection agencies), not only to test the ability of existing tools but also to understand decision-makers' needs and requirements, and train them in the use of these tools. If we are to reduce volcanic risk we must ensure that scientists, managers, and decision-makers are all fully prepared to confront this phenomenon since the best way to guarantee risk reduction is to possess good knowledge of its causes.

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