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Surveying volcanic crises exercises: From open-question questionnaires to a prototype checklist

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A R T I C L E I N F O

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Online multi-choice questionnaire
Emergency measurements
Checklist

A B S T R A C T

Volcanic crisis exercises are usually run to test response capabilities, communication protocols, and decision-making procedures by agencies with responsibilities to cope with scenarios of volcanic unrest with inherent uncertainty, such as volcano observatories and/or civil protection authorities. During the last decades, the use of questionnaires has been increased to evaluate people's knowledge on volcanic hazards and their perception of risk, to better understand their preparedness to respond to emergency measures plans.

In this paper, we present a study carried out within the European Network of Observatories and Research Infrastructures for Volcanology project (EUROVOLC) focused on extracting information on the experience gained during volcanic-crisis exercises by the project's participants and beyond. An open-ended question questionnaire was firstly distributed for a survey within the project community. Through the results obtained, we developed a user-friendly online multi-choice questionnaire that was submitted to the volcanological communities within and outside EUROVOLC. Analyzing the answers to the online questionnaire, we extracted a prototype checklist for guiding the design of such exercises in the future. Our results confirm this type of survey as a very useful tool for gathering information on participants' experience and knowledge, able to understand which data and information may be useful when designing exercises for scientists, emergency managers and decision makers. In particular, the main lessons learnt regard the need i) to increase training activities involving people exposed to volcanic hazards and media, ii) to improve external communication tools (between players and public/media), equipment and protocols and iii) to better define decision-makers' needs.

1. Introduction

In the field of emergency management, exercises or simulations are used to test response and procedures and to train personnel. In this context, these exercises range from small to large-scale ones, conducted at local, national, and international levels (Doyle et al., 2015).

Typically, the volcanic-crisis exercise is a learning experience with interactivity of roles aimed to simulate a pre-defined scenario (e.g., van Ments, 1999; Errington, 1997, 2011; Dohaney et al., 2015; Witham et al., 2020) showing a build-up of different monitoring parameters (such as seismic activity, ground deformation, temperature anomalies, changes in water chemistry, and changes in volcanic gas emissions) which could culminate in a small-to high-size eruption. Exercises are usually run to test crisis response capabilities, communication protocols, and decision-making procedures by the staff of responding agencies (e.g., volcano observatories or civil protection authorities) for a hypothetical scenario of accelerating volcanic unrest (Pierson et al., 2013).

These exercises aim to simulate the reality of a developing crisis, lasting from a few hours to some days (based on the size of the exercises). The organizers observe and query participants, taking notes

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throughout the exercise. Data and information on the unrest are delivered in different moments (stages) of the exercise with participants having a specific time to evaluate and record their actions during the just-completed stage. The data and information about the simulated (volcanic) phenomena are generally shown to participants by projections of time-sequential maps showing the locations of the phenomena, or by simulated tables and files of data, and handouts may be given to inform of the latest data regarding the developing crisis. Besides the exercise organizers, several independent observers can listen to the conversations and ask questions, to make independent third-party evaluations of task accomplishment during the exercise. External participants usually take part in debriefing sessions to collect the first thoughts, reactions, and impressions on the exercise (e.g., Beerens and Tehler, 2016).

Exercises may be mainly divided into "tabletop" and "full-scale". The former involve the command-and-control chain of emergency response (at national, regional or municipality scale, depending on the exercises) and test multiple functions of an organization's operational plan, focusing on the coordination, integration, interaction among the different components, procedures, roles, and responsibilities before, during, or after the simulated event (MIAVITA, 2012). The latter is more appropriate to test the delivery times and implementation of capacity on the field. To make a full-scale exercise realistic and credible, it is necessary to commit relevant resources. Nevertheless, full-scale exercises are fundamental to test the whole civil protection response. Usually, once an emergency plan is issued and some table-top exercises have already been performed, full-scale exercises contribute in a large part to validate the plan, and to consolidate all the procedures (road access, traffic problems, enforced evacuation, communication systems, etc.; MIAVITA, 2012).

The questionnaire-based survey in volcanic emergency procedures can serve as a valuable tool for gathering insights and feedback from stakeholders involved in the management of volcanic crises, but it is also a popular tool within social science research for acquiring information on participant social characteristics, standards of behavior or attitudes with respect to the topic under investigation (Bulmer, 2004; Bird, 2009 and references therein).

In the last decades, many field survey were carried out, using questionnaires designed mainly devoted to assess residents' volcanic hazard and risk perception and how such perception could be related with people's preparedness facing a volcanic emergency (e.g., Anderson-Berry, 2003; Dibben and Chester, 1999; Dominey-Howes and Minos-Minopoulos, 2004; Davis et al., 2005; Barberi et al., 2008; Njome et al., 2010; Jóhannesdóttir and Gísladóttir, 2010; Ricci et al., 2013a), or to test the procedural weaknesses that could emerge during a real crisis (e.g., Martin, 1992; Paton et al., 1999; Kurita et al., 2006; Ricci et al., 2013b; Tobin et al., 2011; Pierson et al., 2013).

The key findings from the questionnaire-based survey analysis can be used to inform the development of a prototype checklist for volcanic crisis exercises. The identified checklist items, recommendations, and insights gained from the survey responses aim to address the gaps, challenges, and specific needs identified, for the effectiveness and efficiency of volcanic crisis exercises and planning. The prototype checklist can be shared with stakeholders and experts for feedback and validation, considering further refinement and adjustment based on new potential insights and recommendations received. The first checklist in planning a volcanic exercise was proposed by Bretton et al. (2019) after the experience collected in VUELCO Volcanic Project's simulations. Recently, Newhall et al. (2020) and Lowenstern et al. (2022) discussed the importance of the use of checklists in current practice at Volcano Observatories.

However, the volcanological community is still called to actively address in several research gaps including: i) standardized protocols and evaluation methods for evaluating and comparing volcanic exercises across different volcanic regions; ii) realistic scenarios (such as multi-vent eruptions, occurrence of pyroclastic flows, lahars, and volcanic gas emissions) to enhance preparedness and response capabilities; iii) communication and public engagement to disseminate accurate information, manage public perception, and facilitate appropriate actions; iv) decision support tools integrating real-time data, and probabilistic hazard assessments to aid decision-making during volcanic crises; v) risk assessment and mitigation strategies to improve hazard and vulnerability assessments, and long-term resilience planning, considering the recovery and reconstruction phases after volcanic events.

In this light, collecting insights about exercises from both the international volcanological community and the civil protection authorities, developing a standard base prototype checklist based on global experience can enhance the effectiveness of volcanic crisis exercises, improve preparedness and response capabilities, contributing to the mitigation of volcanic risks and the protection of vulnerable communities.

In this work, we describe the outcomes of a questionnaire developed to collect information and personal evaluation on the experience gained during volcanic-crisis exercises by the participants of the EUROVOLC (European Network of Observatories and Research Infrastructures for Volcanology) project (https://eurovolc.eu/; last access: 24/06/2023). This project carried out networking and joint research activities and offered trans-national and virtual access to the main European volcano observatories and volcano research infrastructures through activities that addressed four broad transversal themes as: (i) community building; (ii) volcano-atmosphere interaction; (iii) sub-surface progress; and (iv) volcanic crisis preparedness and risk management. Successively, we extended the audience of this survey to a larger volcanological community trying to reach out the maximum number of scientists, technicians and decision-makers who took part in some past volcanic-crisis exercises and in other routine exercises that are internally run at volcano observatories. As final output, we built a prototypical checklist based on the experience collected through questionnaires.

2. Methods

In this section we describe the workflow from the review of past experience in tabletop and full-scale simulation exercises to the development of the prototypical checklist as shown in Fig. 1. First, we created the open-question questionnaire (OQQ; see section 2.1) that was circulated within the EUROVOLC community, inviting people who had organized or taken part in a tabletop exercise to participate. We also asked EUROVOLC partners to distribute it to those civil protection agencies who were not part of EUROVOLC, but with whom they routinely work in their countries.

Information contained in the collected answers was then summarized and categorized (see Supplementary Material S1) as results of the initial pilot survey of EUROVOLC, and then used for the design of a survey comprised of multiple-choice form (OMCF; see section 2.2) to be used in the international volcano risk management community.

In this study, the OMCF was first structured as a Google Form and then as a PDF form, and made available in four different languages (English, Spanish, French and Italian). Although the research community is largely fluent in English, the translation has increased the accessibility to local civil protection officials and to participants coming from different countries. The latest version of the OMCF is freely accessible for download at the Zenodo open-access repository in all four languages (Massaro et al., 2023a; Supplementary Material S4).

For both questionnaires (OQQ and OMCF), the included volunteer organizers and players that were involved in past volcanic crisis simulation exercises. Organizers are considered those who designed, ran, managed, and oversaw an exercise, also including data analysts and feedback presenters (e.g., debriefers). Instead, players complete the exercise, either as individuals or groups.

The OQQs were sent out and collected in the second year of the project, so approximately the survey was open for 8 months. We then analyzed the results and designed the OMCF in the third year of EUROVOLC project, and by February 2021 (original end of EUROVOLC,

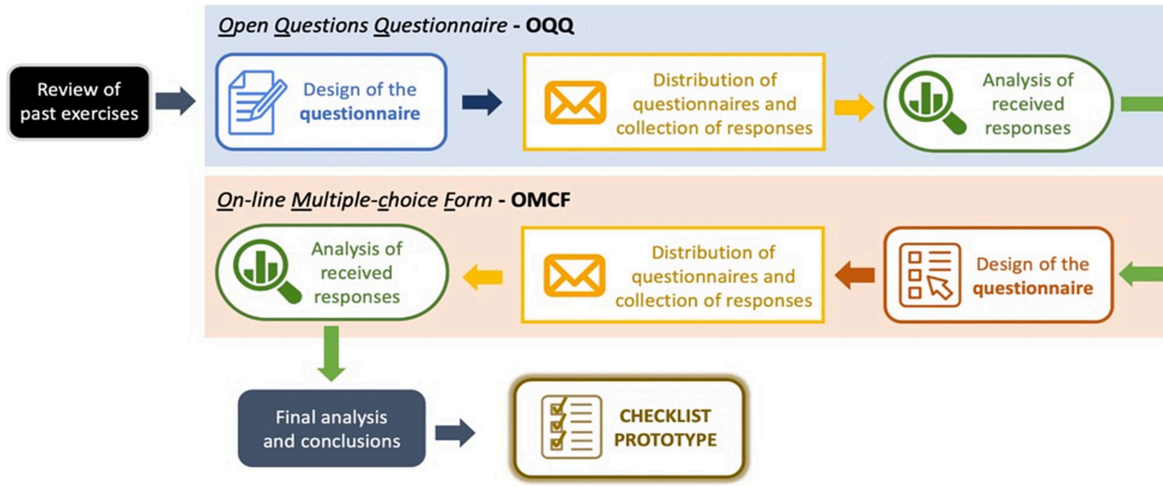

Fig. 1. Workflow from the review of experience in tabletop and full-scale simulation exercises up to the development of the prototypal checklist. OQQ: open-question questionnaire; OMCF: online multiple-choice form.

that then got extended to October 2021 due to COVID19 pandemics) we had already started sending out the OMCF link. The links (in the 4 different languages) are still alive and open.

Finally, we analyzed the information extracted from the received OMCF responses (Supplementary Materials S2-S3) to construct a prototypal checklist to be used when preparing an exercise. We remark that this checklist is an in-progress tool that should be further improved in the future. The latest version of the checklist is freely accessible for download at the Zenodo open-access repository (Massaro et al., 2023b; Supplementary Material S5).

2.1. Design, dissemination, and analysis of responses of the questionnaires

Methodological practices for questionnaires include the definition of the response format (e.g., open/closed questions), mode of delivery, sampling technique, response rate and easy access to the questionnaire to allow the reproduction of the comparison with similar studies (i.e., Bulmer, 2004; Bird, 2009). The length should be also considered since the questionnaire requires only necessary questions (Sarantakos, 2005) as it should take no longer to complete than participants are willing to spend time answering and the interviewer is able to commit (including the time commitment of data entry and analysis).

Typically, closed questions are difficult to construct but easy to analyze (often used within quantitative research) whereas open questions are easy to construct but difficult to analyze due to verbatim comments adding depth and meaning, inviting participants to share their understandings, experiences, reactions, opinions and interpretations of social processes and situations (McGuirk and O'Neill, 2005). Thus, a combination of closed and open questions may be used to provide the survey write-up with quantifiable and in-depth results.

In this study, we used the mixed methods approach, utilizing a qualitative pilot study followed by a quantitative main study which allows for a comprehensive understanding of the role of checklists in volcanic crisis exercises. The qualitative pilot study helped us to refine multiple-choice questions by capturing a range of possible ways of conducting exercises. It also enabled the identification of key challenges, topics, and outcomes that are meaningful to participants, allowing for triangulation and validation of findings, and enhancing the overall robustness of the study.

2.1.1. Open-question questionnaire (OQQ)

The OQQ was formulated in a live brainstorming meeting during the EUROVOLC project. Participants from eight different countries (Iceland, Italy, Ireland, France, Portugal, Spain, Switzerland, and UK) met live and started discussing their experience in full-scale or table-top exercises, trying to put down a list of open questions covering the relevant aspects perceived. Considering the aspects mentioned before, the OQQ was composed of three main sections: (1) Exercise organization and lessons learned; (2) Communication issues; and (3) Data and information. The aspects covered in each of the sections are listed in Table 1.

The OQQ was sent to the EUROVOLC project's participants by email, inviting to fill it in those from the research community and civil protection agencies had played or organized a volcanic-crisis exercise within international projects (e.g., FUTUREVOLC https://futurevolc.hi.is/; VUELCO http://www.vuelco.net/) or national projects (e.g., MESIMEX, https://www.protezionecivile.gov.it/en/approfondimento/2006-mesimex-exercise/, RUAUMOKO, https://dpmc.govt.nz/sites/default/files/2019-11/dpmc-roiar-oia-2019-20-0222-exercise-ruaumoko-final-report.pdfor in routinely planned exercises.

For each question included in the OQQ we analyzed the responses by listing a series of bullet points that, combined with each other, were used

Table 1
List of aspects covered in each of the sections of the OQQ.

OQQ Section	Covered aspects
Exercise organization and lessons learned	• What were the goals of the exercises you organized/took part in? • Which were the main lessons learnt from the exercise in terms of the emergency procedure (e.g., aspects of the emergency procedure that you changed/improved as a result of the exercise)? • Which were the main lessons learnt from the exercise in terms of the exercise itself (e.g., institutions to be involved; maximum number of people/agencies to be involved; exercise duration; exercise products; information provided during the exercise)? • Which scientific information did you use during the exercise? and in what form (e.g., plots, tables, maps)? • Which are the key elements for the table-top exercise to be effective for all institutions involved?
Communication issues	• Which type of information/data were available? • Which communication channels were used? • How to guarantee a transfer of knowledge? • How can scientists and civil protection share the message prior and during a crisis?
Data and information	• What data, among the many we have, was essential for civil protection? • What data/information is needed prior to an eruption to be ready when an unrest starts?

to summarize the content of all the answers received. An example of this procedure is shown in Fig. 2 and the full list of responses to the OQQ and related bullet points per question is provided in Supplementary Material S1. For each specific question, we counted the number of questionnaires in which each bullet point was mentioned. Then, we estimated the corresponding percentage considering the total number of responses received (8; Fig. 3). Results were plotted in bar charts to facilitate their analysis (see all graphs included in Supplementary Material S1).

2.1.2. Online multiple-choice form (OMCF)

The OMCF, user-friendly and easy-to-complete (about 15 min is the estimated time required to fill it in), is composed of 37 questions distributed in eight different sections (some of them reserved to scientists and others to decision-makers/civil protection officers; see Table 2).

The OMCF was first distributed via e-mail among the EUROVOLC community (about 100 receivers), asking those who had already compiled the OQQ to kindly also complete the OMCF on the same experience.

Successively, it was distributed among the participants of the joint workshop between the LAVA (https://anr.fr/Project-ANR-16-CE39-0009, an ANR-funded French project) and EVE (http://www.evevolcanoearlywarning.eu/, an EU-funded project) projects held online on April 12–15, 2021 (http://www.evevolcanoearlywarning.eu/la-reunion-workshop/). In particular, together with the LAVA-EVE workshop's organizing committee, who was expecting participants from civil protections from France, Italy, Spain, UK, Iceland, DR Congo, USA and Ecuador, we distributed the OMCF to the workshop participants, as one of the planned activities in the workshop was an exercise of expert elicitation about scientific response to effusive crises. The estimated number of receivers in this audience was about 50–100 people.

The OMCF was distributed through the Volcano Listserv and the mailing list of the Asociación Latinoamericana de Volcanología (ALVO; https://www.facebook.com/OficialALVO/).

The Volcano Listserv is a mailing list used for the distribution of volcanic activity reports, conference and field trip announcements, employment opportunities, and other items of interest to the volcanological community. Since its creation in 1984, over 2500 people from 56 nations have joined this list, including university faculty and students, members of various geological surveys, aviation officials, newspaper and television reporters, etc. Currently, it acts as the official mailing list from the IAVCEI (International Association of Volcanology and Chemistry of the Earth's Interior, https://www.iavceivolcano.org). The estimated number of receivers in ALVO is in the order of some hundreds people, considering its members from México, Guatemala, El Salvador, Nicaragua, Costa Rica, Panamá, Colombia, Ecuador, Perú, Argentina and Chile since 2010.

We set up a consent form to be compliant with the General Data Protection Regulation 2016/679 (GDPR). We stated that the collected data may be made available to other researchers for research purposes, however, confidentiality will be protected by removing personal data of respondents. The participant gives consent to the processing of the information given, which may be subject to review by responsible

	Descriptive bullet points					
QUESTION: **What were the goals of the exercises you organized/took part in?**	TOOLS TESTING	TESTING REAL DATA ACQUISITION/ TRANSFER/INTERPRETATION	COMMUNICATION	EMERGENCY PLANS TESTING	DEPLOYMENT MONITORING NETWORK	STAFF TRAINING
Example response 1: The main purpose of the simulation was **to test the usability in a real crisis of some of the tools** developed within the project, in order to facilitate the **probabilistic analysis of data** during volcanic unrest crises. Additional aims consisted in **testing the level of communication** and discussion among scientists as well as between scientists and decision-makers.	X	X	X			
Example response 2: The exercises was designed to **test and practice the first actions of the contingency plans**				X		
Example response 3: The main goals were: i) **to give technical and scientific advice to** the Civil Protection; ii) to test the **efficiency and quickness of communications** and **emergency procedures**; iii) to test the capacity to send teams to other islands to **reinforce permanent monitoring networks with portable stations;** and iv) to train the **requesting procedure of data to third parties institutions** essential for modelling proposes.		X	X	X	X	
Example response 4: The main goals of the exercises are: (i) To test all the **emergency plans approved**; ii) to test the systems implemented; iii) to **test communications systems** implemented; iv) to **train the operational personnel**; v) to **train the connections between entities**.			X	X		X

Fig. 2. Example of simplification of the OQQ responses into bullet points. See Supplementary Material S1b for the complete list of answers and bullet points.

	What were the goals of the exercises you organized/took part in?						Which were the main lessons learnt from the exercise in terms of the emergency procedure?						
	TOOLS TESTING	TESTING REAL DATA ACQUISITION/ TRANSFER/INTERPRETATION	COMMUNICATION	EMERGENCY PLANS TESTING	DEPLOYMENT MONITORING NETWORK	STAFF TRAINING	NO RESPONSE	REVISION OF EMEGENCY PLANS	NEW COMMUNICATION PROTOCOLS, TOOLS AND REDUNDANT EQUIPMENT	IMPROVE SCIENTIFIC AND MONITORING DATA ACCESS	INCREMENT TRAINING ACTIVITIES	IMPROVE AVAILABILITY OF MONITORING EQUIPMENT	REVISION OF HAZARD TOOLS/MAPS/SCENARIOS
Completed questionnaire 1	X	X	X				X						
Completed questionnaire 2				X				X	X				
Completed questionnaire 3		X	X	X	X				X	X	X	X	
Completed questionnaire 4			X	X		X		X					
Completed questionnaire 5		X	X	X					X	X			
Completed questionnaire 6	X	X	X										X
Completed questionnaire 7				X				X	X				
Completed questionnaire 8			X	X				X					
Number of questionnaires with this response	2	4	6	6	1	1	1	4	4	2	1	1	1
Percentage of questionnaires with this response	25	50	75	75	12.5	12.5	12.5	50	50	25	12.5	12.5	12.5

Fig. 3. Scheme of score assignment to the different bullet points per question and completed questionnaire. All scores per bullet point are summed up and the percentage with respect to the total of responses received ($n = 8$) is estimated. See Supplementary Material S1 for the complete analysis and all available graphs.

individuals from the EU for monitoring and audit purposes.

3. Results

3.1. OQQ: data availability and responses obtained

For the OQQ, we had 30 potential responders from 8 different scientific institutions and 5 civil protection agencies from Iceland, Italy, Spain, France, Portugal, and the UK. From these, we only received 8 completed questionnaires (< 30%) corresponding to personnel from 4 scientific institutions and EUROVOLC partners and 2 civil protection agencies. Responses were based on different exercises:

- VUELCO (http://www.vuelco.net/) exercise on Cotopaxi, Ecuador (13/11/2014);
- FUTUREVOLC (https://futurevolc.hi.is/) exercise on Katla, Iceland (26/01/2016);
- FUTUREVOLC (https://futurevolc.hi.is/) exercise on Laki, Iceland (3 days in 01/2016);
- ExeFlegrei at Campi Flegrei, Italy (an exercise organized by Italian Civil Protection -ICP- and involving, among other players, Istituto Nazionale de Geofisica e Vulcanologia -INGV-), for which INGV and ICP reported from different points of view (from 16 to 19/10/2019);
- Routinary exercises in Iceland and Azores;

Here we provide a summary of the outcomes obtained from the analysis of the OQQ responses. The reader is referred to the Supplementary Material S1 for further details and a complete analysis of the responses received.

We highlight that the exercises performed by the responders were mainly focused on testing communication tools and protocols, emergency procedures and plans (Fig. 4a). These need to be improved as the main common lessons learnt indicate (Fig. 4b).

From the organizational point of view, more than half of the

Table 2
List of aspects covered in each of the sections of the OMCF. The complete forms in all four languages (English, Spanish, French and Italian) can be downloaded at Massaro et al. (2023a), here reported in Supplementary Material S4.

OMCF Section	Covered aspects
General information	• Name, surname, e-mail address and affiliation of the responder. • Professional activity of the responder (e.g., civil protection officer, decision-maker, scientists, etc.).
General information about the exercise	• Was the exercise focused on a particular volcano? which one? • Did the responder take part in the organization of the exercise? • Was the exercise organized within a research project? Which one? • Is the exercise repeated periodically? How frequently? • How many institutions were involved in the exercise? • Did the exercise actively involve stakeholders other than civil protection agencies? (e.g., inhabitants, tourists, media, etc.)
Exercise (I): Objectives	• What were the goals of the exercises you organized/took part in? (e.g., scientific-tool testing, emergency procedures testing, staff training, etc.)
Exercise (II): Background scientific information	• Which background scientific information (and in what form) from the volcano(es) was made available to the participants during the exercise? How useful was the information? • Any further comment on the background scientific information on the volcano(es) made available during the exercise.
Exercise (III): Scientific data provided during the exercise in real time related to the simulated unrest or volcanic activity (only for scientists)	• Which scientific information (and in what form), related to the simulated unrest or volcanic activity, was provided in real time during the exercise? How useful was the information? • Any further comments on the scientific information provided real time during the exercise and related to the simulated unrest or volcanic activity?
Exercise (IV): Communication from scientists to Civil Protection / decision-makers	• Which type of information/data (and in what form) were provided during the exercise? • How clearly communicated and how understandable was the information? (only for civil protection officers/ decision-makers) • Which communication channels were used? • How did civil protection/decision-makers use the information provided by scientists during the exercise? • Any further comments on communication from scientists to civil protection/decision-makers during the exercise?
Exercise (V): Communication from Civil Protection / decision-makers to scientists	• Which type of information/data (and in what form) were available during the exercise? • How clearly communicated and how understandable was the information? • Which communication channels were used? • Any further comments on the communication from civil protection/ decision-makers?
Exercise (VI): Lessons learnt from the exercise	• Provide a score on the possible lessons learnt from the exercise in terms of the tested procedures (e.g. aspects of the emergency procedure that you changed/improved as a result of the exercise, etc.). • Any further comment on the lessons learnt in terms of the tested procedures?
Exercise (VII): Key elements for exercise organization and evaluation	• What were the lessons learnt from the exercise, in terms of exercise organization? (e.g., institutions to be involved; maximum number of people/ agencies to be involved; exercise duration; exercise products; information provided during the exercise, etc.) • Which are the key elements for an exercise to be effective for all institutions involved? • How can information, data and knowledge be transferred among participants? • Any further comments on the lessons learnt in terms of key elements for the exercise organization and evaluation?
Further comments	• Any advice to give in case someone would like to plan a new exercise? • Any further comments?

responders showed the need for better exercise preparation (Fig. 4c) including, among others: (i) better definition of the pursued objectives; (ii) clear role of the participants; and (iii) proper allocation of time to run and organize the exercise. A proper organization is also declared to be a key element to ensure that the exercise is effective and useful for all institutions involved (Fig. 4d).

For most of the exercises, background scientific information consisted of monitoring parameters and maps of different nature, including those illustrating hazard zones and volcanic scenarios (Fig. 4e). During the exercise, scientists mostly shared monitoring information with civil protection and decision-makers (Fig. 4f), being the main communication channel phone calls (Fig. 4g). The received information was mainly used to define evacuation routes and emergency plans (Fig. 4h). According to the responses obtained, the key elements to guarantee a successful transfer of knowledge among all participants are: i) the existence of adequate communication protocols and the occurrence of regular meetings, ii) the joint definition of such protocols, and ii) increasing the number of exercises and training activities to improve the knowledge exchange (Fig. 4i).

3.2. OMCF: data availability, harmonization and analysis of received responses

A total of 42 questionnaires (5 in Spanish; 21 in English; 13 in Italian; 3in French on different volcanoes around the world were received until 2022, including the responses provided from the participants of the ChEESE (https://cheese2.eu/) exercise at Campi Flegrei, Italy (04/11/2021) and "Vulcano 2022" (https://www.protezionecivile.gov.it/it/approfondimento/esercitazione-vulcano-2022-0/) exercise at Vulcano, Italy (07–09/04/2022) organized by ICP and involving, among other players, INGV.

All responses were compiled in a single table and translated into English (Supplementary Material S2). When responses were left blank, we indicated it with "*n.d.*" (no data, i.e., no response). In case of inconsistencies in the responses (that are <5%), these were also substituted by *n.d.* We considered an inconsistency, for example, when a responder declared to have received as background scientific information the "Eruptive record" in a specific format (e.g., written reports, maps, etc.) but, when asked how useful the information was, the provided answer is "Not provided" (referring to the information "Eruptive record"), or when responders declare that they have not received a specific type of information (e.g., "Emergency procedures and plans")

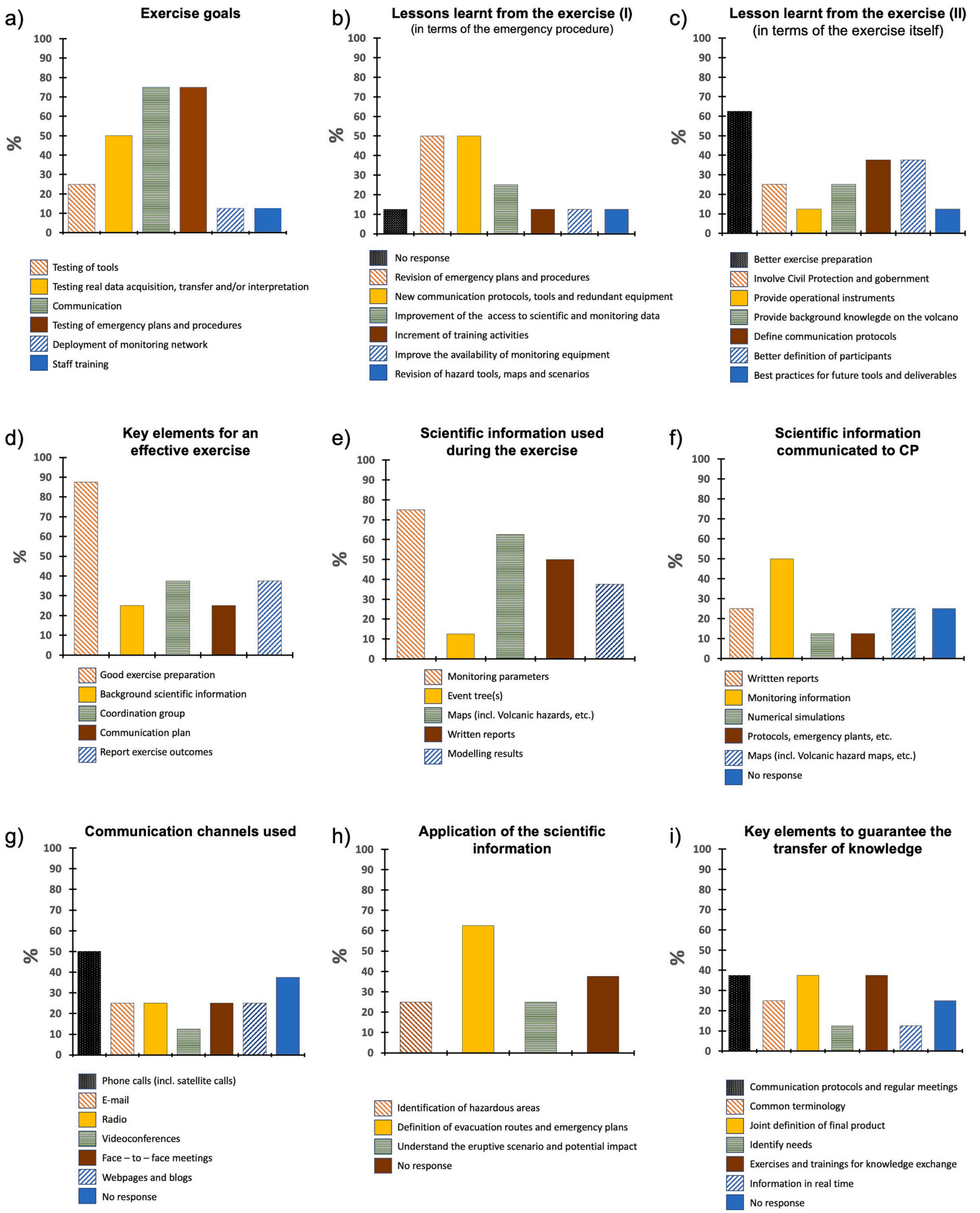

Fig. 4. Bar charts summarizing in bullet points the responses received from the OQQ. See Supplementary S1 for the complete analysis and all available graphs.

but they assigned a score when declaring its usefulness. Considering this, from the 42 questionnaires received, 18 questionnaires needed the response(s) to one (11) or two (7) questions that had to be replaced by *n. d.* (our interpretation is that, in such cases, the questions were not fully clear).

Here we briefly summarize the responses obtained for the OMCF. The reader is referred to the Supplementary Material S3 for a more comprehensive analysis. From all the OMCF responders, ~79% were scientists at universities/ research centres or at volcano observatory, and ~ 19% civil protection officers or decision makers (Fig. 5a). Almost all received on-line forms (~98%) were related to exercises focused on a particular volcano and organized within a research project (~60%). Consequently, only ~31% of the responders declared the exercises to be periodically repeated. Regarding the number of participating institutions, the exercises commonly (~57%) involved >10 institutions. Less than half of the responders (~45%) took part in exercises considering the active participation of thepublic involving principally the inhabitants or residents in the area, the media and/or the schools and educational centres. Among the different potential objectives of the exercises, the testing of emergency procedures and plans, scientific tools, and internal communication and interaction were the most common (Fig. 6a).

According to the skills and expertise of the responders, the most common background scientific information from the volcanoes made available (mostly provided as maps, written reports and/or plots) to the participants during the exercise consisted of: (i) geological information; (ii) monitoring parameters; (iii) eruptive scenarios; (iv) geophysical data; (v) eruptive record; (vi) geochemical information; and (vii) volcanic hazard assessment (Fig. 6b).

Based on the received OCMF, scientific data provided to scientists during the exercise in real time related to the simulated unrest or volcanic activity consisted mostly of: (i) seismic data; (ii) ground deformation; and (iii) geochemical data. From all the information offered to the scientists, seismic data and ground deformation information turned out to be the most useful ones. For the communication from scientists to civil protection/decision-makers, we highlight that during most of the exercises, scientists mostly provided civil protection and/or decision-makers with information on monitoring parameters, eruptive

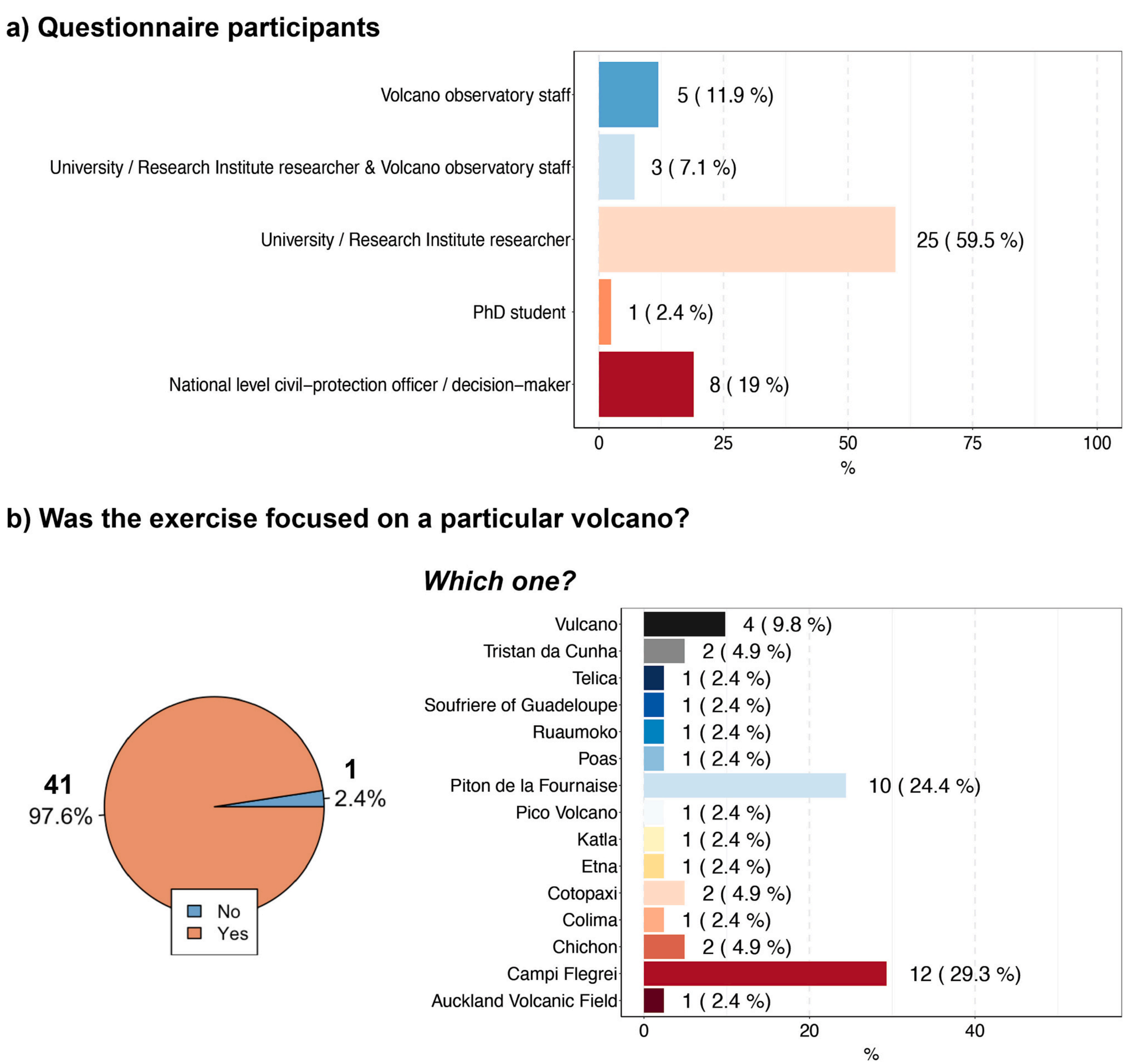

Fig. 5. General information about the provenance of the participants and the volcanoes considered in the exercises.

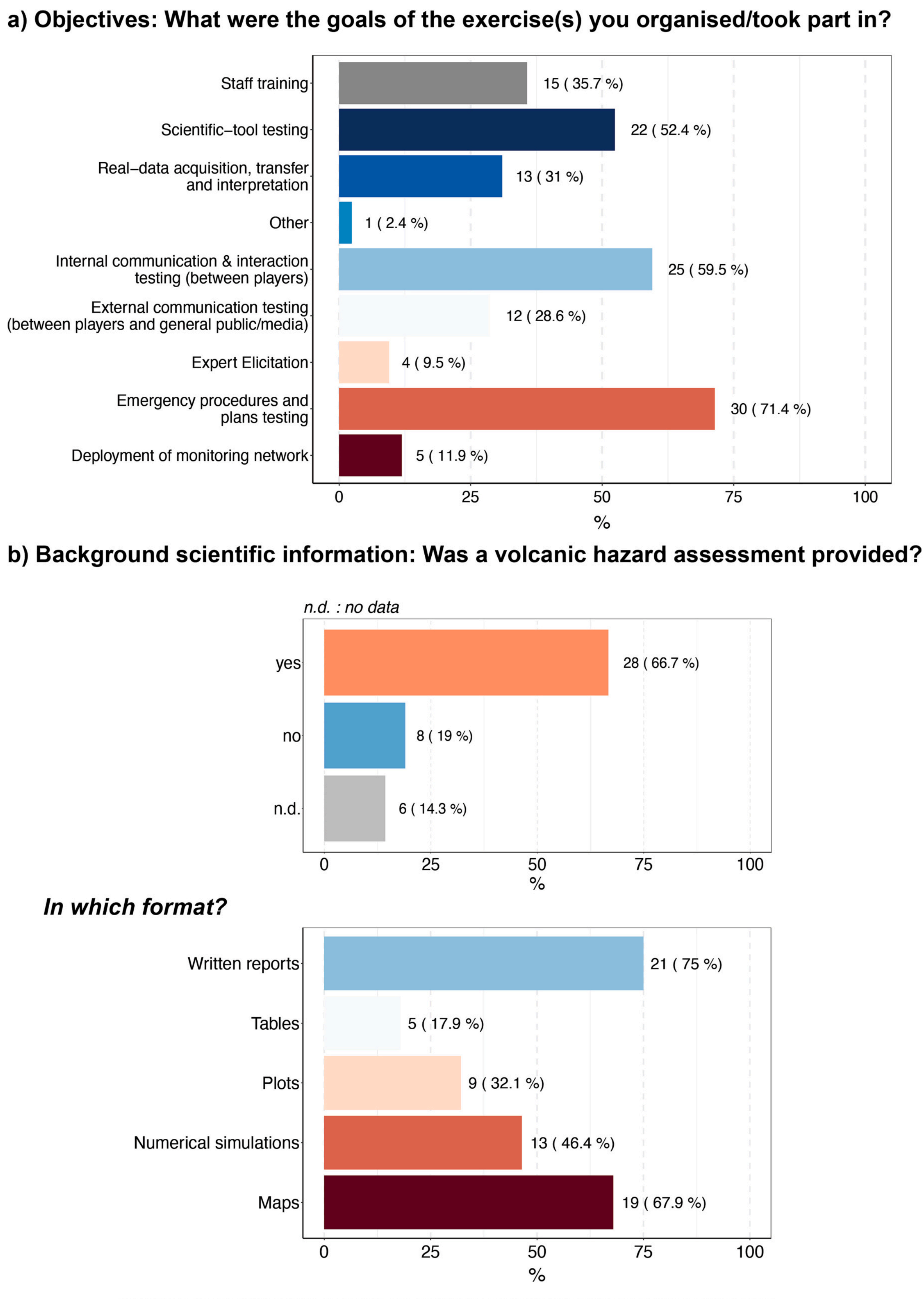

Fig. 6. Examples of background scientific information about the questionnaire participants and the exercises.

scenarios and records, uncertainties, and volcanic hazard assessment in the shape of written reports, maps and/or catalogs; volcanic risk assessment and event trees, despite declared to be useful, were provided to a lesser extent. From these, monitoring parameters were considered the most useful information, followed by eruptive scenarios, volcanic hazard assessment and eruptive records. Theinformation (provided mostly during face-to-face meetings, e-mail, and videoconferences) was mainly used to identify hazardous areas, to establish and define the volcanic alert level, and to understand eruptive scenarios and impact (see Supplementary Material S3).

On the other hand, about the communication from civil protection/ decision-makers to scientists, supplied information was mostly related to (i) volcanic alert levels provided as written reports and/or tables; (ii) emergency procedures and plans mainly in the form of written reports and/or maps; and (iii) communication protocols mainly delivered as written reports. From all these, scientists consider that the volcanic alert levels were the ones more clearly communicated and understandable, followed by the communication protocols and the emergency procedures and plans.

From all potential lessons learnt during the exercises in terms of tested procedures, the ones ranked higher were the need to: (i) revise emergency procedures and plans; (ii) improve external (between players and public/media) communication tools, equipment, and protocol; (iii) increase the training activities; and (iii) better define decision-makers' needs (see Supplementary Material S3). Other valuable lessons include providing background knowledge of the volcanoes and defining external (between players and public/media) communication tools, equipment, and protocols. Based on the participant's experience, the key elements for an exercise to be effective for all institutions involved mainly consist of (i) including a final debrief among all participants and within each participating player; (ii) running the exercise as faithful to reality as possible; (iii) involving decision-makers; and (iv) considering the presence of a coordination group.

3.3. Prototype checklist

Based on the answers to the OMCF, we formulated a prototypal version of a checklist (Supplementary Material S5) for guiding in the design and organization of such exercises. This version is meant to be continuously updated since the data collection is still ongoing based on new answers to the OMCF provided for the next volcanic exercises. Compared to the checklist previously proposed by Bretton et al. (2019), the one presented here is simpler and shorter, as a too complex or long one may discourage its use. The proposed checklist seeks addressing all the relevant aspects of the exercise in plan including:

- Select the goal and focus of the exercise (Sections 1 and 2);
- Identify the organizers, players, and their roles (Sections 3, 4 and 5);
- Fix time, scheduling and location (Sections 6 and 7);
- Define the type of information to be provided before the exercise, who prepares it, in what for, when, and how it will be ready and distributed (Section 8);
- Define the type of information to be provided during the exercise, who prepares it, in what for, when, and how it will be ready and distributed (Sections 9,10 and 11);
- Define a debriefing phase (Section 12);
- Identify lessons learned, needs, possible improvements in procedures and protocols (Section 13).

4. Discussion

Awareness for effective emergency response requires the flow of critical information between scientists, civil protection agencies, local and national authorities, media and public in general. In this scenario, questionnaires can be used to reveal information on public knowledge, attitude, perception, experience, and preparedness levels in relation to natural hazards.

Although based on a limited number of responses, the OMCF highlighted that the participants need for better exercise preparation (Fig. 4b-c; Supplementary Material S2). This aspect may be strengthened by doing more exercises in research projects or in routine activities, as to help the players during the exercise in using more correctly the scientific tools such as hazard maps, event trees, and (or) modeling results (Fig. 4e; Supplementary Material S3). Beyond this, more exercises could be pivotal in both exploring the uncertainties on eruptive scenarios as required for probabilistic volcanic hazard assessment (e.g., Selva et al., 2010; Sandri et al., 2016), along with enhancing the fully deterministic approach with a single scenario.

It is worth also noting that participants found monitoring parameters the most useful information, followed by eruptive scenarios, volcanic hazard assessment and eruptive records (Supplementary Material S3). This finding highlights the need for robust monitoring systems and effective communication channels to provide stakeholders (such as government agencies, and emergency responders) with timely information for decision-making during volcanic events.

The participants' interest in volcanic hazard assessment suggests a recognition of the importance of proactive measures to minimize the impact of eruptions on human lives, infrastructure, and the environment. In this regard, the interest in eruptive records is emblematic not only like a lesson from the past but for the fact that historical data help scientists to identify recurring patterns, assess the potential magnitude and frequency of future eruptions, to be used for quantitative probabilistic volcanic hazard assessment purposes. The same is valid for eruptive scenarios which are used to consider the range of possible eruption outcomes, including different eruption styles, durations, and associated hazards.

By prioritizing these information sources, stakeholders can enhance their understanding of volcanic activity and make informed decisions to protect lives and property. Thus, a multi-hazard scenario planning should be considered overcoming the treatment of each volcanic hazard separately from one another, which limits capacity to explore the complex evolution of volcanism through time, even during an eruptive sequence (Haynes et al., 2008a, 2008b). It is also recognised as one of the key approaches to integrating diverse information requirements for emergency response and recovery planning and preparation (Alexander, 2000), which remains among the main objectives of exercises (Fig. 6a).

Balancing scientific credibility when defining eruptive scenarios is relevant when considering issues of trust and risk communication (e.g., Aspinall et al., 2003; Marzocchi et al., 2012; Leonard et al., 2014) given that the authorities generally viewed the scientists as the most expert source of volcanic information, and they consequently got a high degree of trust. However, distrust among some of the local ministers and population were often caused by the scientists' inability to reduce uncertainty especially in the context of long-lived eruptions (e.g., Montserrat, Haynes et al., 2008a). However, as reported in Komorowski et al. (2018), the improved information and less uncertainty would not straightforwardly lead to better communication or more harmonious acceptance of decision-making processes and of decisions. Here is the need to engage with -not just consult- local populations regarding risk communication and decision-making, tailoring messages to the various audiences, and being clear regarding what is known and not known, plus what is feasible to do to fill in knowledge gaps to support decisions. For example, at Ruapehu volcano (New Zealand) a practical five-step model for effective early warning systems was tested with annual exercises aimed at the volcanic risk management associated with having a ski area on an active volcano (Leonard et al., 2008).

Our questionnaires also highlighted the importance of involving local population and residents during exercises, promoting trust in institutions and scientists, but also highlighted the weakest point of the protocols adopted during emergencies.

Another critical point to consider deals with the unpredictable timescales of volcanic eruptions. Sometimes eruptions may last for a few hours or show extremely long periods. For this reason, in a real crisis, significant time would be needed for discussion and deliberation among and between teams, to reach consensus on the likely course (and possible outcomes) of the build-up of volcanic unrest. Often, because of the rate at which new information was presented to the participants, there was not much time to carry out these discussions and deliberations. This was partly by design, to give participants a sense of how fast new information can come at them in a real crisis, but it would have been possible to provide more time for discussion/deliberation to reach consensus in at least one of the scenario stages (Pierson et al., 2013).

It is worth noting that questionnaires can be biased in several ways due to the sample and exercises reflected in the responses. For example, the reasons could be related to a limited participant pool, exercise design, or lack of real-life context (participants' responses in such exercises might not fully reflect the challenges and decision-making considerations they would face during an actual eruption. Moreover, balancing the participants' background and experience (also based on their gender diversity and geographic provenance) could affect the accuracy and reliability of the responses. Even if this could not always be possible, putting efforts in this aspect is important for giving credibility to the results of the exercise and for providing different points of views on the weaknesses and strengths of the exercise. This is why our investigation is still ongoing and our intention is to continue collecting expert opinions from future exercises in as diverse a range of contexts as possible.

Despite the temporal limitations due to the EUROVOLC project, our preliminary results pose important considerations for those authorities tasked with the responsibility of developing volcanic hazard education programmes and risk mitigation strategies in case of a real volcanic crisis. As final product of this study, the proposed prototype checklist (Supplementary Material S5) aims to establish a standardized approach to conducting volcanic exercises, ensuring comprehensive coverage, assuring quality, identifying gaps, facilitating training, and enabling evaluation and benchmarking. In other words, by systematically going through the checklist, future exercise organizers could assess the completeness and adequacy of their current approach and identify areas where modifications or enhancements are needed. This iterative process would refine and optimize the exercise design and execution, leading to continuous improvement in volcanic risk management.

5. Conclusions

In this study, an open-question questionnaire (OQQ) on the experience gained during volcanic-crisis exercises was firstly distributed within the EUROVOLC-project community. Based on the OQQ responses received, we then created a user-friendly multi-choice online questionnaire (OMCF) in four different languages, that was also submitted to different volcanological communities outside the project through the Volcano Listserv and ALVO community. Our results confirm that this type of survey is a very useful tool for gathering information on participants' experience and knowledge, and to understand which data and information may be useful when designing exercises for scientists, emergency managers and decision makers. In particular, the main lessons learnt regards the need to increase training activities involving people exposed to volcanic hazard and media, to improve external communication tools (between players and public/media), equipment and protocols and to better define decision-makers' needs.

We are aware that there are certain aspects of the OMCF questionnaire design, layout and question selection that need to be carefully considered to ensure the maximum value of this approach in the future. For this reason, we recommend that a more in-depth survey, with a much larger and broader sample size, should be conducted to provide more reliable data for emergency managers. Indeed, we plan to disseminate the OMCF and the checklist through traditional and social media (i.e., Twitter, Instagram, Facebook) but also by producing web products.

Following the idea proposed by Newhall et al. (2020) to adopt the use of checklists for volcanologists and civil protection officers as pilots do in their job, we built a prototypal checklist based on the collected answers to the OMCF as to facilitate volcano observatories, scientific advisory groups, civil protection authorities and decision makers potentially involved in running the volcanic-crisis exercises. After the EUROVOLC project's end, we have planned to continue collecting answers to the OMCF to refine the results and improve the prototypal checklist accordingly. As future steps of the activity, we will also evaluate potential difficulties in providing answers to the multiple-choice questions, that may somehow limit the respondents and cancel out significant nuances hard to capture with the OMCF.

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Disclaimer

The information set out in this publication reflects the authors' views.

CRediT authorship contribution statement

Silvia Massaro: Investigation, Data curation, Visualization, Writing – original draft, Writing – review & editing. **Laura Sandri:** Project administration, Supervision, Conceptualization, Investigation, Methodology, Data curation, Writing – review & editing. **Adelina Geyer:** Conceptualization, Investigation, Methodology, Data curation, Writing – review & editing. **Chiara Cristiani:** Data curation, Conceptualization, Writing – review & editing. **Rosella Nave:** Conceptualization, Writing – review & editing. **Sara Barsotti:** Conceptualization, Methodology. **Susan Loughlin:** Conceptualization, Methodology. **Giuseppe Puglisi:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The OMCFs are available in four languages (Massaro et al., 2023a; https://zenodo.org/record/7482424) and the prototypical versions of the checklist 1.0 (Massaro et al., 2023b; https://zenodo.org/record/7482424)

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jvolgeores.2023.107850.

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