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A scoping review of seismic risk communication in Europe

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Although earthquakes are a threat in many countries and considerable resources have been invested in safety regulations, communities at risk often lack awareness and preparedness. Risk communication is a key tool for building resilient communities, raising awareness, and increasing preparedness. Over the past 2 decades, seismic risk communication has evolved significantly. This has led to a reorientation from a predominantly "one-way", top-down communication model to the promotion of new models in which people, their needs, and their participation in disaster risk management are central elements. The 2015–2030 Sendai Framework recommendations, recent disaster experiences and research have highlighted that new models can improve communication effectiveness. In this paper, we critically explore this transition by conducting a scoping review (n=109 publications) of seismic risk communication in Europe. We analyse the approaches, messages, tools, and channels used for seismic risk communication and how they have changed over time. The results reveal that the stated goals of seismic risk communication are, in decreasing order, to share information, raise awareness, change behaviours/beliefs, and increase preparedness. Pupils, students, and citizens are the primary recipients of communication activities. Over the years, two trends have emerged. First, "two-way", transdisciplinary and bottom-up communication models prevailed over the "one-way" model. Second, communication aimed more at promoting proactive behaviours than just informing the public. Face-to-face, hands-on activities, and serious games are key tools to engage with the public. The results also reveal the emerging role of social media to target different audiences/social groups. Strikingly, only one-fifth of the analysed publications explicitly build on or tests risk communication theories. Future research could focus on comparing practices across countries and risks (e.g., earthquakes and floods) and on innovating communication theories and methodologies, especially by incorporating the role of information technologies and social media.

KEYWORDS
seismic risk communication, seismic risk education, earthquake risk communication, awareness campaigns, community seismic resilience, Europe, seismic risk communication review

GRAPHICAL ABSTRACT

1 Introduction

Risk communication is a key component of risk management. It can impact risk awareness, increase preparedness, and promote the adoption of protective behaviours before, during and after disastrous events. It can also empower communities at risk, e.g., by giving them a voice in risk decision making processes, and by building resilience (e.g., Katsikopoulos, 2021). Lessons learned from risk and emergency communication can also contribute to shape national risk policy agendas and to foster legislative change (e.g., Spence, 2007). At the international level, several frameworks, directives, and guidelines refer to risk communication. For example, in Europe, the Seveso I Directive (Directive 82/501/EEC) promoted risk communication as a right of communities at risk.

International disaster risk reduction frameworks such as the 1994 Yokohama Strategy and Action Plan (IDNDR, 1994), the Hyogo Framework for Action 2005–2015 (UNISDR, 2005), and the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNISDR, 2015), acknowledge the potential of risk communication to foster community empowerment. More precisely, the Yokohama Strategy calls for the promotion of a culture of prevention, including the implementation of effective risk communication strategies and communities' engagement in disaster preparedness and response. It recognizes the importance of involving all sectors of society in disaster risk reduction efforts and promotes the use of traditional and local knowledge in communicating risk. The Hyogo Framework for Action focuses on the development and dissemination of information and early warning systems to improve risk awareness and preparedness at all levels. Finally, the Sendai Framework promotes communication approaches tailored to the needs and capacities of different groups and communities; it recommends communication practices based on scientific data and information as well as local

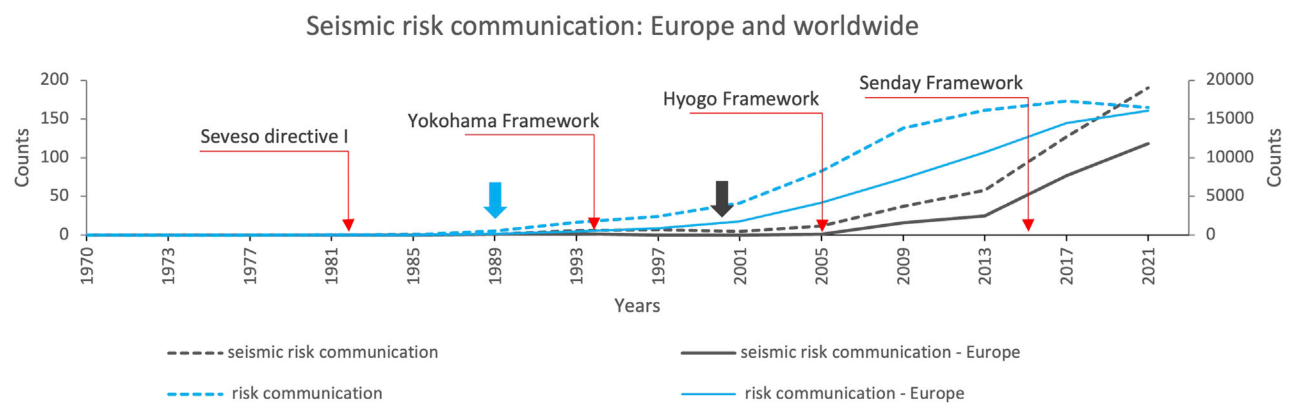

FIGURE 1
Publications on seismic risk communication over time. Raw data (i.e., no removal applied), from the digital search in the Google Scholar database according to the strings listed in the text, are plotted for all-risk (right y-axis) and seismic risk communication (left y-axis) in Europe and worldwide. Publications on all risks in Europe and worldwide start almost at the same time, and precisely in 1989 (blue arrow); however, we must wait over 18 years to have a parallel increase of publications on seismic risk communication (black arrow). The Seveso Directive I (1982), the Yokohama (IDNDR, 1994), the Hyogo (UNISDR, 2005), and the Sendai Framework (UNISDR, 2015) are shown as reference for discussion.

TABLE 1 Numbers of publications shortlisted after each selection phase.

Database		Total	Stage 1	Stage 2	Stage 3
	Publications selected	Publications selected	Publications shortlisted	Publications shortlisted	Publications shortlisted
Scopus	125	482	313	182	109
Web of Science	147				
Google Scholar	167				
Other	43				

and traditional knowledge, innovative technologies and social media, and early warning systems to promote risk awareness and preparedness. It emphasizes the importance of a whole-of-society approach to risk communication that engages all stakeholders, including governments, civil society, the private sector, academia, the media, and communities.

It is noticeable that from the Yokohama Strategy to the Sendai Framework the communication approaches have evolved from the prevailing one-way model towards more inclusive transdisciplinary strategies that directly engage with exposed communities to motivate preparedness actions (Kelman and Glanz, 2014; Tozier de la Poterie and Baudoin, 2015).

What makes the difference between risk and any other type of communication, is that risk communication is closely related to the four main phases of the disaster lifecycle: *mitigation*, *preparedness, response, and recovery* (Flanagan et al., 2011). The Sendai Framework highlights effective risk communication as an essential element at all stages of the disaster lifecycle; it therefore suggests the identification of specific strategies (La Longa et al., 2012; NOAA Social Science Committee, 2016; Balog-Way et al., 2020; Katsikopoulos, 2021). There are several aspects and needs that can be addressed differently depending on the disaster's phase in which the communication occurs. The pre-event, i.e., the *mitigation* and *preparedness phases* of the disaster lifecycle, requires a risk communication focused primarily on raising awareness and providing information about potential hazards and actions to minimize the impact of possible future disasters; timely, accurate, simple and clear information about the current situation, how to protect oneself, where to go and what to do is needed for the *response phase* during an ongoing event; information about available resources, damage reimbursement procedures, public or private insurance systems (if applicable) and potential risks and hazards after the disaster are key aspects to be considered for communication during the *recovery phase*.

An analysis of risk communication strategies can be found in the mid-term review of the implementation of the Sendai Framework (United Nations Official documents, 2023), as well as in Veil et al. (2011) and Dallo et al. (2020). Nonetheless, in-depth analysis of communication practices for a specific risk -e.g., seismic risk-is still a research gap. This study is a scoping review that aims to fill this gap, focusing on seismic risk communication and how it has evolved over time.

According to the World Health Organization, between 1998 and 2017, more than half of all deaths related to natural hazards were due

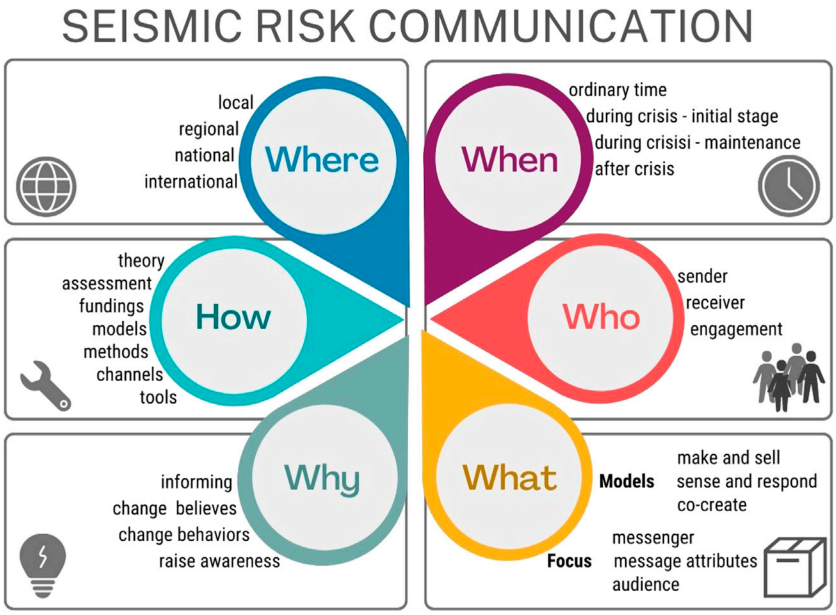

FIGURE 2
Issues investigated and grouped according to the when-who-what-why-how-where- questions to screen the 109 selected publications.

to earthquakes. More than 125 million people were injured, homeless, displaced, or evacuated in the emergency phase of an earthquake disaster during this period (UNISDR and CRED, 2018). These high impacts are at odds with the great effort put into regulations to improve the seismic safety of buildings. Earthquake cost reduction is not only related to the best seismic retrofit technologies or earthquake preparedness programs but also to increased awareness efforts and relevance of earthquake risk management on the public agenda (Spence, 2007). This demonstrate the importance of seismic risk communication and the need to promote it and allocate economic and institutional resources to its development.

This scoping review focuses on the academic literature to describe the evolution of seismic communication approaches, both in practice and in research, in Europe. After presenting the methodology and describing the criteria used to identify and analyze the publications, the results of our analysis are discussed. The Conclusion section summarizes the findings and associated limitations. It also provides insights for potential advances in seismic risk communication.

2 Methodology

Our research follows the scoping review methodology (Munn et al., 2018; Arksey and O'Malley, 2005; Kitchenham et al., 2011; Paré et al., 2015) and is structured around the following general research question (Kitchenham et al., 2011; Paré et al., 2015): "What are the main characteristics of seismic risk communication practice and research in Europe?" and "Have they changed over time?".

To answer these questions, we analysed selected publications retrieved from scholarly literature databases.

2.1 Selection of publications

We selected the publications with an electronic/on-line search, followed by an in-depth revision of each retrieved publication. The electronic search was based on the following terms—and the use of the Boolean "and/or" where necessary—linked to the topic of seismic risk communication (Supplementary Table S1):

- seismic risk communication;
- earthquake risk communication;
- seismic risk education;
- earthquake risk communication;
- educational seismology;
- seismic risk education campaign(s);
- seismic risk awareness campaign(s)

Additional criteria were:

- language: English;
- type of document: full text publications scientific peer-reviewed;
- geographical restriction: case studies or experiences based in European countries.

We conducted an initial search to examine how the literature on seismic risk communication was distributed over time, starting in 1970, 12 years before Seveso I directive. Our research (using Google Scholar) shows that the number of publications increases considerably after the year 2000 (Figure 1). The criteria concerning the year of publication was therefore set between 2000 and 2022.

Based on the above criteria we searched Scopus, Web of Science, and Google Scholar to obtain the most comprehensive coverage of scientific publications (Table 1). Some additional documents were retrieved via citations found in the electronically selected publications.

The search shortlisted 482 documents, which were subjected to further manual screening in three stages:

- ➢ stage 1—reading the title: duplicate documents and non-English language articles were excluded;
- ➢ stage 2—reading abstracts: grey literature (conference abstracts, reports, dissertations, web documents, magazine/newspaper articles), documents not strictly focused on earthquake risk communication and/or not written in English and/or not dealing with case studies in Europe were excluded;
- ➢ stage 3—reading publications: documents that do not focus on earthquake/risk communication issues and/or do not address case studies in European countries were excluded.

The list of selected publications is attached as Supplementary Material.

2.2 Analysis of publications

After the manual screening, we analysed the 109 selected publications (see Supplementary Material) using a set of parameters related to the five key aspects of risk communication described in Figure 2, namely, when the communication takes place, who communicates what to whom, why, and how, also known in communication research as the "5 Ws" (eg., O'Hair and O'Hair, 2020). We divided the publications among all co-authors for close reading and classification.

More precisely we coded the data using a series of questions/parameters, with binary or multiple response options (see Supplementary Table S2). We decided to build our study around the so called 5 W and H questions, and to arrange them in the order that best fits the topic of seismic risk communication.

When is seismic risk communication conducted as part of the disaster lifecycle? We used the definition of disaster's phases in NOAA Social Science Committee (2016) and indicated whether it was conducted during ordinary times (i.e., long-term preparedness, prevention, and mitigation), during Crisis I (i.e., response in the initial stages of warning communication), during Crisis II (i.e., response in the emergency and crisis communication), or during the recovery phase (i.e., post-crisis, recovery, and rehabilitation). We started with the question "When" to emphasize the close relationship between the communication of seismic risk with the disaster lifecycle.

Who are the actors involved in the communication process and what type of engagement was pursued? The "sender" and "receiver" parameters could be answered in a binary fashion (yes/no) with the following attributes: public agencies involved in disaster risk management; nongovernmental organizations; public agencies involved in education (schools); students; citizens/general public; private companies; research centres/universities.

For the "engagement" parameter, we used the following attributes: Mode I (co-design of seismic risk communication activities/strategies); Mode II (joint development of seismic risk communication activities/strategies, e.g., between experts and the public); Mode III (joint implementation of seismic risk communication activities/strategies, i.e., when the public is directly involved in the implementation of a campaign, such as in citizen science); Mode IV (joint assessment/evaluation according to Loeffler and Bovaird, 2021).

What communication models were used and what is the communication/research focus? First, the "communication model" parameter captured a binary response (yes/no) to the following attributes (based on Stewart and Hurt, 2021): the one-way model, which focuses on persuasion and information transfer ("make and sell communications", aiming to educate the public, influence the public debate, foster a more positive attitude towards research, and increase the visibility of sponsors and funding bodies); the two-way model, which includes, for example, audience analysis ("sense and respond communications", having primarily the purpose of public engagement defined as the ways in which the activity and benefits of higher education and research can be shared with the public. Engagement, by definition, is a two-way process, that involves interaction and listening, with the goal of generating mutual benefit (NCCPE, 2018); the three-way model, which is based on social learning and stakeholder engagement processes ("guide and co-create communications", where scientists from multiple disciplines and non-academic stakeholders from business, government and civil society cooperate in socially deliberative research processes that are challenge-led and solution-oriented; e.g., Funtowicz and Ravetz, 1993). Second, the "communication focus" parameter grounded on Balog-Way et al. (2019) and collected binary responses (yes/no) for communication/research with a focus on: the sender (e.g., how to increase trust); message attributes (e.g., framing, affective response, uncertainty); audiences, and audience analysis (e.g., risk perception or preparedness) attributes.

Why has seismic risk communication been performed? We collected a binary response (yes/no) on parameters describing four communication objectives: sharing information; changing beliefs; changing behaviours; raising awareness attributes (based on Bostrom et al., 2018).

How has seismic risk communication been performed? We collected binary responses (yes/no) on seven parameters (Figure 2) and several possible attributes. We identified a list of communication tools (i.e., leaflets, documents; videos, video scribing; mock drills/simulation exercises; serious games, serious videogames; risk communication plans; hands-on tools; infographics, augmented reality; multiple) including those more relevant for risk management used for communication purposes (hazard, risk, vulnerability or exposure maps; emergency plans; warning/alert messages; past event history; risk reduction plans; recovery plans; multiple based on Venutti et al., 2021). We gathered information on the channels used for communicating seismic risk (face-to-face, social media, internet, mass media, or smartphone apps). As for the methods, we looked at whether interviews, focus groups, outreach events, surveys, and classroom activities, have been used. For the mode of communication, we looked at whether it has been in person; remotely/virtual; or hybrid (i.e., partially in person and virtual; multiple). We also collected data on whether the communication benefitted from any financial support (funded by public national agencies; public international agencies; the private sector; multiple; and not available). The last parameter we collected information about, was whether any communication (i.e., NOAA

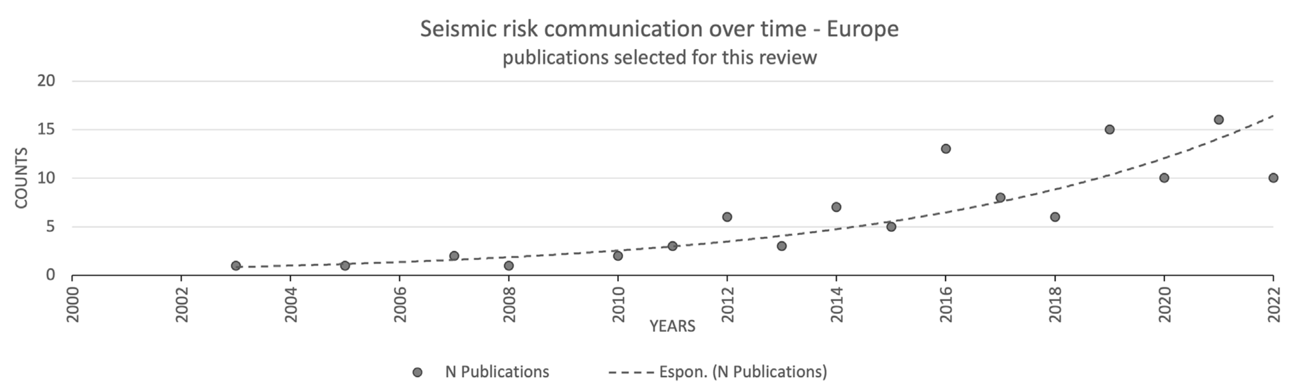

FIGURE 3
Communication of seismic risk over time in the scientific literature selected for this study. The dashed line show the exponential trend.

Social Science Committee, 2016; deficit model, social amplification of risk, risk information seeking and processing model, crisis and emergency communication model, mental model, causal model, behavioural oriented model; multiple; not available) theory has been mentioned by the author(s) of the publication.

Where were seismic risk communication practices conducted? We collected data on the yes/no occurrence of four parameters: local, regional, national, or international (by international, we mean a practice/analysis conducted in multiple countries simultaneously) level. This allowed us to investigate, among other things, whether earthquake risk communication is a cross-border issue.

All collected data were coded, classified, and analysed using spreadsheet software and the results were summarized with frequencies and percentages. Percentages for each year were also calculated to identify changes over time/trends.

3 Results

The first striking finding of our study is that the topic of seismic risk communication has entered in the academic literature several years later than other risks. Indeed, only about 2 decades ago the number of publications on this topic started to increase (Figure 1). The increasing importance of risk communication is generally attributed to international disaster risk reduction frameworks. This is supported by our findings. More precisely, the interest of the scientific literature in risk communication appears to start shortly after the Yokohama framework while we had to wait for the Hyogo Framework to achieve a similar growth for the communication of seismic risk in Europe. It is likely that this growth was also driven by seismic disasters that affected local communities in Europe.

The 109 publications identified using the methodology described in Section 2.1 were predominantly published in geoscience journals (45%), risk or disaster journals (18%), and books (17%). Specialized communication journals were only a minority (11%). The first paper of our selected collection was published in 2003 (Figure 3); it addresses the communication of seismic risk through educational seismology and aims to raise awareness of seismic risk among students and the general public (Cantore et al., 2003). The next paper was published in 2005 (Camassi et al., 2005). It describes EDURISK, the Italian seismic risk awareness campaign launched in 2002 and focused on risk education tools; it was addressed to students, teachers, stakeholders, and the general public. Based on our data, it can be considered the first publication that focuses entirely on seismic risk communication. Two additional articles followed in 2007 (Gruev-Vintila and Roquette, 2007; Spence, 2007). Spence (2007) discusses how success in mitigation is related to awareness efforts and the place of prevention on the public agenda. The article by Gruev-Vintila and Roquette (2007) is the first to focus exclusively on seismic risk communication in Europe and is aimed at the general public. It addresses the social representation of earthquake risk.

Our dataset provides insights into the contribution of women in seismology, which is the topic of the special issue in which this paper is included. In the last 2 decades, a total of 518 scientists have published on earthquake risk communication, 240 (46%) of them are women. The percentage of females compared to male authorship illustrates considerable equality. However, the distribution is discontinuous over time and does not seem to indicate a consolidated trend, as only in a few years (2005–2022) have women published more than men on this topic (Figure 4).

Analysis of the word frequency in the titles of the sampled publications (Figure 5) shows that the main topics covered are disaster, preparedness, risk perception, and social and that the most named country is Italy. Other topics are the targeted audiences for communication, schools and citizens, awareness, community engagement, social media, misinformation, and disinformation. However, we would like to emphasize that the attention towards the school topic becomes more relevant if we sum words frequency for education (al), student(s), young, children, teachers, and schools.

3.1 The key features of seismic risk communication

To summarize the results of the scoping review, we follow the structure of the key questions described in the methodology (see section 2.2).

When - The overwhelming majority of the selected documents (75%) focused on communicating seismic risks in what is referred to as

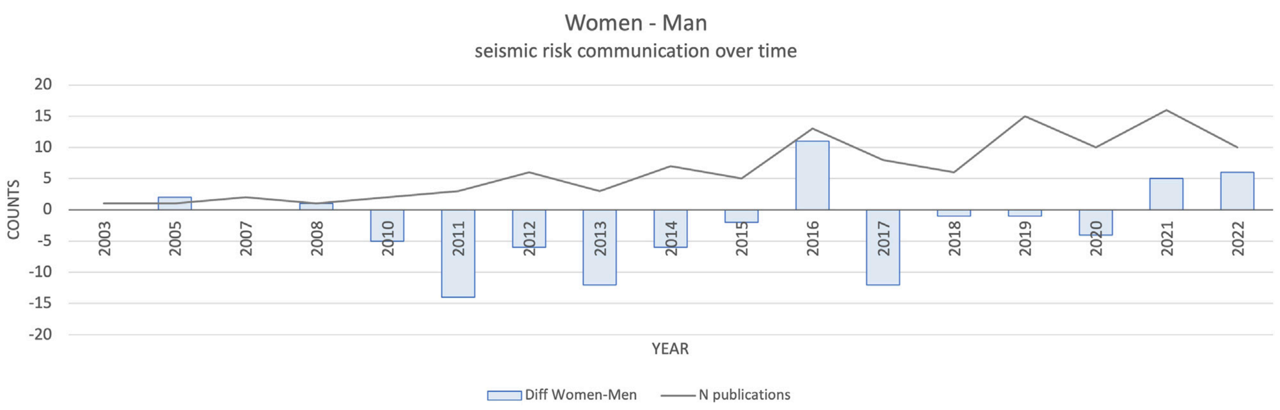

FIGURE 4
Women authorship over time. The diagram plots the difference between the number of male and female authors per year. Only publications selected for this review are considered for this plot.

"ordinary time" (Figure 6), i.e., the pre-event phase of the disaster risk management lifecycle. While this can be seen as a strength in building social resilience, it also highlights that communication in the emergency and recovery phases has received little attention in the scientific literature on earthquake risk.

Who- Research centres and universities are among the main senders/organizers of communication activities (72%), while pupils and students (40%) are the main recipients. Citizens are the next largest group of recipient (27%) in our data sample. Recipient engagement is described in about half of the publications (46%). A vast majority uses a collaborative development or implementation model (Mode II and III described in section 2.2 = 39% of the 46%), while few publications describe a joint evaluation model (Mode IV=5%).

What- The most common communication model is two-way (43%) communication (Stewart and Hurt, 2021). It did not occur in the early years of the XXI century, but soon became a relevant approach used in about half of the publications considered for this review (Figure 7). However, the one-way model is still reported by a fairly large number of publications (29%). Interestingly, the three-way model ("guide and co-create") was adopted by less than 20% of authors, although its prevalence increased over time.

In terms of content, communication in the scientific literature focused on: 1) target audience understanding (36%) confirmed also by several studies on risk perception; 2) message characteristics (24%) including framing, effective response, and uncertainty; 3) sender characteristics (13%), especially how to increase trust. The remaining 27% were multiple, mixed, or other aspects that were not listed in the table.

Why- The reported goals of seismic risk communication (multiple response set) are to share information (62%), raise awareness (47%), change behaviours (27%), change beliefs (16%), and increasing preparedness (4%).

We also compared informative vs. proactive goals. By aggregating the goals of awareness, belief change, behavioural change, and preparedness reported by the authors of each publication, we were able to create an index of proactive communication goals. Our data sample shows that communication has become more proactive than informative over time (Figure 8). Because proactive communication can ensure a better response to events, it supports more resilient communities.

How- The scientific literature included in our sample documents how seismic risk communication has been delivered over the past 2 decades. Interactive and visual language devices were mentioned most frequently, regardless of temporal distribution (Figure 9). Among the interactive tools, those based on serious games and augmented reality are a novelty that appeared in our data sample in early 2016 (e.g., Reitano et al., 2019; Falsaperla et al., 2022).

In person communication (face-to-face scored 39%) largely prevailed over the Internet (7%) and even mass media (4%). Methods used for communication practice have mostly been surveys (18%), and classroom activities (16%), while focus groups, outreach events, and interviews were the least used. However, 24% of the publications reported multiple methods and more than ten percent (13%) referred to methods not among those we have listed for the analysis in section 2.2. Risk communication research and practice are mainly funded by public international (29%) and national (26%) institutions, while the private sector is absent. Only about half of the publications reported an evaluation of seismic risk communication efficiency/performance.

Our data reveal that 80% of publications do not explicitly articulate their theoretical foundations. This reveals that the scientific literature on seismic risk communication is more focused on practice than theory.

When theories are mentioned, the deficit and behavioural-oriented model are the most frequently cited (Figure 10). This result might only apparently point out that the deficit model is still the ongoing way to pursue the communication of seismic risk, as the data we collected only report that the model is mentioned, but not necessarily used. In addition, the aforementioned percentage (20%) is a combined value reported by those manuscripts that mentioned the theory.

Where- The publications investigated in this study describe that the seismic risk communication first started at the local level, documenting practices implemented in different countries, and

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FIGURE 5
Word cloud showing the most frequently used words in the title of the 109 publications used for this scoping review.

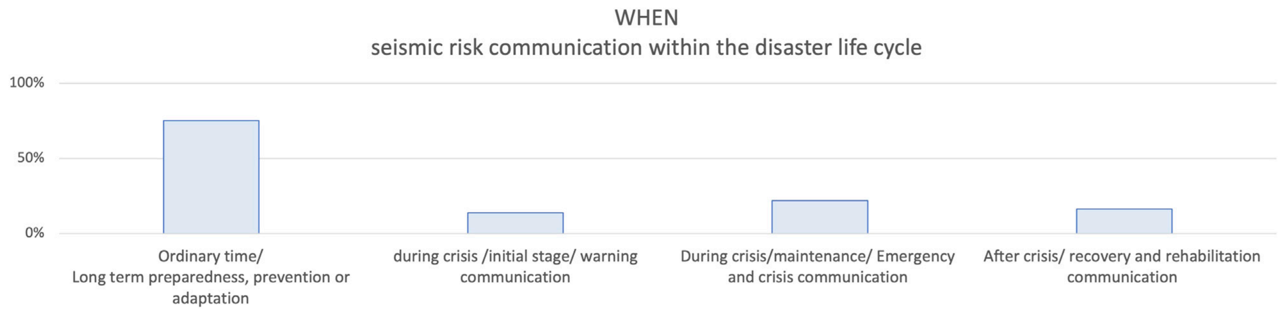

FIGURE 6
The selected publications on seismic risk communication within the disaster lifecycle: ordinary time strongly prevails over the others.

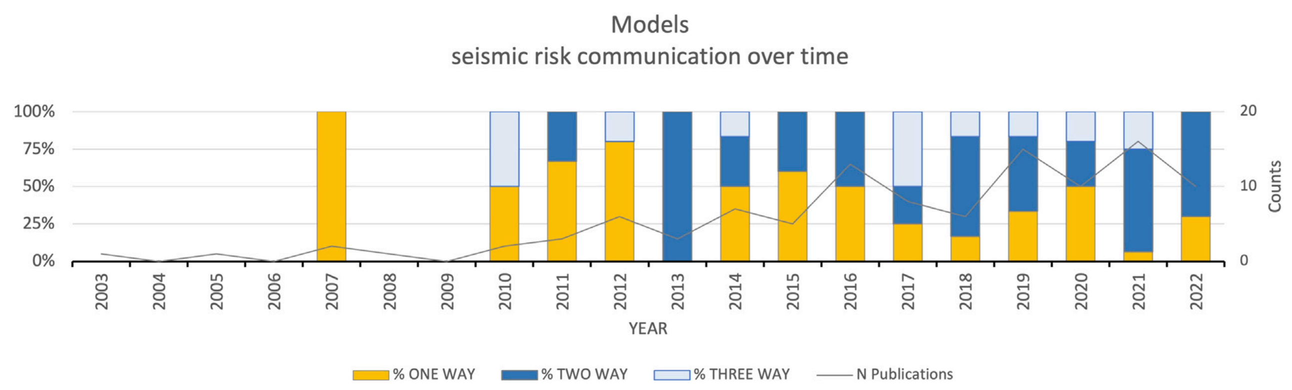

FIGURE 7
Use of communication models (Stewart and Hurt, 2021) in seismic risk over time. The diagram displays the percentage of publications published each year, referring to either one-way, two-way, or three-ways communication.

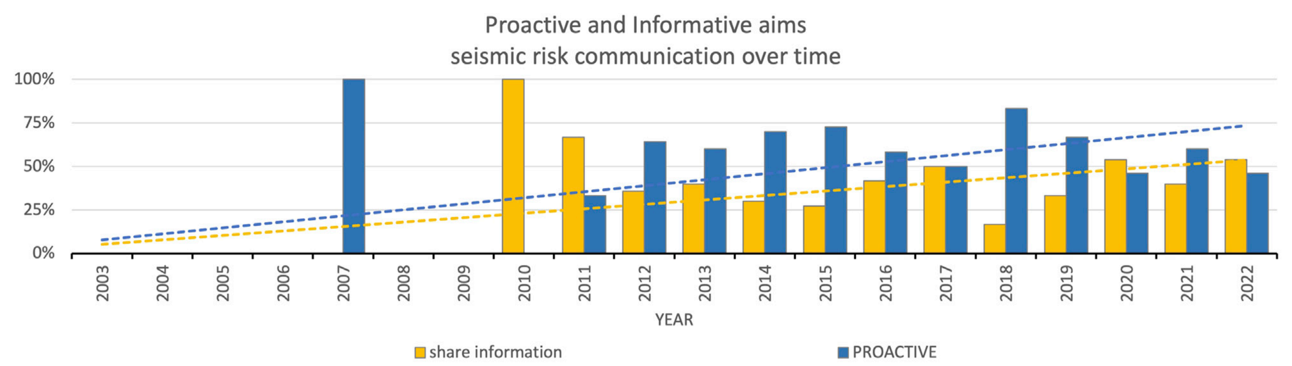

FIGURE 8
Seismic risk communication aims as reported in the publications investigated in this study. The proactive aims are derived by summing awareness raising, change in beliefs, change in behaviours, and preparedness counts. The percentage is computed for the number of publications published each year, so the graph shows the change over time. Only data from more than one publication per year were considered. Proactive aims are growing faster than the sharing of information. The data refer to the sample identified for this study, and the aims are those reported by the authors of the publications.

then took on an increasingly international character over the years (Figure 11).

Italy appears as a case study in about half (43%) of the selected publications, followed by Portugal (22%), Iceland (15%), Romania (9%), Turkey (8%), France, and Greece (6%).

The high percentage of documents for Italy could be due to a sample bias, which can be avoided in a future study by using quota sampling techniques (i.e., one country is used as a quota). However, we chose not to consider this quota because the goal of our study was not to make a cross-country European comparison.

4 Discussion

Our sample of 109 documents provides a multifaceted overview of earthquake risk communication practices and their role in building the resilience of earthquake-prone communities in Europe.

The chosen time interval allowed us to analyse not only the scientific literature but also its evolution with respect to the international recommendation for disaster risk reduction approaches. In the following we discuss the major findings of our research.

4.1 Seismic risk communication: an under-researched topic

The increase of publications in the past 2 decades is an emerging trend, also consistent with the exponential growth of academic publications in recent decades (e.g., Fire and Guestrin, 2019). While interest is increasing, the number of publications is still two orders of magnitude below the publications dealing with communications for other risks (Figure 1). There are many reasons for this, and we hypothesize a few below.

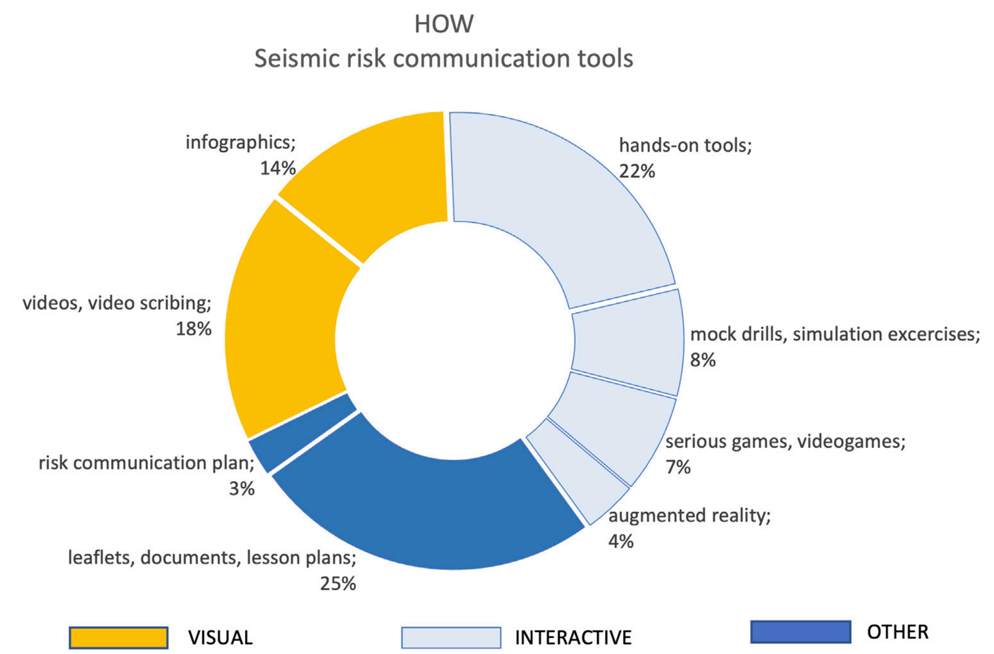

FIGURE 9
Seismic risk communication tools adopted in the selected publications. Visual language tools are computed by aggregating infographics and videos; interactive tools are calculated by aggregating serious games, drills, and hands-on and augmented reality tools; "other" refers to more traditional tools (leaflets, lesson plans, *etc.*).

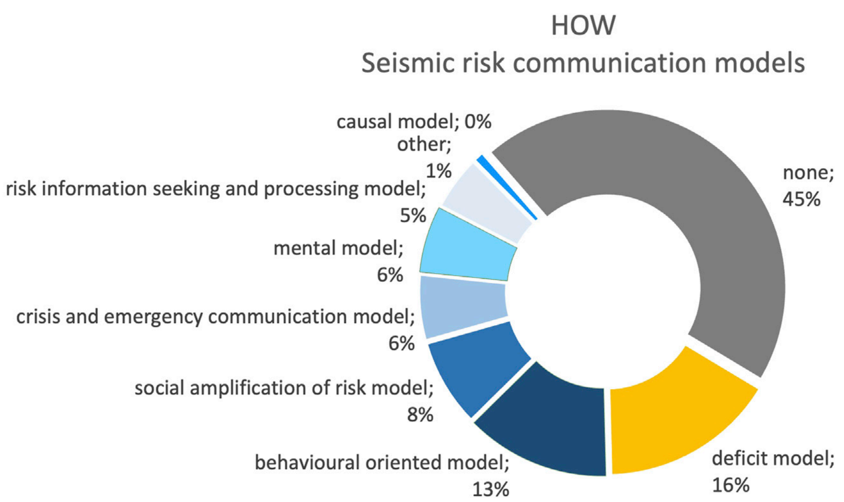

FIGURE 10
Communication models mentioned for seismic risk in the selected publications. Data in the diagram refer to only 20% of the publications, as the remaining 80% did not mention any theory.

First, seismic risk communication has not been considered a scientific discipline *per se.* There are hardly any professorships or chairs at universities that deal exclusively with seismic risk communication. Usually, the topic is covered in a few lectures in disaster risk management, environmental sociology or communication courses (Scolobig and Gallagher, 2021). Generally, risk communication *per se* is not yet included in academic curricula in many European countries. This may be due to several factors, including the initial limited development of risk communication theories and methodologies, which is a cause, but also a consequence, of the lack of courses on the subject; the general fragmentation of disaster risk management education into different disciplines; the limited availability of guidelines on standard requirements for risk communication curricula and professional training for teachers; the limited and often short-term national and international funding for the establishment of

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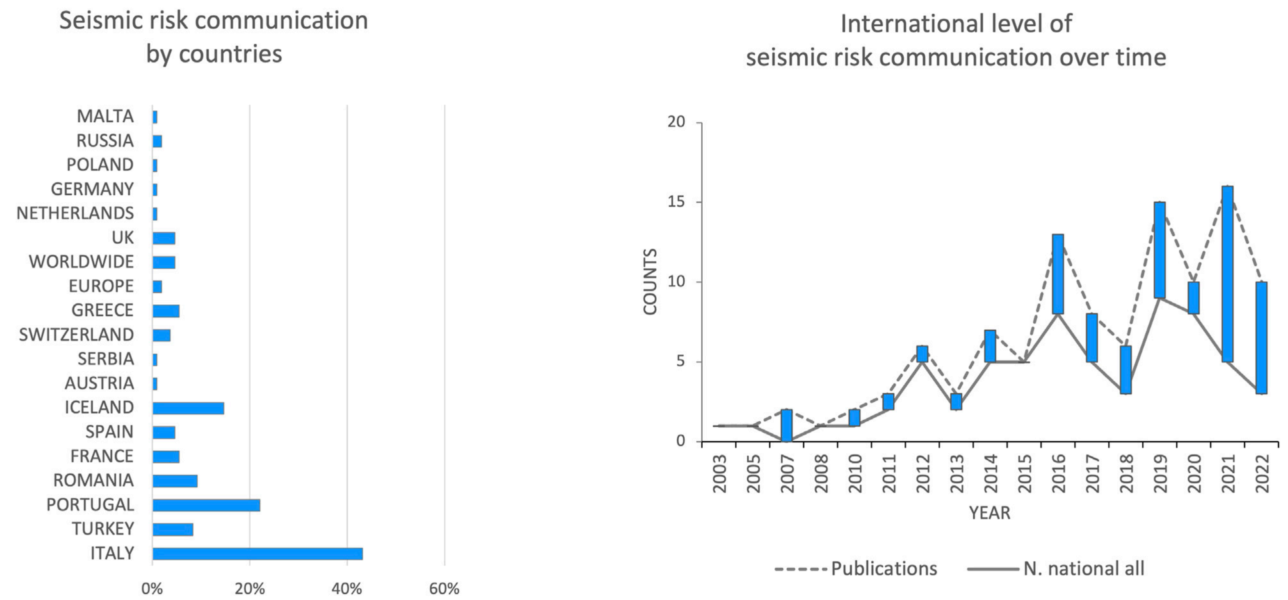

FIGURE 11
Countries in our data sample (bars on the left panel) and the number of publications reporting national or international seismic risk communication studies over time (bars on the right panel).

new academic programs (Alexander, 1997; Alexander, 2003; Menoni et al., 2014; Holloway, 2014; Holloway et al., 2019; for a review, see Scolobig and Gallagher, 2021). Second, practitioners often do not publish their experiences with seismic risk communication campaigns/strategies or lessons learned. Third, only recently scientific journals provide adequate room for these topics. Thus, the relatively low number of publications could be due to a lack of adequate space and expertise, or because this type of engagement is of little relevance to career advancement in the academic context and therefore not worth the effort to publish (Leshner, 2007). Fourth, the seismic risk community working on communication is relatively smaller compared to other risk communities (e.g., flood risk).

However, further research, e.g., using in-depth interviews with leading academics, researchers, and university professors, is needed to better understand the reasons for the observed trend.

4.2 Opening up the seismic risk communication lifecycle

We found that the communication about seismic risk takes place largely outside the emergency; indeed, the pre-event time is what sensitizes and enables communities to face the hazard in the best way. However, it is rather difficult to focus people's attention on earthquake-related events unless not in the emotional aftermath of catastrophic events (Crescimbene et al., 2014). The time interval of interest for a given earthquake is often quite short (from a few minutes to a few days) and reaching the target audience in this time window would be extremely important for communicating earthquake risk (Camilleri et al., 2020). In normal times, people are not often exposed to earthquakes or even interested in learning about them, and thus may have misconceptions about seismic hazard and risk.

Few scientific publications report research or practice in times of crisis. We can surmise some reasons for this. Earthquakes are difficult to forecast, thus warning communication studies have so far played a limited role. Yet, during earthquake crises, the scientific community is busy with other commitments and after the 2009 L'Aquila earthquake trial (Jordan, et al., 2011), may be reluctant to communicate directly with the public (Fallou et al., 2022a). Thus, the primary sources of communication are risk communication experts, government officials, emergency responders, non-governmental organizations - who generally do not report their experiences in the literature. This sometimes leaves the field to individuals who are not specifically trained in seismology and may not be able to provide the media with scientifically sound information for the public and could lead to a loss of public trust (Musacchio and Piangiamore, 2016). In addition, risk communication must address the problem of the spread of fake news which can be amplified by the virality of social media. Uninformed people can prevent the smooth flow of relief efforts, and jeopardize preparedness and recovery efforts (Chen et al., 2018; Mero, 2019; Peng, 2020; Zhou et al., 2021). In times of crisis, fear is an aggravating factor for the spread of misinformation (Fearn-Banks, 2016; Fallou et al., 2020; Mustać et al., 2021), and can be reduced through communication.

Because different types of misinformation can spread at different stages of the earthquake cycle, debunking communication is an ongoing task in seismology (Fallou et al., 2022b) that requires collaborative efforts among scientists and science communicators. Overall, misinformation about earthquakes is fuelled by uncertainty, misunderstanding, cognitive bias, lack of scientific knowledge, or even lack of scientific consensus (Dryhurst et al., 2022). The tools and response strategies to misinformation must be constantly adapted to the nature of the misinformation and implemented promptly. It is critical to communicate to the public what information is available, the level of uncertainty, and the potential risks (Vlek, 2019; Dallo et al., 2020; Dryhurst et al., 2022). To be effective, this information must be tailored to the public in terms of tools, content, and approaches (Lamontagne and Flynn, 2014; Goulet and Lamontagne, 2018; Kouskouna et al., 2021; Savadori et al., 2022). Behavioural recommendations should include clear and locally relevant instructions on actions to be taken (Dallo et al., 2020). Incorporating emotion into communication efforts will contribute to meaningful dialogue between scientists and the public (Lamontagne and Flynn, 2014; Lacchia et al., 2020).

4.3 Proactive communication

The increasing proactive stance, as opposed to passive information sharing that emerges from the publications analysed, underscores that seismic risk communication is increasingly becoming a tool to help communities cope with the hazard (Celik and Corbacioglu, 2010). The recipients are mostly students and citizens, and the bottom-up approach to resilience building is increasingly seen as an effective communication tool (e.g., Camassi et al., 2005; Panic et al., 2013; Musacchio et al., 2016a; Musacchio et al., 2016b; Custodio et al., 2016; Peruzza et al., 2016). Communication tools rely mainly on interaction with the public (face-to-face or through surveys) and are greatly influenced by people's trust in the communicator and the means of communication (Slovic, 1987; Paton, 2007; Goulet and Lamontagne, 2018; Balog-Way et al., 2020; Çoban and Göktaş, 2022). However, the potential of new technological tools to engage with the public is still underestimated. For example, augmented reality, an emerging tool that is well-known among young people, is rarely used to communicate earthquake risks (Reitano et al., 2019; Falsaperla et al., 2022).

Risk education programs targeting children emphasize the resilience aspect of communication. They have a great potential in fostering disaster-resilient communities through the domino-effect that children have in educating adults and their environment (Finnis et al., 2007; Ronan et al., 2008; Piangiamore et al., 2015; Rodríguez-Giralt et al., 2020). Several publications (Cantore et al., 2003; Camassi et al., 2005; Courbolulex et al., 2012; Zaharia et al., 2013; Lanza et al., 2014; Zollo et al., 2014; Musacchio et al., 2015; Piangiamore et al., 2015; Baytiyeh and Öcal, 2016; Custodio et al., 2016; Musacchio et al., 2016a; Peruzza et al., 2016; Saraò et al., 2016; Tataru et al., 2016; Zaharia et al., 2016; Barnaba et al., 2018; Peruzza et al., 2018; Musacchio et al., 2019a; Berenguer et al., 2020; Solarino et al., 2021a; Mohadier et al., 2021; Musacchio et al., 2021; Piangiamore et al., 2021; Scaini et al., 2022) point out the need for earthquake risk education in school curricula as a first step to reducing the impacts of future earthquake disasters and making vulnerable communities more resilient to future crises. However, our analysis also points out a critical gap in seismic risk communication practice: there are only a very few case studies devoted to assess effectiveness (e.g., Crescimbene et al., 2019; Plat et al., 2019; Musacchio et al., 2021). Another critical gap concerns the limited availability of theory-based research. Unfortunately, this is a trend already detected in social vulnerability, resilience, and adaptation research (e.g., Kuhlicke et al., 2023). There are clear benefits of explicitly using theories, including, e.g., reducing ambiguities, enhancing transparency, improving comparability, ensuring a productive development of this research field, and supporting better evidence-based policy recommendations (*ibidem*). Explicit articulation of theories is essential to advance this field.

More efforts are needed to systematically focus seismic risk communication on recipient`s needs. For example, we need to better understand the mechanisms that influence people's perceptions of earthquake risk and how risk perception studies can be used to co-design communication campaigns/strategies between experts and stakeholders (Mileti and O'Brien, 1992; Dooley et al., 1992; Wachtendorf and Sheng, 2002). Social research has found evidence that analysis of community risk perception needs is the starting point for any risk communication effort (Slovic, 1993; Shaw et al., 2004; Marti et al., 2018). Assessing public risk perceptions is propaedeutic to help decision-makers and defining communication strategies to improve community resilience (Marincioni et al., 2012; Crescimbene et al., 2014; Vicente et al., 2014; Crescimbene et al., 2015; Baytiyeh and Öcal, 2016; Blake et al., 2017; De Pascale et al., 2017; Rego et al., 2018; Avvisati et al., 2019; Almeida et al., 2020; Nunes et al., 2020; Albulescu et al., 2021; Savadori et al., 2022). Also, the application of strategies for vulnerability reduction and emergency preparedness appears to be strongly influenced by people's perception of risk, gender, ethnicity, social class, cultural beliefs, and past experiences with disasters (Marincioni et al., 2012; Baytiyeh and Oecal, 2016; Becker et al., 2017; Marti et al., 2018; Vlek, 2019). The great variability of individual perceptions, points of view, and previous experience with earthquakes makes risk assessment very subjective (Siegrist and Cvetkovic, 2000; Lindell et al., 2009), so people may use different mitigation strategies to address the same risks (Johnston et al., 1999; Audru et al., 2013). Fatalism sometimes becomes a self-defeating attitude, especially in developing countries (Baytiyeh and Oecal, 2016). Individuals are also subject to believing that negative events are less likely to happen to them (Spittal et al., 2005). At the same time, people's sense of community is a cultural value that positively influences individual risk preparedness (Paton, 2003; Spittal et al., 2005).

Well-structured and properly disseminated hazard and risk information programs appear to engage communities and effectively influence people's actions (Asgary and Willis, 1997; Tanaka, 2005; Paton, 2007; 2008; Tataru et al., 2011; Okazaki et al., 2015; Postiglione et al., 2016; Musacchio et al., 2019b; 2019c). Indeed, it is not the information itself that determines the action, but the way people interpret it in the context of their experiences (Rogers, 1983; Paton, 2008). Further research is needed to better understand how often risk perception studies are the backbone of targeted risk communication strategies.

4.4 The role of social media and information technologies

In the last 2 decades, we have witnessed the growth of information technologies, especially social media, which enable rapid interpersonal communication and collaboration, even during disasters. Several platforms operated by seismological centers provide earthquake information in real or near real-time, supported by social media and the electronic press, and are highly functional tools for emergency managers (Craifaleanu et al., 2011; Lindsay, 2011; Amato et al., 2012; Bossu et al., 2018; Bragato et al., 2021; Pignone et al., 2022; Wang et al., 2022). Experience from various earthquake prone areas has shown that direct information through official websites accessible to the public, as well as TV and radio programs, are effective and well accepted ways to communicate (Jordan et al., 2011; Tekeli-Yesil et al., 2019; Tekeli-Yesil et al., 2020). However, authoritative information and warnings should be consistent across communication channels to achieve the desired public response (Devès et al., 2019; Dallo et al., 2020; Inal Onal et al., 2021). Social media and smartphone apps play an increasingly important role in disasters (Bossu et al., 2018; Amiresmaili et al., 2021; Mustać et al., 2021). They provide timely, actionable information during a crisis and reduce public anxiety (Reuter and Kaufhold, 2018; Fallou et al., 2020). Consequently, warning and notification systems, combined with specific guidance and procedural knowledge, can provide citizens with prompt information about a disaster, allowing them to reduce anxiety (Cvetkovic et al., 2019).

The various technological platforms not only provide information about risk in the pre-disaster and post-disaster periods but can also provide feedback to crisis managers for reassessing the current situation, responding, and reorganizing disaster management, and providing scientific data for post-disaster processing (e.g., Sbarra et al., 2009; Bossu et al., 2018; Quitoriano and Wald, 2020). For example, social networks can engage the public to participate in online earthquake damage assessment, providing important feedback for rapid and comprehensive macroseismic intensity assignment and distribution. Such two-way communication will in turn prove critical for better management and reduce risk and loss or damage (Katsikopoulos, 2021).

4.5 Geographical distribution

According to our results, communication about seismic risks in Europe is unevenly distributed among countries, with Italy having the highest number of documents included in the investigated dataset, followed by Portugal, Iceland, Romania, Turkey, France, and Greece. Some countries such as Greece, which is among the European countries with the highest seismic hazard, are certainly underrepresented. This may be related to our criteria for document selection and does not necessarily point to a lack of concern for seismic risk communication. For example, Greece is one of the few countries where disaster and emergency education textbooks are distributed to all children and used as the main teaching material in every school (Kouskouna et al., 2021).

However, as far as Italy is concerned, we cannot but mention two important earthquakes that, in our opinion, have strongly influenced earthquake risk communication in Italy. These are the 2002 San Giuliano di Puglia earthquake (Mw=5.7), which resulted in the collapse of a school and the death of 26 children and their teacher (e.g., Dolce, 2009), and the 2009 L'Aquila earthquake (Mw=6.3) and its well-known associated lawsuit (e.g., Jordan et al., 2011; Herovic et al., 2017). These two events triggered a tremendous emotional impact on the public and the scientific community, changing the approach to seismic risk communication. It is also worth mentioning that after the 2002 San Giuliano di Puglia earthquake, special attention was paid to the seismic safety of schools (Dolce, 2009), especially in terms of structural aspects. On the other hand, little attention has been paid to other potential sources of injury and loss, such as individual or community behaviour (emergency or not) and non-structural elements (collapse of ceilings, overturning of cabinets and shelves, escape routes, *etc.*) (Peruzza et al., 2016; Musacchio et al., 2019a; 2019b; Solarino et al., 2021b; Falsaperla et al., 2021; Ferreira et al., 2021; Lopes et al., 2021).

A comparison proposed by Appleby-Arnold et al. (2020) among countries with different seismic risk, such as Romania (high risk) and Malta (low risk), offers evidence of a different 'disaster risk perception' by European citizens. Nevertheless, the need for seismic awareness and preparedness is increasingly becoming a cross-border issue due to the growing trend of human mobility (movement of individuals or groups on short visits or holidays) for example, from countries with low or negligible seismic risk to earthquake-prone countries. It should be noted, however, that to identify cross-national similarities and differences in earthquake risk communication, further research is needed to compare existing practices for different hazards (e.g., floods, earthquakes, *etc.*), and provide databases of best practices in Europe and beyond.

4.6 Limitations

As with any scoping or systematic review study, results and interpretations thereof apply only in the context of the selected scientific literature, using the search criteria described in section 2.2. We acknowledge that the picture we obtain in this study may be biased because it does not include documents in languages other than English, grey literature, and reports. Other sampling methods (e.g., based on country quotas) may be used in the future. Also, the methodological "5 W″ framework that we used for data analysis (see Section 2) can certainly be improved and the parameters included in the analysis can be expanded. On the other hand, some parameters can also be analysed by collecting "excerpts" of qualitative evidence/publications, which can then be processed using qualitative data analysis programs such as Nvivo or MAXqda. Nevertheless, we believe that the main characteristics we identified in the selected publications can provide an interesting overview of the topic and serve as a reference for future studies.

5 Conclusion

Seismic risk communication is a process that starts with understanding people's needs and knowledge and leads to the active involvement of people whose behaviour can contribute to reducing the risk of damage and to improving preparedness.

Scientific, economic, and institutional resources must be deployed to engage with stakeholders involved in the seismic risk communication lifecycle and to build long-term relationships with communities at risk. Thus, effective risk communication is the result of long-term learning processes that do not end with the simple use and sharing of information but also include risk awareness, and leveraging the appropriation of values, decisions, and actions to mitigate risks. Scientific and technological knowledge -coupled with the respect for different cultures and values- can be disseminated through public campaigns and mass communication channels to increase awareness of impending risk.

Our scoping review identifies several best practices and gaps that can provide insights for future improvements. Seismic risk communication in Europe over the last 2 decades:

- is described in the scientific literature as occurring mainly in the pre-crisis phase of the disaster lifecycle when risk awareness and capacity to cope with hazards can be effectively built. The emergency and recovery phases are largely ignored;
- is increasingly proactive, with an emphasis on a bottom-up strategy that relies on youths to build the resilience of future generations;
- is relying increasingly on social media to provide timely and actionable information in times of crisis and to engage citizens, following a two-way risk communication model, in the pre-crisis time. Social media are also used to provide scientific data for post-disaster processing;
- is practiced in an uneven way in the different countries.

Despite general agreement with the best practices recommended in the 2015–2030 Sendai Framework, there is still a long way to go to keep up with current trends in risk communication. The future agenda for the communication of seismic risk should focus on building trust with the public, tailoring communication to their needs and moving towards a three-way model of seismic risk communication, that engages actors from different sectors—academia, business, government, and civil society—for the common goal of seismic resilience. Actions are even more necessary to curb the spread of fake news and its negative impact on disaster management. Moreover, our results show that a vast majority of the analysed practices do not explicitly build on risk communication theories. We believe that more efforts should be done to link practice and theory, e.g., by testing the effectiveness of existing models, updating them and by defining new ways to communicate. The agenda for change is still open and requires everyone's commitment.

Author contributions

GM conceived the study, performed the statistical analysis, and prepared the figures. ASa Managed the data collection, organized the database, and analysed most of the data. All authors contributed to the design of the study, to data analysis, the writing of specific sections, the revision of the manuscript, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

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