Two decades of seismic risk communication in Europe: a scoping review

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Abstract

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 two decades, risk communication has evolved significantly. This has led to a reorientation from a predominantly "one-way", top-down communication model to the promotion of "two-way" or "three-way" models in which people, their needs, and their participation in disaster risk management and co-creation are a central element. The reasons for this shift are many. For example, recent disaster experiences and research have highlighted that one-way, passive risk communication is poorly interpreted, often misunderstood, and can even destroy public trust in emergency management authorities.

In this paper, we critically explore this transition by conducting a scoping review (n=109 publications) of seismic risk communication in Europe. We analyze the approaches, messages, tools, and channels used for seismic risk communication and how they have changed between 2000 and 2022, emphasizing how public engagement in risk communication has been *de facto* implemented over the past 20 years. The results reveal that the stated goals of seismic risk communication are, in decreasing order, to share information, raise awareness, change behaviors/beliefs, and increase preparedness. Pupils, students, and citizens are the primary recipients of communication activities. Over the years, two trends have emerged. First, the "two-way" or "three-way" communication models became more prevalent than the "one-way" model. Second, the aims of communication became more proactive than informative.

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 as an information and dissemination channel in the efforts to reach audiences that are so diverse in terms of age, culture, and education. Strikingly, only one fifth of the analyzed publications explicitly builds on or tests risk communication theories. Future research must focus particularly 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*

1 Introduction

Risk communication is a key component of risk management. It influences awareness and preparedness, can shape risk governance, and even change behaviors and opinions. It can also empower communities at risk by promoting the implementation of best practices, increasing preparedness, recovery, and resilience (e.g., Katsikopoulos, 2021), and using lessons learned from past disasters to foster policy and legislative change (e.g., Spence, 2007).

In Europe, the Seveso I Directive (Directive 82/501/EEC) has promoted risk communication as a right of communities at risk since 1982. International frameworks and strategies, such as the Sendai Framework (UNISDR, 2015), have acknowledged the potential of risk communication to promote community empowerment and have transformed risk communication from a right to be informed to a risk management tool. In addition, disaster risk management and risk communication approaches have become two-way and people-centered: "*there is a need for the public, private sector, and civil society organizations, as well as academia and scientific and research institutions, to work more closely, together and to create opportunities for collaboration*" (Sendai Framework, UNISDR, 2015).

The two-way model of risk communication and people-centered focused approach has been referred to as the first mile (Kelman and Glanz, 2014). As Stewart (2018: 2) points out, "*communicating that first mile to reach the people who directly face hazard threats ought to be a fairly uncontentious component in hazard preparedness and mitigation efforts. Yet, such a participatory approach marks a methodological move away from the prevailing one-way mode of knowledge transfer towards more inclusive transdisciplinary strategies that incorporate peer-role models, adopt social network-based strategies, and directly engage with communities in motivating preparedness actions*."

However, what makes risk communication different from any other form of communication, is the close relationship with the disaster lifecycle. This requires the establishment of specific strategies depending on whether communication occurs in the pre-impact, impact/event, or recovery phase of disaster risk management (Balog-Way et al., 2020; NOAA, 2016).

Literature reviews can provide useful insights and lessons learned to improve, refocus, or better tailor risk communication and assess the level of engagement of the scientific community in communicating with the broader public. There are several aspects specific to risk communication that can be addressed in a literature review. The disaster lifecycle bound of risk communication, the actors (state and non-state agencies, organizations, stakeholder groups, and the public) at different spatial and temporal scales, the knowledge and understanding of the needs of beneficiaries, the focus, the aims, and the tools are all crucial aspects that can be addressed.

Research emphasizes that scientists and/or authorities involved in risk communication processes should not only provide the right information at the right time, but more importantly, understand the information needs of citizens/stakeholders, monitor their responses, engage in awareness and education activities, and co-design and evaluate risk communication strategies (e.g., La longa et al., 2012; Katsikopoulos, 2021). A recent literature review highlights that trust in communication messengers, message characteristics, and audience engagement are of paramount importance in risk communication research (Balog-Way et al., 2020). A summary of best practice guidelines in risk communication can be found in Veil et al. (2011) and Dallo et al. (2022), where the authors emphasize the importance of getting to know the audience and building a relationship of trust with them to better understand their needs and concerns (Goulet and Lamontagne, 2018).

Seismic activity is only one of the many hazards of risk communication, but it is highly relevant in the landscape of disasters. According to the World Health Organization, more than half of all deaths related

to natural hazards between 1998 and 2017 are due 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).

However, 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 correlated with the best seismic retrofit technologies or earthquake preparedness programs. Instead, this reduction is associated with increased awareness efforts and increased relevance of earthquake risk management on the public agenda (Spence, 2007). This not only shows the value of seismic risk communication but also the need to promote it and dedicate economic and institutional resources to its development.

This paper aims to review the literature on seismic risk communication over the last two decades. To our knowledge, no systematic literature review has been conducted so far on this topic. Thus, this paper fills a gap. Particularly, it is a scoping review (Munn et al., 2018; Arksey and O'Malley, 2005; Kitchenham et al., 2011; Paré et al., 2015) that spans about 20 years and aims to describe the evolution of communication and highlights debates about the current state and future directions in the field. The analysis focuses on European countries, where progress toward an earthquake-safe society is threatened by the relatively low recurrence rate of highly destructive earthquakes (Spence, 2007) and where risk communication may therefore be critical to disaster risk management.

The two key questions, and specific objectives, of this review concern the main characteristics of seismic risk communication over the past 22 years in Europe in terms of:

- practice and research
- role in building the resilience of earthquake-prone communities

Indeed, it is 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 is 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. Overall, misinformation about earthquakes is fueled by uncertainty, misunderstanding, cognitive bias, lack of scientific knowledge, or even lack of scientific consensus (Dryhurst et al., 2022)

This paper is organized as follows. First, we present the methodology and describe the criteria used to identify and analyze the publications. The results of the analysis are described and discussed in the respective sections Results and Discussion. The Conclusion section summarizes the findings and associated limitations.

2 Methodology

Our research follows the scoping review methodology (Arksey and O'Malley, 2005) 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?" To answer this question, we analyzed selected publications retrieved from three scholarly literature databases, i.e., Scopus, Web of Science, and Google Scholar. The full list of selected publications is attached as Supplementary Material (Suppl. 1).

2.1 Selection of publications

Publications were initially selected electronically and then manually revised. The electronic search was based on the following search terms - and the use of the Boolean "and/or" where necessary - that we thought might better represent the topic of seismic risk communication in a general sense (see Table S1 in the Supplementary Material for details):

- 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:

- year of publication: from 2000 to 2022
- language: English
- type of document: full text publications scientific peer-reviewed
- geographical restriction: case studies or experiences based in European countries.

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: gray 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.

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

Table 1: Numbers of publications shortlisted after each selection phase.

2.2 Analysis of publications

After the manual screening, the 109 remaining publications (see Suppl. 1) were scrutinized using a set of parameters related to the five key aspects of risk communication described in Figure 1, namely when the communication takes place, who communicates what to whom, why, and how, also known in communication research as the "5 Ws" (e.g., O'Hair and O'Hair, 2020). Articles were divided among all co-authors for close reading and classification. Thus, data collection was structured quantitatively. Disagreements were resolved through discussion among the coauthors.

Publications were coded using a series of questions/parameters, with binary or multiple response options (see Table S2 in the Supplementary Material for details), including:

When is seismic risk communication conducted as part of the disaster lifecycle? Based on NOAA (2016**),** we indicated whether it was conducted during ordinary times (i.e., long-term preparedness, prevention), during Crisis I (i.e., initial stages of warning communication), during Crisis II (i.e., emergency and crisis communication), or during the recovery phase (i.e., post-crisis, recovery, and rehabilitation)

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 centers/universities.

For the "engagement" parameter, we used the following attributes: Mode I (co-design of seismic risk communication activities/strategies); Model II (joint development of seismic risk communication activities/strategies, e.g., between experts and the public); Model 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); Model IV (joint assessment/evaluation according to Loeffler and Bovaird, 2021).

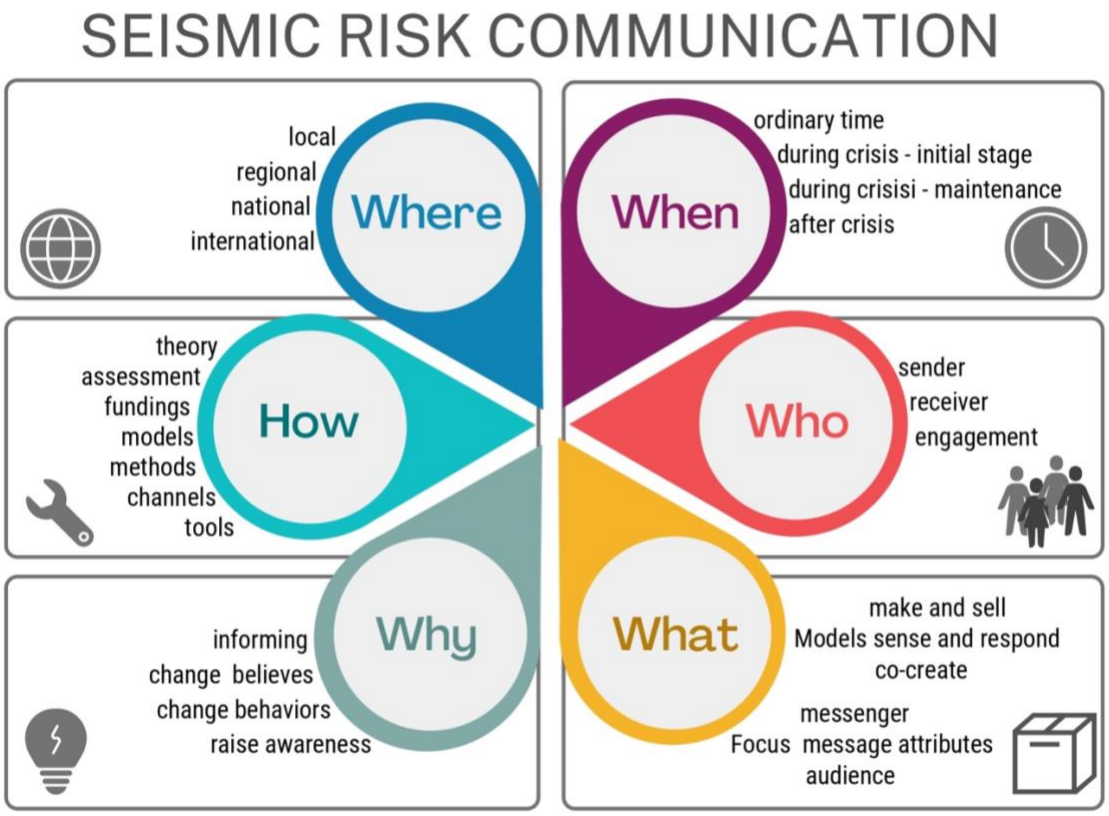

Figure 1: Issues investigated and grouped according to the when-who-what-why-how-where- questions to screen the 109 selected publications.

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: the one-way model, which focuses on persuasion and information transfer ("make and sell communications"); the two-way model, which includes, for example, audience analysis ("sense and respond communications"); the three-way model, which is based on social learning and the stakeholder engagement process ("guide and co-create communications") (for a description of this typology, see Stewart and Hurt, 2021). Second, the "communication focus" parameter grounded Balog-way et al. (2019) and collected binary responses (yes/no) for communication/research 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 behaviors; Raising awareness attributes (based on Bostrom et al., 2018).

How has seismic risk communication been conducted? We collected binary responses (yes/no) on seven parameters (Figure 1) and several possible attributes. We searched for 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, 2016; deficit model, social amplification of risk, risk information seeking and processing model, crisis and emergency communication model, mental model, causal model, behavioral 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 analyzed 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.

We would like to stress here that, as with any review study, the results and interpretations thereof apply only within the context of the scientific literature shortlisted using the search criteria described in the previous section.

3 Results

A review of publications on risk and seismic risk communication provides insights into the evolutionary growth of seismic risk communication over time and shows that the number of scientific publications in Europe has increased over the last twenty years (Fig. 2).

Comparing publications on all risks, including the seismic risk, from 1970 onwards, similar growth is observed in both cases. However, while publications on risk communication appeared more frequently after 1989, a parallel trend did not affect risk communication on earthquakes until 2000 (Fig. 2), about eighteen years after the Seveso Directive I, when public risk communication became mandatory in Europe. Moreover, our data do not show any clear correlation between an increase in scientific papers and the publication of international disaster risk frameworks, such as the Sendai framework endorsed by the United Nations (UNISDR, 2015) to support risk communication.

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 (Fig. 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 to

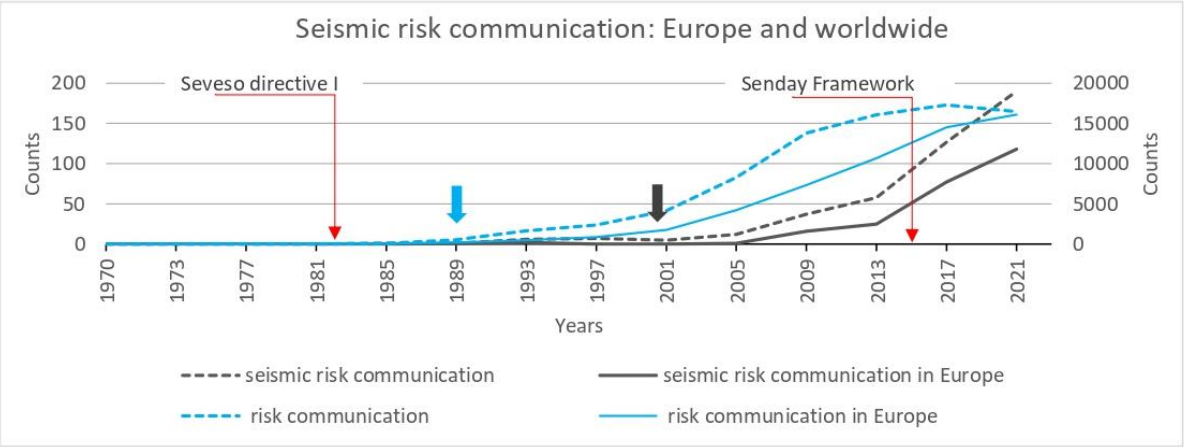

Figure 2: Publications on seismic risk communication over time. Raw data (i.e., no removal applied), from the digital search in the Google Scholar database according to the strings listed in the text, are plotted for all-risk (right y-axis) and seismic risk communication (left y-axis) in Europe and worldwide. Publications on risk communication in Europe and worldwide are shown to occur almost at the same time, and precisely in 1989 (blue arrow); however, a parallel increase in the publications on the communication of seismic risk started more than 18 years later (black arrow). The Seveso Directive I (1982) and the Sendai Framework (UNISDR, 2015) are shown as reference for discussion.

focus entirely on seismic risk communication. Two additional articles followed in 2007 (Spence, 2007; Gruev-Vintila and Roquette, 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. Since 2016, seismic risk communication has been a more stable research topic in the scientific literature at the European level, but still with a fairly small number of documents per year ranging from five to sixteen. Especially since 2019, the number of scientific publications has averaged thirteen per year. 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 two decades, a total of 518 scientists have published on earthquake risk communication, 240 (46%) of them are women.

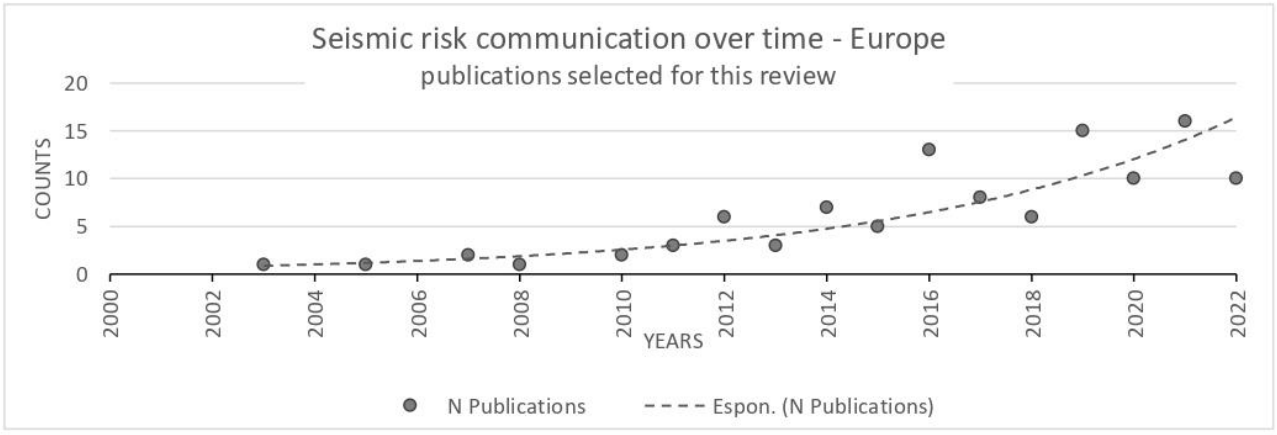

Figure 3: Communication of seismic risk over time in the scientific literature selected for this study. The dashed line plots a computed trend.

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, 2008, 2016, 2021, 2022) have women published more than men on this topic (Figure 4).

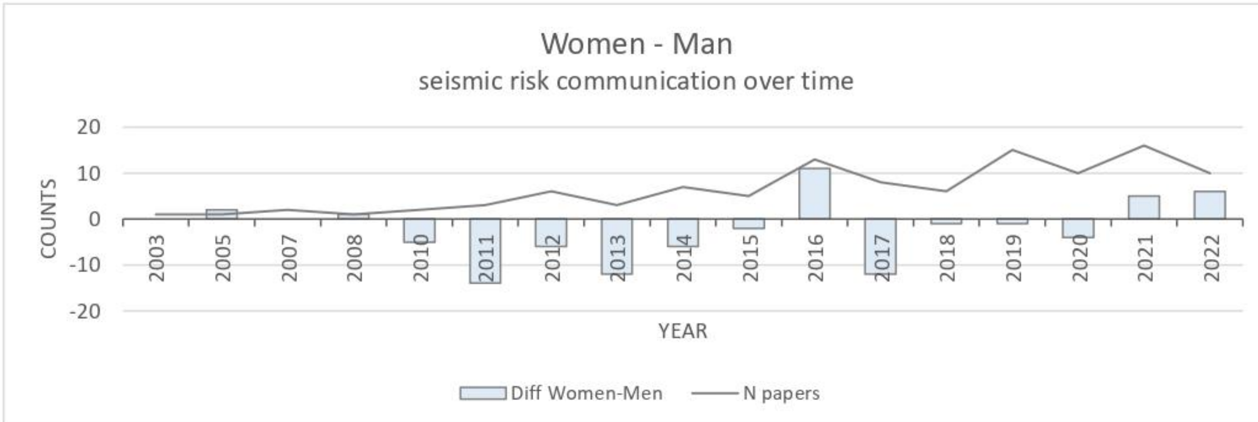

Figure 4: Female authorship over time. The diagram plots the difference between the number of male and female authors per year. Only publications selected for this review are considered for this plot.

Figure 5: Wordcloud displays the most frequently used words in the title of the 109 publications used for this scoping review.

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 "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.

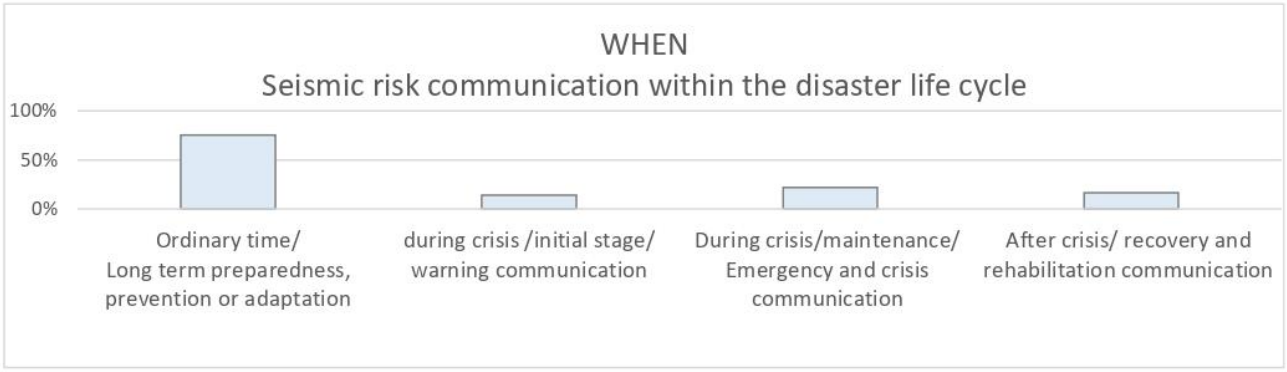

Figure 6: The selected publications on seismic risk communication within the disaster lifecycle: ordinary time strongly prevails over the others.

Who- Research centers 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 recipients (27%) in our data sample. Recipient engagement is described in about half of the publications (46%) using a collaborative development and implementation model (Mode II and III described in section 2.2.=39%), while few publications describe a joint assessment model (Mode IV=5%).

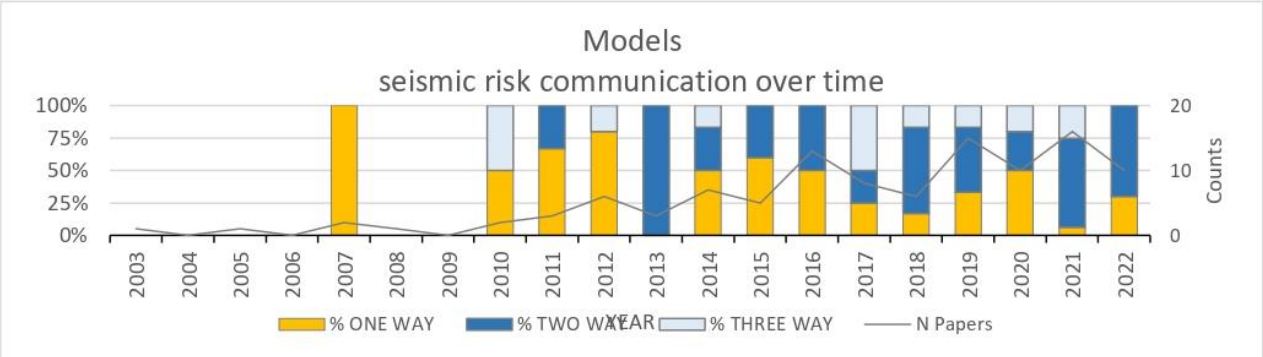

Figure 7: Use of communication models (Stewart and Hurt, 2022) in seismic risk over time. The diagram displays the percentage of publications published each year, referring to either one-way, two-way, or three-ways communication.

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 (in decreasing order): i) target audience understanding (36%) confirmed also by several studies on risk perception; ii) message characteristics (24%) including framing, effective response, and uncertainty; iii) 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%) and raise awareness (47%) followed by change behaviors (27%), change beliefs (16%), and increase preparedness (4%).

We also compared informative vs. proactive goals. By aggregating the goals of awareness, belief change, behavior 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 two 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., Musacchio et al., 2016b; 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.

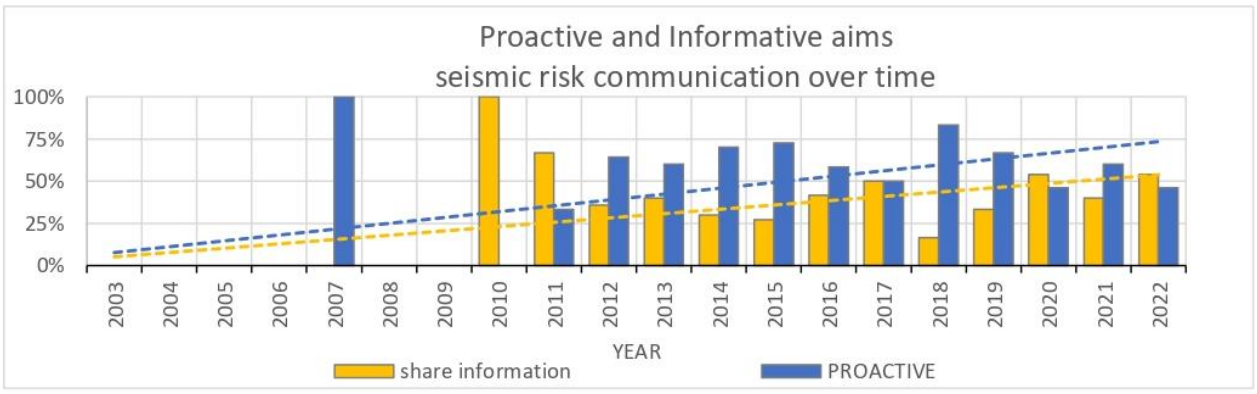

Figure 8: Seismic risk communication aims as reported in the publications investigated in this study. The proactive aims are derived by summing awareness raising, change in beliefs, change in behaviors, and preparedness counts. The percentage is computed for the number of publications published each 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.

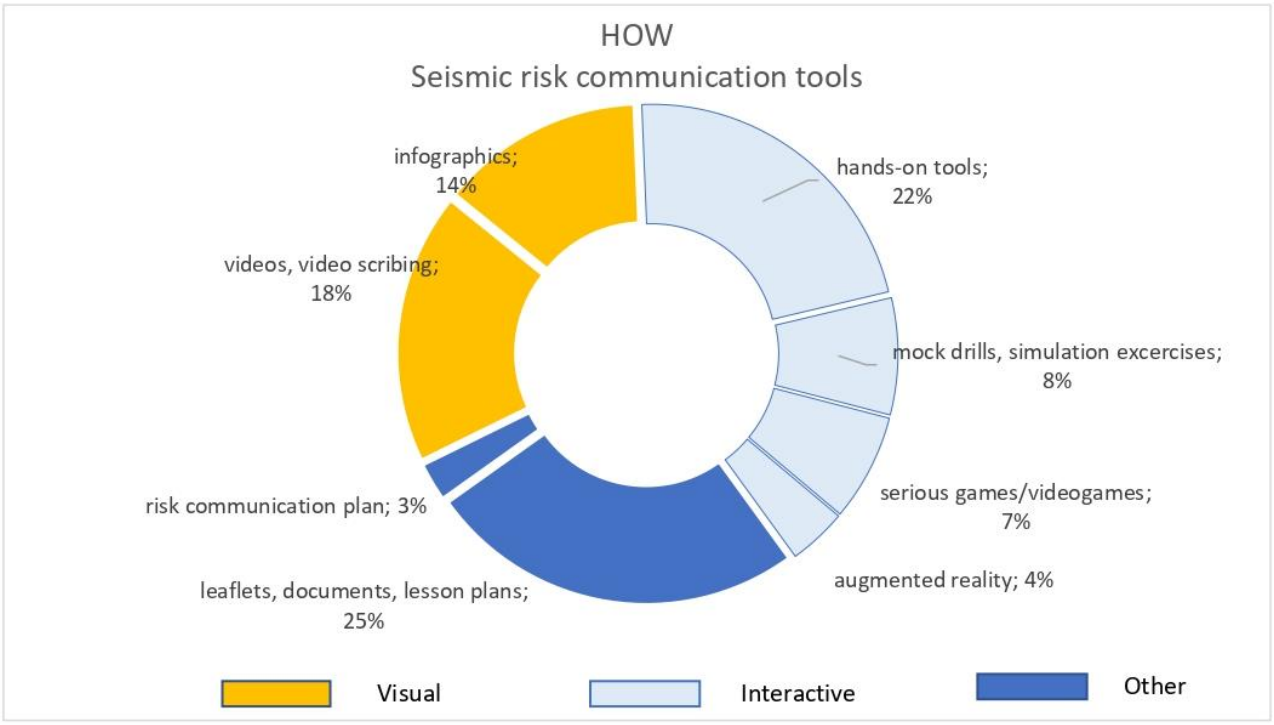

Figure 9: Seismic risk communication tools adopted in the selected publications. Visual-language tools are computed by summarizing infographics and videos; interactive tools are calculated by summarizing serious games, drills, and hands-on and augmented reality tools; "other" refers to more traditional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

Our data reveal that the communication of seismic risk has no stated theoretical background. Only a few publications (20%) mention communication theories explicitly; among these, the deficit model and

behavioral-oriented models have been the most discussed ones (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 adopted. 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 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.

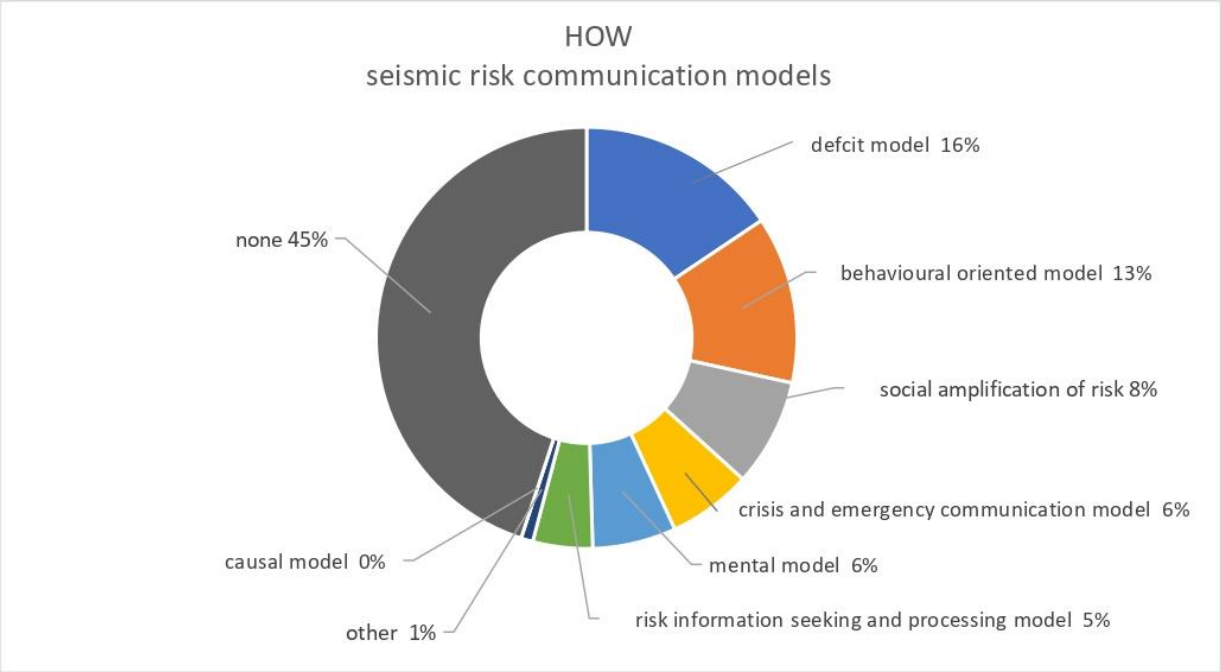

Figure 10: communication models mentioned for seismic risk in the selected publications. Data in the diagram refer to only 20% of the publications, as the remaining 80% did not mention any theory.

4 Discussion: two decades of seismic risk communication

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 over the last two decades.

The chosen time interval allowed us to identify in the scientific literature the beginning of interest in documenting the topic of seismic risk communication and its development. This emerging trend is also consistent with the exponential growth of academic publications in recent decades (e.g., Fire et al.,

2019). However, although interest in earthquake risk communication is increasing, the topic does not seem to be as interesting to academics. The number of publications is consistently two orders of magnitude lower than communications for other risks (Figure 2). There are many reasons for this, and we hypothesize a few below.

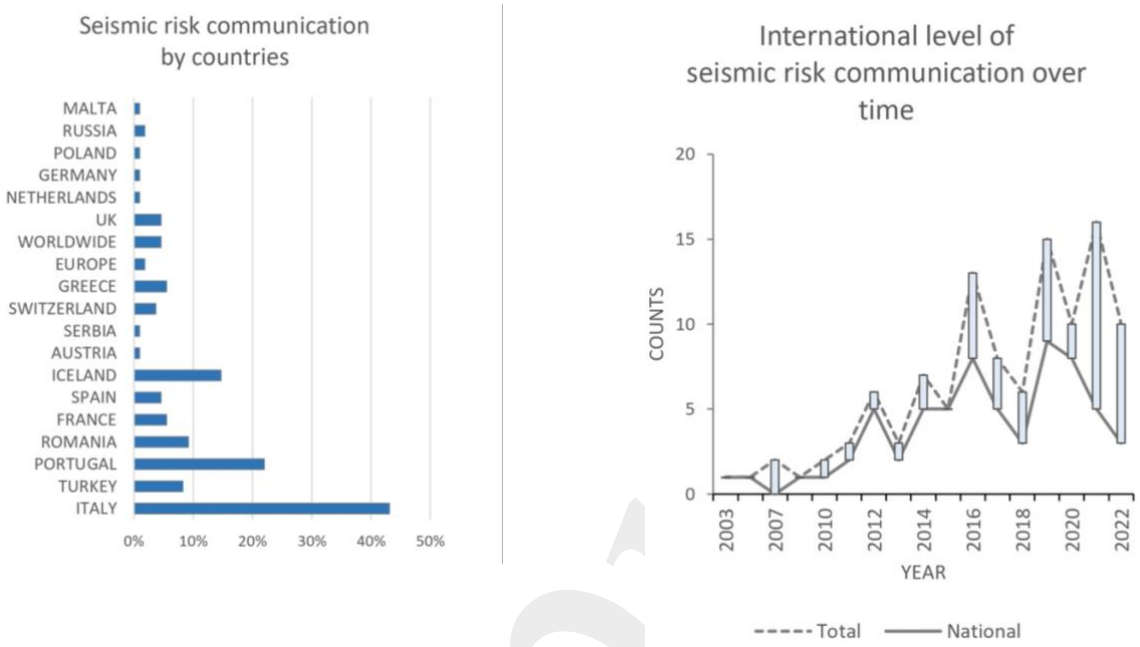

Figure 11: Countries in our data sample (bars on the left panel) and the number of publications reporting national or international seismic risk communication studies over time (bars on the right panel).

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 on disaster risk management or environmental sociology or in communication courses (Scolobig et al., 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 new academic programs (Alexander, 1997, 2003; Menoni, 2014; Holloway, 2014, 2017; for a review, see Scolobig et al., 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. In addition, few journals specifically address seismic risk communication. Thus, the relatively low number of publications could also be due to a lack of adequate space and expertise, or because this type of engagement is considered to be 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., climate risk or technological risk, or 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

The analysis of the 109 documents allows us to answer the key question underlying this review: What are the main characteristics of risk communication in terms of its role in building the resilience of earthquake-prone communities?

The increasing proactive stance, as opposed to passive information sharing that emerges from the publications analyzed, 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., 2016; Custodio et al., 2016; Peruzza et al., 2016). Communication tools rely mainly on interaction with the public (face-to-face or through surveys). Nevertheless, 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).

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. Transposition and interpretation processes are greatly influenced by people's trust in the communicator and the means of communication (Slovic, 1987; Paton, 2007; Çoban and Göktaş, 2022).

The resilience aspect of communication is also emphasized by risk education programs targeting children may be more important in fostering disaster-resilient communities than those targeting adults, because children play an important role in educating adults through the transmission of knowledge at school and at home (Finnis et al., 2007; Ronan et al., 2008; Piangiamore et al., 2015; Rodríguez-Giralt et al., 2020). The increasing proactive and educational side of seismic risk communication is also a strength (Figure 8). Several publications (Cantore et al., 2003; Camassi et al., 2005; Courbolulex et al., 2012; Zollo et al., 2014; Lanza 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., 2013; 2016; Barnaba et al., 2018; Peruzza et al., 2018; Musacchio et al., 2019a; Berenguer et al., 2020; Musacchio et al., 2021; Mohadier et al., 2021; Piangiamore et al., 2021; Solarino et al., 2021a; 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, communication practices and programs should be evaluated for their effectiveness. This is seldomly done and there are only a very few case studies devoted to facing such an issue (e.g., Plat et al. 2019; Crescimbene et al 2019; Musacchio et al., 2021)

Although this study points out that the audience has been the major focus of seismic risk communication, more efforts are needed. A better understanding of 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) should be pursued; efforts in these fields can be a major added value to geophysical studies carried out to improve our understanding of earthquake dynamics and seismic wave propagation and to preserve the memory of past catastrophic seismic events (e.g., Peruzza et al, 2018). 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).

This is also the case because 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). 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; Muttarak and Lutz 2014; Okazaki et al., 2015; Postiglione et al., 2016; Musacchio et al., 2019b; 2019c). Further research is needed to better understand how often risk perception studies are the backbone of targeted risk communication strategies. Thus, future research should address this question: how often are risk communication campaigns based on analysis of communities' information needs and risk perceptions?

In the last two 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 (Lindsay, 2011; Craifaleanu et al., 2011; Bossu et al., 2018; Amato et al., 2012; 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, 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 (Fallou et al., 2020b). 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).

Although social networks can have positive effects on crisis management (Reuter and Kaufhold, 2018), their use also has some drawbacks, such as the spread of fake news that can go viral. 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 our scoping review, we found few scientific publications reporting 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); on the other side, risk communication experts (who are not specifically trained in seismology) may not be the best choice during crises as spokespersons to the Media that need to provide the public with scientific coverage (Musacchio and Piangiamore 2016). This leaves the field to individuals who may not be able to provide scientifically sound information and could lead to a loss of public trust. In addition, risk communication must address the problem of the spread of fake news. In times of crisis, fear is an aggravating factor for the spread of misinformation (Fearn-Banks, 2016; Fallou et al., 2020a; 2020b; Mustać et al., 2021), and can be reduced through communication.

Because different types of misinformation can spread at different stages of the earthquake cycle, preconviction and debunking communication is an ongoing task in seismology (Fallou et al., 2022a) that requires collaborative efforts among scientists and science communicators. 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., 2022; 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). Behavioral 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).

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 behavior (emergency or not) and nonstructural elements (collapse of ceilings, overturning of cabinets and shelves, escape routes, etc.) (e.g., Peruzza et al., 2016; Musacchio et al., 2019a, 2019b; Falsaperla et al., 2021; Ferreira et al., 2021; Lopes et al., 2021; Solarino et al., 2021b).

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.

We acknowledge that the picture we obtain in this study may be biased because it does not include documents in languages other than English, gray literature, and reports. Other sampling methods (e.g., based on country quotas) may be used in the future. Also, the methodological "5W" 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 analyzed 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.

Conclusions

The culture of prevention is the result of a long-term learning process that is not exhausted by the simple use and sharing of information but must also include awareness of risks, and leveraging the appropriation of values, decisions, and actions to mitigate risks. Public campaigns through mass communication channels can raise awareness of impending risk, based on scientific and technical knowledge and respect for different cultures. Education is critical to building a culture of prevention and resilience to mitigate the impacts of natural hazards along with scientific information and knowledge of mitigation measures. This means that - - our concrete efforts to improve earthquake risk

management must also focus on education, capacity building, and the development of best practices if they are to be effective

Our review of the seismic risk communication over the past two decades has shown that there is growing interest, albeit rather modest, in the extent of earthquake-related damage that continues to affect at-risk communities. The communication of seismic risk is mainly delivered in ordinary time within the disaster lifecycle, and it is increasingly proactive, i.e. aimed at raising awareness, changing behaviors and beliefs, and increasing preparedness. However, one of the main threats is misinformation that may be amplified by social media and be critical during the emergency phase.

There is increasing recognition of the need to establish a relationship of trust with the public, tailor communication to the public's needs and involve the public in communication. In addition, the importance of close interaction among scientists, communication experts, and stakeholders that emerges from our study suggests the need for major efforts from all actors involved to maximize the effectiveness of seismic risk communication.

Seismic risk communication is a process that starts with understanding people's needs and knowledge and leads to the active involvement of people whose behavior can contribute to reducing the risk of damage to structural and nonstructural components and improve 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.

5 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.

6 Author Contributions

G.M. conceived the study, performed the statistical analysis, and prepared the figures. A.Sa. managed the data collection, organized the database and analyzed the majority 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.

Data Availability Statement

The datasets generated and analyzed for this study can be found in the as Supplementary Material.

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ANNEX

Supplementary Material

1 Description

The following material contains supplementary tables and references to the manuscript. In particular:

- Table S1: strings used to select the publications electronically
- Table S2: parameters and attributes that were used in this study
- References: List of 109 publications for the scoping review according to the selection criteria of section 2.1 (of the manuscript) and Table S1

2 Supplementary Tables

Table S1Search strings used to select publications in three databases: Google Scholar, Scopus, and Web of Science. The filters applied were “find articles with the exact phrase” and “anywhere in the article”

Google Scholar	**Scopus**	**Web of Science**
Europe "seismic risk communication "	“seismic risk communication”	"seismic risk communication" OR "communicating seismic risk" OR "communicate seismic risk" OR "earthquake risk communication" OR "communicating earthquake risk" OR "communicate earthquake risk"
Europe "earthquake risk communication"	"EQ risk communication"	“seismic risk education” OR "educational seismology"
Europe "seismic risk education"	"in Europe" "seismic risk education" OR "earthquake risk education" OR "educational seismology" "seismic risk"	"education campaign*" "seismic risk"
Europe seismic "risk education campaigns"	Seismic Risk Education	“earthquake risk education”
Europe earthquake " risk education campaigns"	educational seismology	
educational seismology -US -California -Mexico -Asia -Japan	Europe " awareness campaign" OR " awareness campaigns" "seismic risk"	
	awareness seismic campaign	
	Seismic And Risk and Communication	
	seismic AND risk AND education	

Table S2: Parameters and attributes retrieved from the 109 selected publication grouped as follows: when (a), who (b), what (c), why (d), how (e1, e2, e3)

(a)

WHEN **in the risk communication lifecycle: before, during, after the event** **Prevention-preparedness/druring the crisis/recovery**			
Ordinary time/ Long term preparedness, prevention or adaptation	during crisis /initial stage/ warning communication	During crisis/maintenance/ Emergency and crisis communication	After crisis/ recovery and rehabilitation communication
1=yes 0=no 11=doubt	1=yes 0=no 11=doubt	1=yes 0=no 11=doubt	1=yes 0=no 11=doubt

(b)

WHO							
				Engagement/co-production modes			
Sender/ organiser/ messenger		Receiver/ target audience		Receiver engagement in communication	If yes		
1=public agencies working in DRM; 2= NGOs; 3=public auth. working in edu. 4= students 5= citizens/general public; 6=private company 7= Research centres/university 10=other 11=doubt	specify OTHER	1=public ag. DRM; 2= NGOs; 3=public authorities working in education 4= citizens/general public; 5= students/pupils; 6= private companies; 10=other 11=doubt 12=mixed 13=multiple	specify OTHER	1=yes 0= no 11=doubt	1=co-design 2=co-development 3=co-implementation 4=co-assessment 10=other 11=doubt	specify OTHER	specify doubts

(c)

WHAT			

Communication models (Stewart and Hurt 2022)		Research focus (Balong-way et al.2019)	
1. one way 2. two way 3. three way 10=other 11=doubt	specify OTHER	1= sender/messanger 2=message attributes 3=audiences 10=other 11=doubt 12=mixed 13=multiple	specify OTHER

(d)

WHY			
Communication aims (Bostrom et al. 2018)			
1= sharing information 2=changing beliefs 3= changing behaviours 5= raise awareness 10=other 11=doubt 12=mixed 13=multiple	specify OTHER (i.e. prevention, preparedness, find a strategy...)	specify mixed	specify multiple

(e 1)

HOW										
Risk communication tools			Risk management tools used for communication purposes (Venutti et al. 2021)		Channels			Methods		
1=leaflets, documents; lesson plans 2=videos; video scribing 3= mock drills/simulation exercises; 4= serious games; serious videogames 5= risk communication plan; 6= hands-on tools (e.g. plate tectonics model, seismometers, shake tables, edu-models) 7= infographics 8=augmented reality 10=other 11=doubt 12=mixed 13=multiple	specify OTHER	specify multiple	1=hazard, risk, vulnerability or exposure maps; 2=emergency plans; 3= warning/alert messages; 4= past event history; 5=risk reduction plans; 6=recovery plans; 10=other 11=doubt 13=Multiple tools	specify OTHER	1=face to face; 2= social media; 3= website 4=Tv, radio; 5= newspapers; 6=smartphone apps; 10=other 13= multpile channels	specify OTHER	specify multiple	1= interviews 2= focus groups/outreach events 3=surveys 4=classroom activities 10=other 11=doubt 12=mixed 13=multiple channels	specify OTHER	specify multiple

(e2)

HOW				
Modes		Funded by		Risk communication evaluation included
1=in person 2=remotely/virtual 3=hybrid 10=other 11=doubt 12= mixed methods	specify OTHER	1=public national agencies 2=public international agencies 3=private sector 5=not available 10=other 11=doubt 13=multiple sources	specify OTHER	1=yes; 0=no; 11= doubt

(e3)

THEORY (only what the authors declar)	
	if theory is mentioned

Theory mentioned (NOAA 2016)	defcit model	social amplification of risk	risk information seeking and processing model	crisis and emergency communication model	mental model	causal model	behavioural oriented model	
y=1 n=0 doubt=11 out of scope/ review paper=3	mentioned=1 no=0 doubt=11	mentioned=1 no=0 doubt=11	mentioned=1 no=0 doubt=11	mentioned=1 no=0 doubt=11	mentioned=1 no=0 doubt=11	mentioned=1 no=0 doubt=11	mentioned=1 no=0 doubt=11	Other theory is directly mentioned or used: specify

3 List of selected publications

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