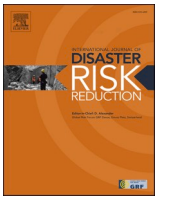
International Journal of Disaster Risk Reduction 130 (2025) 105803

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr



Impacts of hazard maps on individual reaction? Results from a case study in South Tyrol, Italy

Lydia Pedoth [a,b,*], Agnieszka Elzbieta Stawinoga [c], Thomas Thaler [b,d], Stefan Schneiderbauer [e,f,g,h], Fabio Carnelli [a], Doris Damyanovic [b]

[a] Eurac Research, Center for Climate Change and Transformation, Bolzano, Italy
[b] BOKU University, Institute of Landscape Planning, Vienna, Austria
[c] Eurac Research, Statistics Office, Bolzano, Italy
[d] International Institute for Applied Systems Analysis, Population and Just Societies Program, Laxenburg, Austria
[e] Eurac Research, Center for Global Mountain Safeguard Research, Bolzano, Italy
[f] United Nations University, Institute for Environment and Human Security, Bonn, Germany
[g] Department of Geography, Qwaqwa Campus, University of the Free State, Bloemfontein, South Africa
[h] International Research Institute of Disaster Science, Tohoku University, Japan

ARTICLE INFO

Keywords:
Risk perception
Risk communication
Hazard maps
Natural hazards
Community preparedness
Alpine region

ABSTRACT

This study investigates the impact of hazard maps on people's risk awareness, risk perception and willingness to engage in risk management activities in South Tyrol, Italy. By comparing empirical survey data from municipalities with and without approved hazard maps, the research aims to understand how these maps influence people's awareness and attitudes towards natural hazards. The results show that while hazard maps significantly improve risk perception and encourage proactive behaviour, their effect on knowledge about risk relevant tools and measures remains limited. There is a high level of uncertainty and misinformation regarding existing risk mitigation measures, particularly in communities without approved hazard maps. The results show that hazard maps have a significant impact on public risk perception. In communities with approved hazard maps, people perceive a greater need for additional protective measures and have a lower sense of security in case of a natural hazard event. The study also shows that hazard maps increase people's willingness to become more involved in risk management activities. The study emphasizes the importance of targeted risk communication strategies and suggests that hazard maps should be complemented by ongoing risk communication initiatives and participatory formats to achieve sustainable engagement and increase people's preparedness. Additionally, the research highlights the potential of hazard maps to raise awareness and encourage active participation but also identifies challenges and the need for comprehensive follow-up activities to ensure long-term impact.

1. Introduction

Natural hazards, such as floods, droughts, landslides, earthquakes, and heat waves, can have a huge impact on peoples' livelihoods [1]. The probability of being affected by an event, which can create large amounts of damage are not equally distributed across the

* Corresponding author. Eurac Research, Center for Climate Change and Transformation, Bolzano, Italy.
E-mail address: lydia.pedoth@eurac.edu (L. Pedoth).

https://doi.org/10.1016/j.ijdrr.2025.105803
Received 21 March 2025; Received in revised form 11 August 2025; Accepted 4 September 2025
Available online 5 September 2025

globe [2–5]. Mountain regions face particular challenges from natural hazards due to their geographical, climatic and socio-economic characteristics [6,7]. In many cases, mountain regions can be considered as vulnerable, because of their remoteness [8]. Further, they are strongly affected by climate change [9]. Mountain regions are experiencing rapid warming and large populations rely on them either directly or indirectly. These areas are also rich in biological and cultural diversity, playing a critical role in supplying essential resources and services to communities in the mountains and downstream [1]. Key challenges in managing risk in such complex social and geographical contexts include a) how to enhance individual and collective response to natural hazard events, and b) determining who is responsible for planning and implementing mitigation measures [8,10–12]. In the past decades non-state actors have come to play a more prominent role and responsibility in natural hazard risk management than before [11]. Non-state actors encompass a diverse range of entities, including non-governmental organisations, community-based organisations, private sector companies and academic institutions. However, this shift which is also described as behavioral turn [13] also raises the question on how to encourage them to become more engaged and active. Risk communication and risk perception, along with their interrelationships, are key components in the discourse on how to better protect and prepare societies from a social science perspective.

Risk communication is a crucial point for increasing risk awareness, and different targeted communication strategies should be pursued at different levels [10,14]. Maps, for example, play an important role in natural hazard management and are an important tool for risk communication to inform individuals and communities about the potential threat with the goal to improve the individual and collective preparedness [15–18] such as the successful implementation of the European Union Floods Directive (Floods Directive (2007/60/EC). Many authors agree that the use of maps can significantly contribute to successful risk communication [15,19–22]. For example, Wenk et al. [22] argue that maps are suitable as a core instrument for informing the public, reasoning that they have the potential to raise awareness, promote personal responsibility, and communicate residual risks. However, it is also evident that map-based risk communication presents various challenges. These include the distortion and filtering of information due to public biases [22] and varying abilities among the general public to use interactive maps [15,20]. But also, how can we use hazard maps for strategies of reducing risks at individual and community level?

Especially in the field of hazard zone planning there is still a knowledge gap regarding the impact on people's risk awareness, perception, and behavior. It is particularly difficult to study and quantify the impact of policy instruments such as hazard maps on the awareness or attitudes of the population, as there is usually not the possibility of having a control group because a policy instrument is usually implemented in a whole region. The other possibility, which is a long-term study examining the situation before and then after the introduction of a policy instrument, is usually not available due to the lack of longitudinal social science studies and other factors may have changed over the period [23].

Against this background, this study provides the opportunity to understand and analyse the influence of natural hazard plans on peoples' risk awareness and risk perception by comparing empirical data from municipalities with and without a hazard plan within the same region.

The objective of the study is to examine the influence of the natural hazard plan as a risk management policy instrument on risk awareness, risk perception and opinions regarding personal responsibility.

For this purpose, the municipalities were divided into two groups, one with and one without an approved natural hazard plan.

This study aims to explore and test three key hypotheses:

1. The presence of legally binding natural hazard zone plans at municipality level influences peoples' awareness about measures and tools to reduce risk of natural hazards,
2. The presence of legally binding natural hazard zone plans at municipality level increases people's risk perception,
3. The presence of legally binding natural hazard zone plans at municipality level increases people's willingness to be more involved in risk management measures.

We distinguish between 'risk knowledge' and 'risk awareness'. By recognizing that an unambiguous demarcation between both terms is difficult, we refer to 'risk knowledge' as the dynamic understanding that individuals or groups have about factual and contextual information concerning hazards, risk levels, exposure and capacities, in short: what one knows [24–26]. In contrast, risk awareness is understood as the extent to which an individual or community is in general conscious of the presence of a risk [27]. Hence, risk awareness is describing a cognitive orientation toward risks, encompassing attitude, vigilance, and responsiveness, in short: how cognisant and responsive one is with his/her knowledge [28,29]. In this study, we focus on investigating the *risk awareness* of individuals and communities. We consider the level of *risk knowledge* as crucial factor influencing risk awareness but we do not seek to analyse the factors influencing risk knowledge. Finally, by risk perception, we mean the subjective judgment individuals or groups make about the severity and probability of a risk. This perception is influenced by cognitive, psychological, social, and cultural factors, which can lead to variations in how risks are evaluated and responded to compared to their actual statistical probabilities [28,30–33].

2. Study area

South Tyrol, an autonomous province in northern Italy, is in the Eastern Alps, south of the main Alpine ridge. Its climate is mild and dry with an average temperature of 12.3 °C. South Tyrol's landscape is characterized by high mountains (up to 3905 m a.s.l.) and densely populated and intensively used valleys. The majority of South Tyrol's run-off system is part of the upper Etsch/Adige River catchment and its contributors. Due to its geological and morphological terrain, the mountainous region of South Tyrol is subject to various natural hazards: floods, mass movements, avalanches and forest fires are phenomena that are familiar to both the urban population and the population in rural areas. These hazards can potentially jeopardise human activities and lives. An increase in the

average annual duration of rainfall events and debris flow occurrence in South Tyrol can be observed [34] and consequently, the number and scope of floods, rockfalls, landslides, avalanches and other natural hazards has been increasing.

In South Tyrol, the permanent settlement area, i.e. the potentially populated area, corresponds to just over 5 % of the total area of the province. All extensive settlement areas and the largest transport infrastructures are concentrated in the valley bottoms of the larger rivers often surrounded by steep mountain slopes which makes spatial expansion impossible. Within the Italian administrative context, South Tyrol is administered as an autonomous province due to its history as a border region and part of Austria until 1918 and the presence of linguistic and cultural minorities. The Autonomous Province of Bolzano has legislative autonomy, allowing it to create and implement its own laws regarding natural hazard management.

Natural hazards are integrated into the provincial law on spatial planning, which includes construction concessions and other regulatory measures (Provincial Law No. 9 of 10 July 2018 on Spatial Planning and Landscape Protection). Risk management in South Tyrol, particularly through hazard zone planning, differs from other Italian regions by adopting a more innovative and comprehensive approach based on a risk concept rather than just hazard mapping [17]. Inspired by the Swiss approach to risk management, the integration of multiple hazards into the legal framework and the use of risk maps are key aspects of South Tyrol's approach to hazard management [17,35]. In 2008, South Tyrol introduced risk-based spatial planning, shifting from traditional hazard mapping to a more comprehensive risk assessment approach. Standardized risk maps help compare risk situations and support decision-making in technical mitigation measures and spatial planning projects. The mandatory hazard zone planning scheme is applied across the entire area, giving it a superior legal status compared to land-use plans in other regions [17]. The hazard zone planning in South Tyrol is therefore a long-term, risk-based, and legally binding protection measure against various natural hazards. It aligns with European Union directives and incorporates methodologies from Switzerland and Austria, with which it is coordinated, in order to boost cross-border cooperation and effectiveness [17,17].

Risk management has traditionally been seen as a duty of public institutions, but in recent years and due to systemic changes (climate change, governance change, financial aspects) the involvement of different type of actors became more and more important and aspects such as risk awareness and risk communication became integrative part of risk governance [36–39].

Indeed, in South Tyrol, according to provincial law (Provincial Law No. 13 of 11 August 1997, Article 22-bis; Decree of the Provincial Governor (Landeshauptmann) of 5 August 2008, No. 42 and of 19 October 2019, No.23) every municipality is obliged to develop a natural hazard plan that, after the approval by the provincial government, becomes a legally binding plan and receives a legal status superior to local land-use and development plans. Therefore, these natural hazard plans have a direct impact on spatial planning at local level. The hazard zone plans are drawn up by consultants on behalf of municipalities, taking into account the criteria set out in the relevant guidelines. The hazard zone plan includes a hazard zone map as one of its key components, alongside accompanying reports describing and summarising the hydrogeological hazards threatening settlements and infrastructure. The plan also contains other useful information for technicians and experts, such as thematic maps and information relevant to the preparation of expert reports and compatibility assessments. The plan is drawn up by experts and do not foresee any direct involvement of the population. After the plan has been approved, it must be made public in the municipality and every citizen can inspect it and lodge an

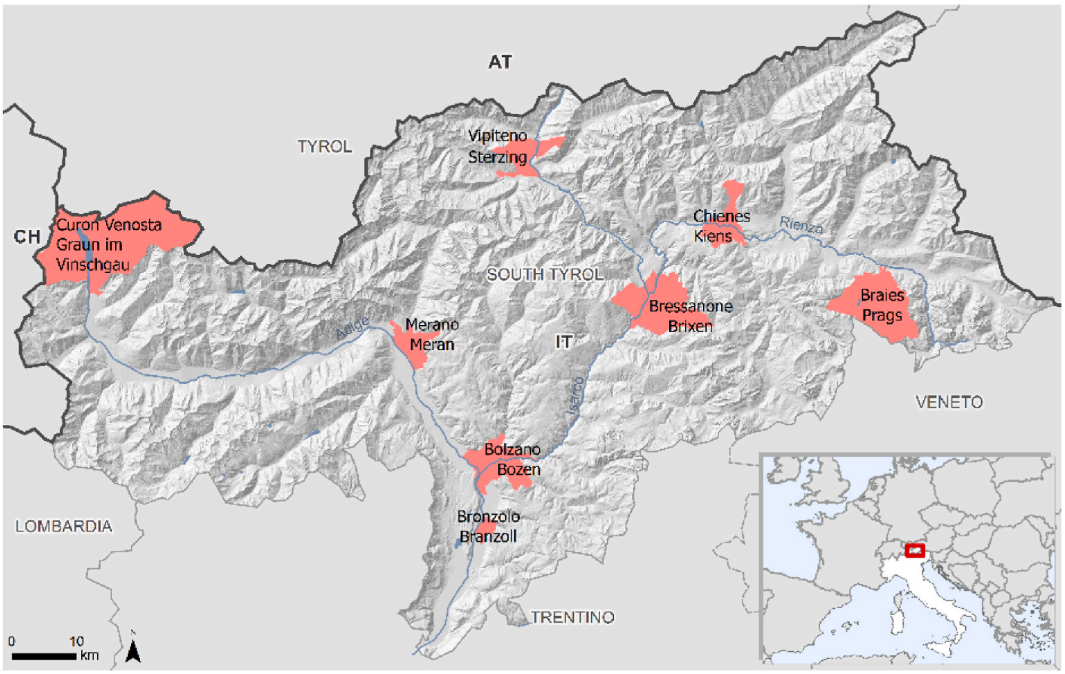


Fig. 1. The 8 municipalities within the study area of South Tyrol (Italy).

objection. In addition, each municipality must organise a citizens' meeting at which the plan is presented. How exactly the meeting is organised is up to each municipality, as is the decision whether to hold additional communication activities or information events. In 2019 when the study was conducted, in about half of the 116 South Tyrolean municipalities these hazard plans had already been approved. The other municipalities are in the phase of development or approval. This situation allows to compare the situation between municipalities that already have an approved plan in place and those that have not, and to analyse if and how the presence of these hazard plans impacts people's risk awareness about natural hazards and their risk perception.

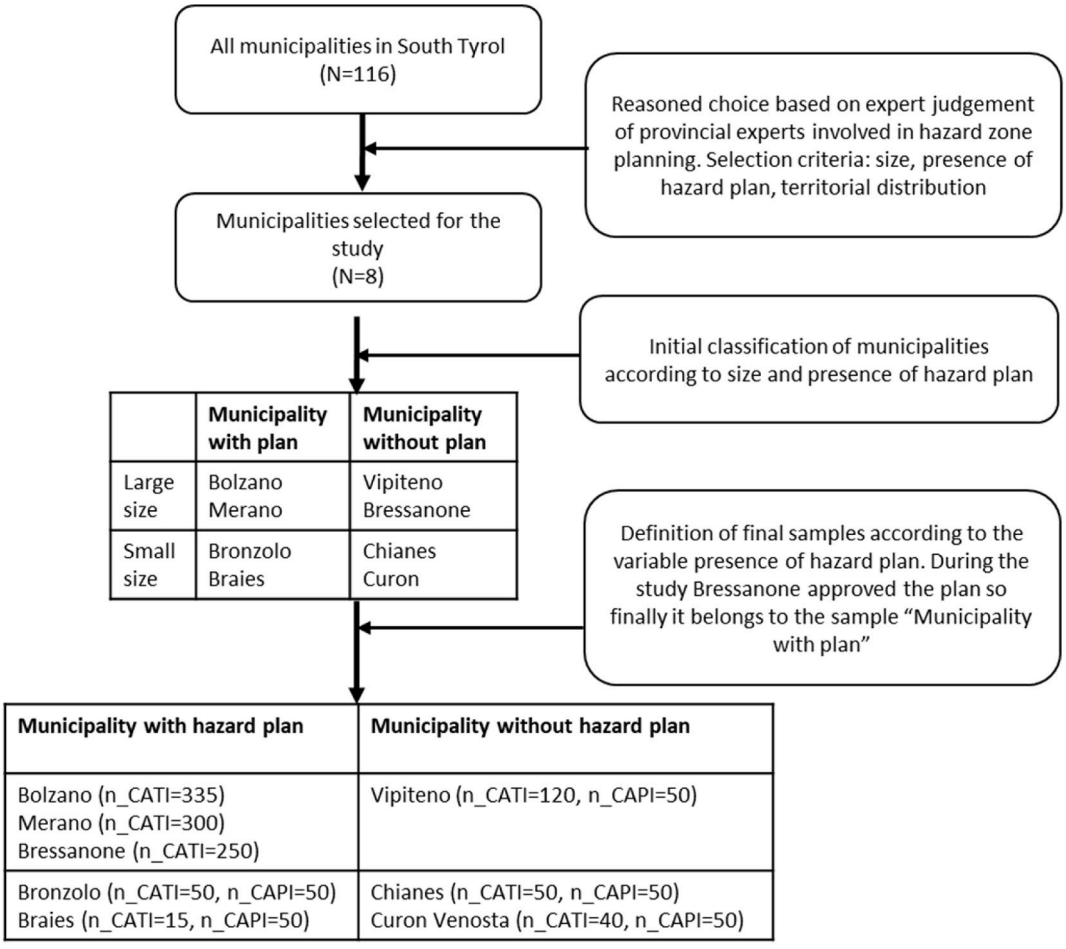
Fig. 1 shows the case study area, and the municipalities selected for the study.

3. Methodology

3.1. Selection of municipalities

The following 3 criteria determined the selection of the 8 municipalities of the study: 1) Size of municipality (small/rural municipalities and large/urban municipalities), 2) experience of events that have taken place in the years preceding the study, and 3) existence of an approved hazard zone plan. We grouped all 116 municipalities in South Tyrol according to these criteria. Each of the resulting groups included different municipalities, the selection of the municipality for each group was made together with natural hazard experts of the region considering a balanced geographical distribution within the region and selecting municipalities that experienced different types of natural hazard events (avalanches, debris flow, flooding). The flowchart in Fig. 2 shows the process of sample selection.

In the original research design, the sample of "Municipalities without Plan" included the municipality of Bressanone (250 respondents), which approved its hazard zone plan during the study and therefore, for the data analysis, is classified in the group of "Municipalities with Plan." Consequently, the sample "Municipalities Without Plan" was considerably reduced and therefore has only 153 respondents compared to those with plan, which had 1257 respondents.



	Municipality with plan	Municipality without plan
Large size	Bolzano Merano	Vipiteno Bressanone
Small size	Bronzolo Braies	Chianes Curon

Municipality with hazard plan	Municipality without hazard plan
Bolzano (n_CATI=335) Merano (n_CATI=300) Bressanone (n_CATI=250)	Vipiteno (n_CATI=120, n_CAPI=50)
Bronzolo (n_CATI=50, n_CAPI=50) Braies (n_CATI=15, n_CAPI=50)	Chianes (n_CATI=50, n_CAPI=50) Curon Venosta (n_CATI=40, n_CAPI=50)

Fig. 2. The process of sample selection. n_CATI refers to the number of respondents interviewed using the Computer Assisted Telephone Interview (CATI) method and n_CAPI refers to the number of respondents interviewed using the Computer Assisted Personal Interview (CAPI) method.

3.2. Sampling and data collection through questionnaire

The size of the selected municipalities varies between 536 inhabitants in Braies and 33,325 in Merano (as of December 2018). For Bolzano, the largest city in terms of total population, only 2 neighborhoods (Aslago and Rencio) were considered for the calculation of the sample, as only these were affected by a recent event. The sample for the survey included only the adult resident population and was stratified according to age, gender, and municipality of residence. Table 1 shows the composition of the sample by gender, age and educational level. The sample additionally demonstrates a representative distribution of the selected municipalities.

The data collection process was conducted by a specialized market research firm through anonymous Computer Assisted Telephone Interview (CATI) and Computer Assisted Personal Interview (CAPI) methodologies between June 17 and July 10, 2019. Interviews were administered in either German or Italian, according to respondent preference. The private agency was responsible for collecting the data and applying the RIM technique for weighting the data. The authors of this manuscript independently carried out the research design, development of the questionnaire and all data analyses. The respondents were informed about the purpose of the research and the use of the data. During the data collection process, it became apparent that it was particularly difficult to obtain the desired number of interviews in the municipality of Curon Venosta. Therefore, the neighbouring municipality of Val di Vizze, which fulfils the same criteria as Curon Venosta (small municipality, without an approved hazard zone plan, with a recent natural hazard event), was selected to boost the interviews for Curon Venosta with 34 interviews to reach the desired total number of 90 interviews. As with probability sampling, the units were determined randomly. The socio-demographic characteristics age and gender have been adjusted to the latest data provided by the Italian National Institute of Statistics (ISTAT).

Data were collected through a questionnaire of 42 questions of different types (e.g., single answer, multiple choice, Likert scale) and divided into 4 sections: 1) risk awareness related to natural hazards, 2) risk perception, 3) responsibility in risk management, including the role of citizens, and 4) suggestions for improving risk management and risk communication procedures.

The data of the initial sample (N = 1410) were subjected to post-stratification calibration weighting procedure to ensure the representativeness of the overall data in terms of the parameters gender, age, and municipality of residence, as well as the representativeness of the data of the individual municipalities by gender. The breakdown by age within each municipality was not pondered but checked in advance by selecting the interview rates. The maximum error rate of the overall data is 2.6 %, with a confidence interval of 95 %. To offset the distribution of municipality, age, and gender of the sample against that of the population of the 8 municipalities of interest, the data were weighed using the Random Iterative Method (RIM), which considers two or more variables when weighing data. This technique automatically generates weight for the desired characteristics by modifying multiple variables simultaneously, while attempting to maximise the effectiveness of the weighting. The RIM weighting procedure was performed in Excel using a macro (SSCI) with a RIM number of 2 and 4 iterations. WEFF metric is equal to 1.29 and all the procedure resulted in increased efficiency of 77.76 %. Respondents under-represented get a weight larger than 1, and those in over-represented groups get a weight smaller than 1. In our case wights varies from 0.11 to 2.05 with average value equal to 1.29 and standard deviation 0.44. The highest value of the weight (on average 1.7) has been assigned to respondents from Merano and the lowest value (on average 0.13) to respondents from Braies. Respondents from Bolzano have obtained weight around 1.3.

3.3. Data analysis

The collected data were recoded and analysed using the statistical software SPSS, version 29.0 [40]. Generally, the absolute and relative frequencies were calculated to explore the distribution of categorical and ordinal variables. To answer the research questions, the data was divided into two groups, responses from municipalities with an approved hazard zone plan and from municipalities without an approved plan. Several crosstabs were then created, and the corresponding associations as well as the differences in mean values and distribution were checked. Nominal variables were analysed using the independent $\chi 2$ test. Z-test was applied to compare column proportions. In this test, categories sharing the same lowercase letter (e.g., *a*) have column proportions that do not differ significantly, while differing letters (e.g., *a* and *b*) indicate significant differences between groups. Furthermore, to test the differences between two groups in the case of ordinal variables, the non-parametric Independent-Samples Mann-Whitney *U* Test was applied. The

Table 1
Characteristics of the survey sample (N = 1410).

Variable	Level	Frequency	Percent
Gender	Female	724	48.7
	Male	686	51.3
Age class	18–29	217	15.4
	30–39	199	14.1
	40–49	257	18.3
	50–59	256	18.1
	60–69	185	13.1
	≥70	296	21.0
Highest level of education	Elementary school	51	3.6
	Middle school	241	17.1
	Professional school	160	11.3
	High school	649	46.0
	University degree	276	19.6

values of the mean ranks (MR) measuring average values of scores being ranked from lowest to highest are indicated in brackets after the respective groups under comparison. Therefore, the group with the highest mean rank is the group with the greatest number of high scores in it. The statistical significance was set at 0.05 for all tests developed.

4. Results

In this section and the tables included, we present the results of our statistical analyses regarding the extent to which the presence of hazards plans has impacted people's risk awareness and risk perception. In our study, the aspect of risk awareness is addressed through two questions. The first question pertains to the awareness of the presence of a hazard zone plan within one's own municipality, while the second question relates to awareness of existing technical mitigation measures against natural hazards. As far as the aspect of awareness about the existence of a hazard zone plan in one's own municipality is concerned (see Table 2), our data show that in municipalities with plan, uncertainty is lower, with a lower proportion stating that they could not give an answer (28.7 %) than in municipalities where there is no plan (39.3 %). In municipalities that have a plan and in which at least one information event has taken place, people have a better awareness, 64.6 % say that there is a plan which corresponds to reality, and only 6.7 % say that there is no plan, which is incorrect. In municipalities without a plan, 4.4 % stated that there is no plan, which corresponds to reality, and more than half, 56.3 %, said that there is a plan in their municipality, but this does not correspond to reality. In municipalities without a plan, the proportion of those who do not know and those who state knowledge that does not correspond to reality is therefore greater. Our data show that there is an influence on the awareness about the existence of hazard plans but that in addition to ignorance, misinformation is also very present, especially in communities where there are no plans ($\chi 2$ (2) = 7.48, p-value = 0.024).

For the second question linked to risk awareness, respondents were presented with a predefined list of existing technical mitigation measures and could select multiple options to indicate those they were aware of. There was also an option to indicate 'I don't know any measures'. The results from the this question linked to awareness (Table 3) show that the proportion of individuals reporting to know many technical mitigation measures (5 or more) is equally large in both groups (16.4 % and 16.5 %), while the proportion of those reporting no awareness of existing measures is even larger in the group with approved hazard plan (13.8 %) compared to the group without plan (5.5 %). Generally, there is a relationship between how many measures people know and the existence of a hazard plan in the municipality ($\chi 2$ (5) = 55.51, p-value = 0.001) but no positive impact on the awareness, meaning that in municipalities with hazard plan more people indicate to not know any technical mitigation measures than in municipalities without plan. People in communities without a plan (MR = 857,20) are generally even more familiar with protective measures than people in municipalities with a plan (MR = 625,65) (Mann-Whitney U test = 38688.500, p-value <0.001).

Concerning our first hypothesis, the results from the two questions show that the presence of a legally binding hazard plan at municipality level only minimally affects people's risk awareness related to natural hazards and that there is not only a lot of uncertainty but also misinformation.

For the aspect of risk perception, we collected data referring to the perceived need for additional protection measures, the perceived safety and preparedness in case of a natural hazard event occurring in the municipality of residence, the trust in information sources and the perceived probability of being directly affected. Our findings indicate that there is a relation between the perceived need for additional technical mitigation measures and the presence of a hazard plan in the municipality ($\chi 2$ (2) = 8.28, p-value = 0.016). In communities where a hazard plan has been approved and presented to the population, a higher percentage of individuals perceive a need for additional protective measures (12.2 % versus 5.2 %, as detailed in Table 4).

The analysis of the differences in sources of information deemed trustworthy based on the presence of an approved hazard plan reveals only minor variations in distribution. In the survey, respondents were asked which information sources they consider most trustworthy for receiving information about natural hazards. A multiple-choice question with predefined information channels was used, allowing a maximum of three responses. Traditional media (newspapers, radio and TV) were identified as the most reliable sources of information in both groups, followed by volunteer fire departments, civil protection organisations and institutional websites (e.g. municipality, province) (see Fig. 3).

Regarding the feeling of safety in case of an event happening in the municipality (on a scale from 1 = not at all safe and 10 = very safe) our data don't show any differences in distributions between two groups of municipalities (Mann-Whitney U test statistic = 57,807, p-value = 0.455), there is only one significant difference in proportion for the answer "I would feel very safe" (see Fig. 4,

Table 2
Awareness of hazard plan (Identical lowercase letters (a) next to percentage values indicate that there is no statistically significant difference in proportions between the two groups. Different letters (a and b) indicate a significant difference in proportions between the two groups.).

Variable	Level	Frequency	Percent
Municipalities Without Plan	Yes	86	56.3a
	No	7	4.4a
	Don't know	60	39.3a
	Total	153	100.0
Municipalities With Plan	Yes	812	64.6b
	No	84	6.7a
	Don't know	61	28.7b
	Total	1257	100.0

Table 3
Awareness about existing technical mitigation measures.

Variable	Level	Frequency	Percent
Municipalities Without Plan	none	8	5.5a
	1	12	7.8a
	2	38	24.9a
	3	37	24.1a
	4	33	21.3a
	5 or more	25	16.4a
Municipalities With Plan	none	173	13.8b
	1	242	19.2b
	2	350	27.8a
	3	191	15.2b
	4	93	7.4b
	5 or more	208	16.5a

Table 4
Additional need for technical mitigation measures in the municipality.

Variable	Level	Frequency	Percent
Municipalities Without Plan	Yes	8	5.2a
	No	101	66.3a
	Don't know	43	28.5a
Municipalities With Plan	Yes	153	12.2b
	No	831	66.1a
	Don't know	273	21.7a

difference in column proportion for value 10). Other differences are not significant. In municipalities with hazard plan, less people indicate to feel very safe in case of an event (26.6 % versus 35.1 % in municipalities without plan).

In our study, we additionally examined risk perception by asking participants to estimate the probability of being personally affected by a natural hazard event within the next five years using two questions: one regarding their own municipality and another concerning their own house or apartment. We found no differences between the two groups in the perceived probability that their own municipality could be affected by a natural hazard event within the next five years (Mann-Whitney U test statistic = 56,963, p-value = 0.329). However, we did observe differences regarding the perceived probability of their own house or apartment being affected in the next 5 years (Mann-Whitney U test statistic = 50,199, p-value = 0.003). People living in municipalities without a plan (MR = 543.65) think it is less likely that their own house or flat will be affected than people living in municipalities with a plan (MR = 652.64). It is worth noting that the proportion of respondents who consider it "not at all probable" is significantly lower in communities with a plan compared to those in municipalities without a plan (33 %–43.8 %).

Our third hypothesis investigates the relationship between the presence of the hazard zone plan and the willingness to engage in proactive risk mitigation measures. The results in Table 5 reveal differences in willingness to participate (34.6 % compared to 19 % in municipalities without plan) and to delegate responsibility to institutions ($\chi 2$ (2) = 16.61, p-value = 0.001) between groups.

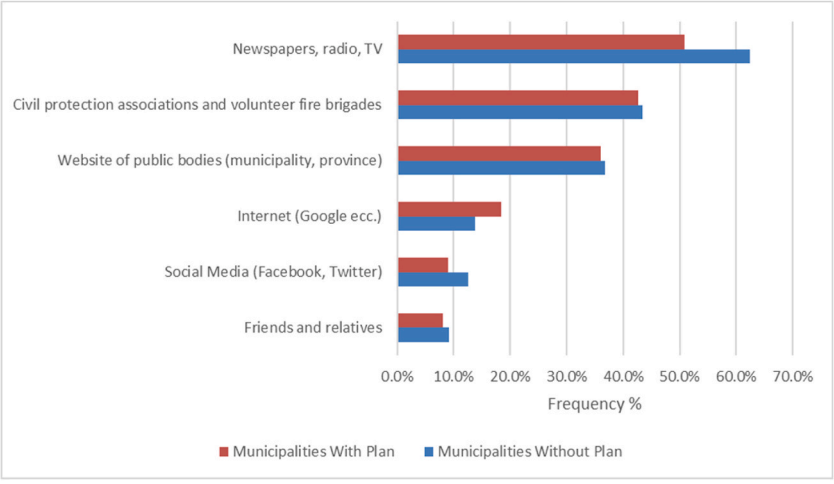


Fig. 3. Information sources considered most trustworthy for receiving information about natural hazards (n = 1410, n_Municipalities with Plan = 1257, n_Municipalities without Plan = 153).

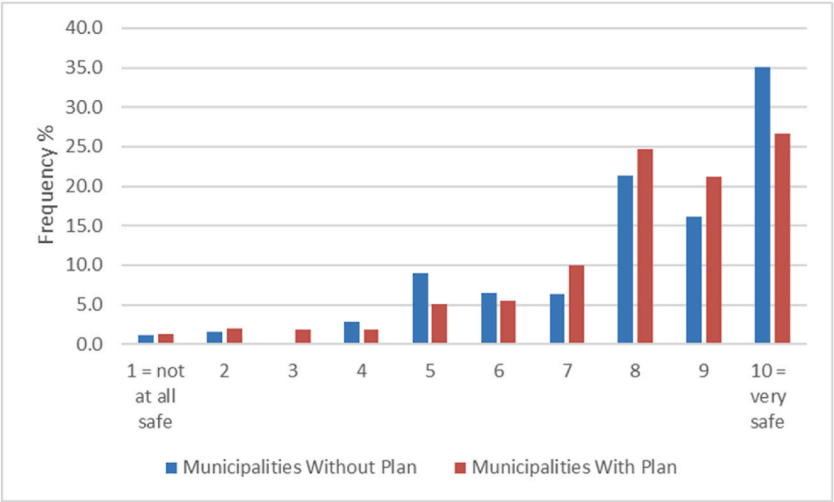


Fig. 4. Perceived safety in case of a natural hazard event (n = 1410).

When asked about their past participation in the system for the prevention of risks from natural hazards, most respondents in both groups reported no participation (46.4 % and 45 %). The question allowed for the selection of various measures, such as property protection measures, civil protection exercises, and membership in relevant associations, with multiple options possible.

The data regarding the conditions under which individuals are willing to undertake protective measures for their homes reveal that in municipalities with an approved plan, a significantly higher proportion of respondents' express willingness to act if their neighbors also take protective measures (see Table 6, multiple responses allowed).

Finally, given that our study seeks to improve natural hazard management and risk communication, we investigated which measures, according to the respondents, could lead to these improvements. In all municipalities of our study the most indicated measures are „improve the knowledge about risks" and „improve risk communication towards citizens". Table 7 shows the differences between the two groups in terms of the frequency of responses for various measures to improve the management of natural hazards (multiple responses allowed, $\chi 2$ (2) = 92.5, p-value = 0.001).

The results present a mixed picture of the impact of hazard plans on risk awareness, risk perception, and willingness of engagement. Although awareness of hazard plans is higher in municipalities with a plan, uncertainty about the presence of a hazard plan remains common in both groups. There is no consistent pattern of familiarity with existing technical mitigation measures. Our results show a positive correlation between the presence of a hazard plan and the perceived importance of technical mitigation as well as the likelihood of being personally affected by natural hazard events. A higher proportion of residents in municipalities with a hazard plan are willing to participate in risk reduction activities. These differences found between the two groups of municipalities are discussed further below.

5. Discussion and conclusion

Hazard zone maps are an important component of risk management, with a long-standing tradition of being developed for various natural hazards, scales, and methods depending on the context. A common characteristic of these maps is their creation by experts, and they primarily serve as technical tools for risk prevention. However, there is growing recognition that raising awareness and involving the public in risk management are increasingly important. In this regard, risk perception and risk communication play a significant role in building risk awareness that can better prepare communities for natural hazard events. Previous studies have highlighted that the current approaches to designing these maps, the language used, and the modes of communication often create a trade-off between experts and non-experts [41–43]. At the same time, there is evidence of a public interest in learning and skill development [44]. Using questionnaires in two groups of municipalities, one group with and one group without approved natural hazard plan, our study

Table 5
Involvement of citizens.

Variable	Level	Frequency	Percent
Municipalities	Yes	29	18.8a
Without Plan	No, it is the responsibility of institutions	106	69.7a
	Don't know	18	11.5a
Municipalities	Yes	435	34.6b
With Plan	No, it is the responsibility of institutions	731	58.2b
	Don't know	91	7.2b

Table 6
Conditions for undertaking mitigation measures for the own home.

Variable	Level	Frequency	Percent
Municipalities	Financial incentives	33	23a
Without Plan	Better information on possible actions	56	39.1a
	If neighbors do the same	12	8.7a
	Others	42	29.2a
Municipalities	Financial incentives	309	27.1a
With Plan	Better information on possible actions	511	44.7a
	If neighbors do the same	189	16.5b
	Others	132	11.6a

Table 7
Activities to improve natural hazard management.

Variable	Level	Frequency	Percent of cases
Municipalities	Improve risk knowledge	52	34.3a
Without Plan	Improve risk communication to citizens	53	34.7a
	Build new or more robust technical mitigation measures	14	9.4a
	Promote ecosystem solutions	23	15.0a
	Create new emergency plans	5	3.3a
	Introduce mandatory insurance	35	22.9a
	Train local technicians and professionals	17	11.0a
	Train citizens, families and schools	48	31.4a
	Don't know	13	8.8a
Municipalities	Improve risk knowledge	339	27.0a
With Plan	Improve risk communication to citizens	356	28.3a
	Build new or more robust technical mitigation measures	191	15.2a
	Promote ecosystem solutions	279	22.2b
	Create new emergency plans	101	8.0b
	Introduce mandatory insurance	75	6.0b
	Train local technicians and professionals	311	24.7b
	Train citizens, families and schools	517	41.1b
	Don't know	100	8.0a

investigates the extent to which hazard zone plans influence public awareness of natural hazards, risk perception, and willingness to act.

Regarding our first hypothesis that hazard zone plans have an impact on the public's awareness related to natural hazards, our findings indicate that public familiarity with natural hazards and hazard zone plans remains generally low. The presence of such plans, coupled with isolated communication events, did not substantially improve public risk awareness. This limited impact can be attributed to the predominantly technical nature of these events, which are often conducted by experts using specialized language and presenting highly complex content [45,46]. To address this issue, it is essential to adapt the information and terminology to meet the needs of non-expert audiences. Additionally, a comprehensive, multi-level strategy targeting diverse groups over a sustained period is necessary to achieve meaningful knowledge dissemination and engagement. Continuous provision of information highlighting the existence of risks and proposing appropriate preventive and protective measures can significantly contribute to behavioural change. However, there is no one-size-fits-all strategy for risk communication and it must be tailored to the specific context and target audience [47] and should include maps as well as text messages [20] and apply mixed media formats such as video, textual information, maps, mobile apps [48].

Despite the limited effect on the knowledge of risk management tools, our results confirm our second hypothesis, as they show that the presence of hazard zone plans significantly influences public risk perception, as shown in previous studies [20,49]. The visualization of hazard zones has a direct impact on individuals' feelings of safety. It contributes to an increased need for protection and a general feeling of insecurity, thereby reducing the subjective sense of security. Specifically, hazard maps play a crucial role in shaping perceptions with their visual representations of risk often leading to heightened awareness but also to initial uncertainty and calls for increased protective measures. These findings underscore the dual role of hazard zone maps: while they are effective tools for raising awareness, they can also contribute to feelings of insecurity when risks are visually emphasized. At the same time, however, our results show that they can also have a positive effect on the willingness of citizens to be more involved and take responsibility, which confirms our third hypothesis. However, it is important to note that, while our data reveal differences in willingness to participate between the two groups, the question used is not a direct or unbiased measure of personal commitment. The presence of the plan appears to enhance awareness of the necessity for collective action. This active participation, however, requires clear and actionable strategies to translate the initial willingness into concrete measures. It should be noted though, that the relation between knowledge concerning risk management tools, risk awareness and risk perception with desired behavioral responses is complex and requires further work to explore how this heightened awareness of the need for collective action can translate into behavioural change. We also acknowledge that the observed effects may result not only from the visual impact of the map, but also from the context and framing of the

information provided during the information events.

In this context, it is also important to highlight the differences observed in perceived probability of being affected by natural hazard events at municipal level compared to personal level. Our findings show that respondents often perceive a higher probability of their municipality being affected than of their own houses being affected. This is consistent with existing literature which has found that, even when aware of risks from natural hazards, individuals tend to psychologically distance themselves [29,38,50]. Rather than viewing themselves as potential contributors to mitigation efforts, many people delegate both the perceived risk and the responsibility for action to institutions or society at large [51–53]. This delegation of responsibility can limit individuals' engagement in risk management, highlighting the need for more targeted communication strategies that emphasise individual agency.

Previous research has demonstrated that personal experience of natural hazards increases risk perception [51,52]. However, our findings suggest that already the presence of a hazard zone plan, coupled with a public information event, can lead to an increase in risk perception among the population. This highlights the potential effectiveness of well-designed public information events. Furthermore, our findings highlight the critical importance of thoughtful planning and communication skills when organising such events. Effectively translating technical information for non-expert audiences is a significant challenge, but is crucial for encouraging informed and proactive responses to natural hazards [54].

We conclude that natural hazard maps are limited in their impact on the level of awareness of tools and measures of natural hazard risk reduction of the population. While it can provoke and raise awareness in the short term, this effect alone is not sufficient to achieve sustainable knowledge gains. Instead, it should be seen as the first step in a broader process that needs to be complemented by targeted follow-up activities to ensure long-term effects. These could include ongoing educational initiatives, participatory formats or stronger institutional support to deepen and sustain the momentum generated by the hazard zone plan. This need for comprehensive strategies poses several challenges for public administrations such as allocating enough resources for disaster preparedness for example due to the lack of political support and insufficient advocacy for disaster preparedness initiatives [55,56].

The introduction of the hazard zone plan should therefore be regarded as an initial step in a broader process of engagement. While it successfully raises awareness and highlights the relevance of natural hazards at both individual and community levels, it does not necessarily equip people with the knowledge about tools to act effectively. However, while the plan increases willingness to engage and participate in risk mitigation efforts, it can also lead to a reduced sense of safety. This paradox presents an important opportunity: the heightened engagement and awareness triggered by the hazard zone plan should be leveraged through follow-up activities and initiatives. By linking the presence of the plan to sustained efforts, such as community education programs, participatory planning processes, and ongoing public communication campaigns, we believe that it is possible to foster long-term changes in attitudes and behaviors related to natural hazard management and therefore improve community preparedness.

CRediT authorship contribution statement

Lydia Pedoth: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Agnieszka Elzbieta Stawinoga:** Writing – review & editing, Methodology, Formal analysis, Data curation. **Thomas Thaler:** Writing – review & editing, Supervision. **Stefan Schneiderbauer:** Writing – review & editing, Supervision, Conceptualization. **Fabio Carnelli:** Writing – review & editing, Project administration. **Doris Damyanovic:** Supervision, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Lydia Pedoth reports financial support was provided by European Commission. Fabio Carnelli reports financial support was provided by European Commission. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The research leading to these results has received funding from the funding programme Interreg Italia-Österreich - European Regional development Fund, under Grant Agreement ITAT3015, RiKoST- Risk communication strategies. The authors thank the Department of Innovation, Research University and Museums of the Autonomous Province of Bozen/Bolzano for covering the Open Access publication costs.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2025.105803.

Data availability

Data will be made available on request.

References

[1] IPCC, Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the, Intergovernmental Panel on Climate Change, 2022 [Online]. Available: https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_FullReport.pdf.

[2] T.W. Collins, S.E. Grineski, J. Chakraborty, A.B. Flores, Environmental injustice and Hurricane Harvey: a household-level study of socially disparate flood exposures in greater Houston, Texas, USA, Environ. Res. 179 (Dec. 2019) 108772, https://doi.org/10.1016/j.envres.2019.108772.

[3] J.D. Gourevitch, R.M. Diehl, B.C. Wemple, T.H. Ricketts, Inequities in the distribution of flood risk under floodplain restoration and climate change scenarios, People Nat. 4 (2) (Apr. 2022) 415–427, https://doi.org/10.1002/pan3.10290.

[4] B.F. Sanders, D. Brady, J.E. Schubert, E.-M.H. Martin, S.J. Davis, K.J. Mach, Quantifying social inequalities in flood risk, ASCE OPEN Multidiscip. J. Civ. Eng. 2 (1) (Dec. 2024) 04024004, https://doi.org/10.1061/AOMJAH.AOENG-0017.

[5] O.E.J. Wing, et al., Inequitable patterns of US flood risk in the anthropocene, Nat. Clim. Change 12 (2) (Feb. 2022) 156–162, https://doi.org/10.1038/s41558-021-01265-6.

[6] S. Schneiderbauer, J.L. Delves, L. Pedoth, R. Wyss, T. Luthe, Chapter 15 - risk and resilience research in mountains worldwide - review and reflections, in: S. Schneiderbauer, P.F. Pisa, J.F. Shroder, J. Szarzynski (Eds.), Safeguarding Mountain Social-Ecological Systems, Elsevier, 2024, pp. 101–108, https://doi.org/10.1016/B978-0-12-822095-5.00015-2.

[7] S. Schneiderbauer, et al., Risk perception of climate change and natural hazards in global mountain regions: a critical review, Sci. Total Environ. 784 (Aug. 2021) 146957, https://doi.org/10.1016/j.scitotenv.2021.146957.

[8] R. Wyss, et al., Mountain resilience: a systematic literature review and paths to the future, Mt. Res. Dev. 42 (2) (Oct. 2022), https://doi.org/10.1659/MRD-JOURNAL-D-21-00044.1.

[9] S. Kotlarski, A. Gobiet, S. Morin, M. Olefs, J. Rajczak, R. Samacoïts, 21st century alpine climate change, Clim. Dyn. 60 (1) (Jan. 2023) 65–86, https://doi.org/10.1007/s00382-022-06303-3.

[10] F. Carnelli, L. Pedoth, Enhancing risk governance by addressing key risk communication barriers during the prevention and preparedness phase in South Tyrol (Italy), Sustain. Dev. (Aug. 2023) sd.2687, https://doi.org/10.1002/sd.2687.

[11] P. Satizábal, I. Cornes, M. De Lourdes Melo Zurita, B.R. Cook, The power of connection: navigating the constraints of community engagement for disaster risk reduction, Int. J. Disaster Risk Reduct. 68 (Jan. 2022) 102699, https://doi.org/10.1016/j.ijdrr.2021.102699.

[12] K. Weber, D. Damyanovic, T. Thaler, Impacts of social contracts for citizens in the austrian flood risk management system, Int. J. Disaster Risk Reduct. 102 (Feb. 2024) 104266, https://doi.org/10.1016/j.ijdrr.2024.104266.

[13] C. Kuhlicke, et al., The behavioral turn in flood risk management, its assumptions and potential implications, WIREs Water 7 (3) (May 2020) e1418, https://doi.org/10.1002/wat2.1418.

[14] L. Pedoth, et al., Improving risk communication strategies through public awareness and engagement: insights from South Tyrol and Carinthia, in: M. Teich, C. Accastello, F. Perzl, K. Kleemayr (Eds.), Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR), IntechOpen, 2022, https://doi.org/10.5772/intechopen.99517.

[15] M. Hagemeier-Klose, K. Wagner, Evaluation of flood hazard maps in print and web mapping services as information tools in flood risk communication, Nat. Hazards Earth Syst. Sci. 9 (2) (Apr. 2009) 563–574, https://doi.org/10.5194/nhess-9-563-2009.

[16] D. Henstra, A. Minano, J. Thistlethwaite, Communicating disaster risk? An evaluation of the availability and quality of flood maps, Nat. Hazards Earth Syst. Sci. 19 (1) (Feb. 2019) 313–323, https://doi.org/10.5194/nhess-19-313-2019.

[17] S. Link, J. Stötter, Internal communication a prerequisite for risk governance: hazard zone planning in South Tyrol, Italy, Environ. Hazards 14 (2) (Apr. 2015) 87–102, https://doi.org/10.1080/17477891.2014.993580.

[18] NRC, Successful Response Starts with a Map: Improving Geospatial Support for Disaster Management, National Academies Press, Washington, D.C., 2007 11793, https://doi.org/10.17226/11793.

[19] I. Alcántara-Ayala, M. López-Mendoza, G. Melgarejo-Palafox, R.C. Borja-Baeza, R. Acevo-Zarate, Natural hazards and risk communication strategies among Indigenous communities: shedding light on accessibility in Mexico's Mountains, Mt. Res. Dev. 24 (4) (Nov. 2004) 298–302, https://doi.org/10.1659/0276-4741.

[20] Y. Cao, B.J. Boruff, I.M. McNeill, The smoke is rising but where is the fire? Exploring effective online map design for wildfire warnings, Nat. Hazards 88 (3) (Sep. 2017) 1473–1501, https://doi.org/10.1007/s11069-017-2929-9.

[21] H. Faulkner, D. Ball, Environmental hazards and risk communication, Environ. Hazards 7 (2) (2007) 71–78, https://doi.org/10.1016/j.envhaz.2007.08.002.

[22] M. Wenk, C. Neuhold, S. Fuchs, Zielgruppenspezifische Darstellung von Hochwassergefahren und -risiko, Österreichische Wasser- Abfallwirtsch. 70 (5–6) (Jun. 2018) 328–340, https://doi.org/10.1007/s00506-018-0470-z.

[23] P. Hudson, A.H. Thieken, P. Bubeck, The challenges of longitudinal surveys in the flood risk domain, J. Risk Res. 23 (5) (May 2020) 642–663, https://doi.org/10.1080/13669877.2019.1617339.

[24] N. Pidgeon, B. Fischhoff, The role of social and decision sciences in communicating uncertain climate risks, Nat. Clim. Change 1 (1) (Apr. 2011) 35–41, https://doi.org/10.1038/nclimate1080.

[25] O. Renn, Three decades of risk research: accomplishments and new challenges, J. Risk Res. 1 (1) (Jan. 1998) 49–71, https://doi.org/10.1080/136698798377321.

[26] A. Bosschaart, W. Kuiper, J. Van Der Schee, J. Schoonenboom, The role of knowledge in students' flood-risk perception, Nat. Hazards 69 (3) (Dec. 2013) 1661–1680, https://doi.org/10.1007/s11069-013-0774-z.

[27] J. Weichselgartner, P. Pigeon, The role of knowledge in disaster risk reduction, Int. J. Disaster Risk Sci. 6 (2) (Jun. 2015) 107–116, https://doi.org/10.1007/s13753-015-0052-7.

[28] P. Slovic, Perception of risk, Science 236 (4799) (Apr. 1987) 280–285, https://doi.org/10.1126/science.3563507.

[29] E. Mondino, A. Scolobig, M. Borga, G. Di Baldassarre, The role of experience and different sources of knowledge in shaping flood risk awareness, Water 12 (8) (Jul. 2020) 2130, https://doi.org/10.3390/w12082130.

[30] R.E. Kasperson, J.X. Kasperson, The social amplification and attenuation of risk, Ann. Am. Acad. Polit. Soc. Sci. 545 (1) (May 1996) 95–105, https://doi.org/10.1177/0002716296545001010.

[31] L. Sjöberg, Risk perception by the public and by experts: a dilemma in risk management, Hum. Ecol. Rev. 6 (2) (1999) 1–9.

[32] W.J.W. Botzen, J.C.J.H. Aerts, J.C.J.M. Van Den Bergh, Dependence of flood risk perceptions on socioeconomic and objective risk factors, Water Resour. Res. 45 (10) (Oct. 2009), https://doi.org/10.1029/2009WR007743, 2009WR007743.

[33] S. Birkholz, M. Muro, P. Jeffrey, H.M. Smith, Rethinking the relationship between flood risk perception and flood management, Sci. Total Environ. 478 (Apr. 2014) 12–20, https://doi.org/10.1016/j.scitotenv.2014.01.061.

[34] R. Schlögel, C. Kofler, S.L. Gariano, J. Van Campenhout, S. Plummer, Changes in climate patterns and their association to natural hazard distribution in South Tyrol (Eastern Italian Alps), Sci. Rep. 10 (1) (Mar. 2020) 5022, https://doi.org/10.1038/s41598-020-61615-w.

[35] S. Link, J. Stötter, The development of mountain risk governance: challenges for application, Jan 16 (2015), https://doi.org/10.5194/nhessd-3-429-2015.

[36] B. Ryan, K.A. Johnston, M. Taylor, R. McAndrew, Community engagement for disaster preparedness: a systematic literature review, Int. J. Disaster Risk Reduct. 49 (Oct. 2020) 101655, https://doi.org/10.1016/j.ijdrr.2020.101655.

[37] Alpine Signals – Special Edition, no. 7, Permanent Secretariat of the Alpine Convention, Natural Hazard Risk Governance. Report on the State of the Alps, Permanent Secretariat of the Alpine Convention, 2019.
[38] A. Scolobig, B. De Marchi, M. Borga, The missing link between flood risk awareness and preparedness: findings from case studies in an Alpine Region, Nat. Hazards 63 (2) (Sep. 2012) 499–520, https://doi.org/10.1007/s11069-012-0161-1.
[39] M. Taylor, K.A. Johnston, B. Ryan, A community engagement approach to natural hazard communication, in: W.T. Coombs, S.J. Holladay (Eds.), The Handbook of Crisis Communication, first ed., Wiley, 2022, pp. 327–342, https://doi.org/10.1002/9781119678953.ch22.
[40] IBM Corp, IBM SPSS Statistics for Windows, Version 29.0.2.0 Armonk, IBM Corp, NY, 2023.
[41] M. Alexander, C. Viavattene, H. Faulkner, S. Priest, Translating the complexities of flood risk science using KEEPER – a knowledge exchange exploratory tool for professionals in emergency response, J. Flood Risk Manag. 7 (3) (Sep. 2014) 205–216, https://doi.org/10.1111/jfr3.12042.
[42] R.A. Bradford, et al., Risk perception – issues for flood management in Europe, Nat. Hazards Earth Syst. Sci. 12 (7) (Jul. 2012) 2299–2309, https://doi.org/10.5194/nhess-12-2299-2012.
[43] B. De Marchi, A. Scolobig, The views of experts and residents on social vulnerability to flash floods in an Alpine region of Italy, Disasters 36 (2) (Apr. 2012) 316–337, https://doi.org/10.1111/j.1467-7717.2011.01252.x.
[44] P. Kamstra, et al., Awareness without learning: a preliminary study exploring the effects of beachgoer's experiences on risk taking behaviours, Heliyon 8 (12) (Dec. 2022) e12186, https://doi.org/10.1016/j.heliyon.2022.e12186.
[45] B.R. Cook, M.D.L. Melo Zurita, Fulfilling the promise of participation by not resuscitating the deficit model, Glob. Environ. Change 56 (May 2019) 56–65, https://doi.org/10.1016/j.gloenvcha.2019.03.001.
[46] I.C. Cornes, B. Cook, P. Satizabal, M. de Lourdes Melo Zurita, "(In)action": rethinking traditional understandings of disaster risk reduction, Aust. J. Emerg. Manag. 34 (1) (Jan. 2019) 52–57.
[47] K.A.W. Snel, P.A. Witte, T. Hartmann, S.C.M. Geertman, More than a one-size-fits-all approach – tailoring flood risk communication to plural residents' perspectives, Water Int. 44 (5) (Jul. 2019) 554–570, https://doi.org/10.1080/02508060.2019.1663825.
[48] M.H. Vien, S.L. Ivey, H. Boyden, S. Holm, L. Neuhauser, A scoping review of wildfire smoke risk communications: issues, gaps, and recommendations, BMC Public Health 24 (1) (Jan. 2024) 312, https://doi.org/10.1186/s12889-024-17681-0.
[49] M.A. Thompson Clive, J.M. Lindsay, G.S. Leonard, C. Lutteroth, A. Bostrom, P. Corballis, Volcanic hazard map visualisation affects cognition and crisis decision-making, Int. J. Disaster Risk Reduct. 55 (Mar. 2021) 102102, https://doi.org/10.1016/j.ijdrr.2021.102102.
[50] R. Maiella, et al., The psychological distance and climate change: a systematic review on the mitigation and adaptation behaviors, Front. Psychol. 11 (Nov. 2020) 568899, https://doi.org/10.3389/fpsyg.2020.568899.
[51] P. Bubeck, W.J.W. Botzen, J.C.J.H. Aerts, A review of risk perceptions and other factors that influence flood mitigation behavior, Risk Anal. 32 (9) (Sep. 2012) 1481–1495, https://doi.org/10.1111/j.1539-6924.2011.01783.x.
[52] G. Wachinger, O. Renn, C. Begg, C. Kuhlicke, The risk perception paradox-implications for governance and communication of natural hazards: the risk perception paradox, Risk Anal. 33 (6) (Jun. 2013) 1049–1065, https://doi.org/10.1111/j.1539-6924.2012.01942.x.
[53] W. Ammann, S. Dannenmann, L. Vulliet (Eds.), RISK21 - Coping with Risks due to Natural Hazards in the 21st Century: Proceedings of the RISK21 Workshop, Monte Verità, Ascona, Switzerland, 28 November - 3 December 2004, Taylor & Francis, 2006, https://doi.org/10.1201/9780203963562.
[54] B.R. Cook, I. Cornes, P. Satizábal, M. De Lourdes Melo Zurita, Experiential learning, practices, and space for change: the institutional preconfiguration of community participation in flood risk reduction, J. Flood Risk Manag. (Oct. 2022) e12861, https://doi.org/10.1111/jfr3.12861.
[55] M.M. Bechtel, M. Mannino, Ready when the big one comes? Natural disasters and mass support for preparedness investment, Polit. Behav. 45 (3) (Sep. 2023) 1045–1070, https://doi.org/10.1007/s11109-021-09738-2.
[56] W.J. Petak, Emergency management: a challenge for public administration, Public Adm. Rev. 45 (3) (Jan. 1985), https://doi.org/10.2307/3134992.