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Hydrological Sciences Journal

ISSN: 0262-6667 (Print) 2150-3435 (Online) Journal homepage: https://www.tandfonline.com/loi/thsj20

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To cite this article: E. Mondino, A. Scolobig, M. Borga, F. Albrecht, J. Mård, P. Weyrich & G. Di Baldassarre (2020) Exploring changes in hydrogeological risk awareness and preparedness over time: a case study in northeastern Italy, Hydrological Sciences Journal, 65:7, 1049-1059, DOI: 10.1080/02626667.2020.1729361

To link to this article: https://doi.org/10.1080/02626667.2020.1729361

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Published online: 26 Feb 2020.

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HYDROLOGICAL SCIENCES JOURNAL
2020, VOL. 65, NO. 7, 1049–1059
https://doi.org/10.1080/02626667.2020.1729361

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Exploring changes in hydrogeological risk awareness and preparedness over time: a case study in northeastern Italy

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ABSTRACT
Hydrogeological hazards are increasingly causing damage worldwide due to climatic and socio-economic changes. Building resilient communities is crucial to reduce potential losses. To this end, one of the first steps is to understand how people perceive potential threats around them. This study aims at exploring how risk awareness of, and preparedness to, face hydrological hazards changes over time. A cohort study was carried out in two villages in the northeastern Italian Alps, Romagnano and Vermiglio, affected by debris flows in 2000 and 2002. Surveys were conducted in 2005 and 2018, and the results compared. The survey data show that both awareness and preparedness decreased over time. We attribute this change to the fact that no event had occurred in a long time and to a lack of proper risk communication strategies. The outcomes of this study contribute to socio-hydrological modelling by providing empirical data on human behaviour dynamics.

ARTICLE HISTORY
Received 20 June 2019
Accepted 11 December 2019

EDITOR
S. Archfield

GUEST EDITOR
M. Sanderson

KEYWORDS
socio-hydrology; risk awareness; risk preparedness; debris flow; longitudinal data; hydrogeological hazard

1 Introduction

Economic losses caused by natural hazards – in particular hydrogeological extremes such as floods, debris flows and droughts – have increased dramatically over the past decades (UNISDR 2018). Risk is generated by the way in which natural hazards and society interact and mutually shape each other (White 1945, Slovic 1987, Di Baldassarre *et al.* 2017, 2018b). This mutual shaping is characterized by two main feedback mechanisms: the influence a given natural hazard has on the society it strikes or threats (i.e. its negative impacts or perceptions), and the way in which society responds and influence one or more components of risk (broadly defined as a combination of hazard, exposure and vulnerability) via policies and measures for disaster risk reduction (DRR) (Di Baldassarre *et al.* 2018b). For instance, the occurrence of a flood event might increase flood risk awareness. As a result, people, in turn, can respond by: (a) altering the frequency of flooding events (e.g. building structural protection measures; Jongman *et al.* 2015), (b) reducing their exposure to flooding (e.g. resettling away from rivers; Mård *et al.* 2018), or (c) reducing their vulnerability to flooding (e.g. improving their knowledge on what to do in case of flooding, Kuhlicke *et al.* 2011, or introducing early warning systems, Kreibich *et al.* 2017). Similar dynamics can be observed for other natural hazards: if an earthquake occurs, people could suffer emotional and financial damages, and this, in turn, shapes their way to approach the hazard. They might consider moving away from the risk area (Armaş 2008), or investing in mitigation measures (Asgary and Willis 1997), or simply improving their preparedness if they do not have sufficient economic resources, e.g. to relocate.

To better understand societal responses to natural hazards, there is a need to unravel how the frequency and intensity of extreme events influence risk perceptions. Specifically, it is fundamental to assess how such perceptions change over time, and what drives the change. This can help researchers, practitioners, and policy-makers to explain why certain communities are more risk aware and prepared than others, and to integrate human behaviour dynamics into disaster risk management (Aerts *et al.* 2018). In 2005, De Marchi *et al.* (2007) conducted a survey on risk awareness, preparedness and social vulnerability. One of the aims of the survey was to better understand the relationship between risk awareness and preparedness (the results are presented in Scolobig *et al.* 2012). To explore changes in risk awareness and preparedness in the absence of extreme events, we repeated the same survey in 2018. Longitudinal studies help not only to spot changes in comparison to previously recorded perceptions and behaviours, but also to recognize any correlation between variables, as well as to avoid misleading conclusions being reached (Siegrist 2013). In fact, potentially misleading results from cross-sectional studies could end up in erroneous policy recommendations. In light of these characteristics, the need for longitudinal data has been highlighted by a number of scholars in the natural hazards field (see, for instance, Lindell and Perry 2000, Spence *et al.* 2011, Terpstra 2011, Fielding 2012, Siegrist 2013, van Duinen *et al.* 2015, Babcicky and Seebauer 2017, Di Baldassarre *et al.* 2018a).

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Yet, empirical approaches to understand how risk awareness changes over time are limited. The majority of studies have a cross-sectional nature and focus on which factors might affect the awareness in a specific point in time. Grothmann and Reusswig (2006), in their study on factors affecting preparedness, propose two categories: socio-economic factors and socio-psychological factors. This distinction is applied here too. The former group includes items such as age, gender, education, income, ownership of home, while the latter include, among others, personal experiences (e.g. previous experiences with the hazard), fear, feelings of worry. For example, the ownership of the house an individual lives in tends to increase the risk awareness (Grothmann and Patt 2005, Bubeck *et al.* 2012). Regarding socio-economic factors, such as household income, its effect varies across case studies. Some studies found no significant correlation (Grothmann and Patt 2005, Botzen *et al.* 2009), others found a negative correlation, i.e. the higher the income the lower the perceived risk (Babcicky and Seebauer 2017). On the other hand, the location of the house in terms of proximity to the hazard shows a positive correlation with the perception of risk (Miceli *et al.* 2008, Botzen *et al.* 2009, Wachinger *et al.* 2013, Babcicky and Seebauer 2017). The majority of cases and reviews taken into account show no statistically significant correlation between age, gender, and education and the perceived risk (Bubeck *et al.* 2012, Ludy and Kondolf 2012, Babcicky and Seebauer 2017). However, some scholars found younger people to have a higher risk awareness than older ones (Miceli *et al.* 2008, Babcicky and Seebauer 2017), and women higher than men (Miceli *et al.* 2008). The difference between urban *versus* rural inhabitants was discussed, for example, by Botzen *et al.* (2009), who found no statistically significant correlation with the perception of risk. Scolobig *et al.* (2012) found instead that rural inhabitants were more aware of the risk compared to urban inhabitants. Typically, socio-economic factors alone are not sufficient to predict hydrogeological risk awareness, and often need to be integrated with socio-psychological (or socio-cognitive) factors (Grothmann and Patt 2005, Grothmann and Reusswig 2006).

Among the socio-psychological factors, previous experience with the hazard in general tends to increase the risk awareness (Grothmann and Patt 2005, Burningham *et al.* 2008, Miceli *et al.* 2008, Botzen *et al.* 2009, Bubeck *et al.* 2012, Fielding 2012, Scolobig *et al.* 2012, Babcicky and Seebauer 2017), but it depends on the severity of the experience (Wachinger *et al.* 2013, Becker *et al.* 2014). This confirms the inconsistency of the effects of previous experience with the hazard highlighted by Botzen *et al.* (2009), and correlates to the "risk perception paradox" that Wachinger *et al.* (2013) pointed out in their review: higher risk perception does not necessarily mean higher personal preparedness. This concept, in fact, was also highlighted by others (Bubeck *et al.* 2012, Becker *et al.* 2014) and goes back to the feelings regarding the previous experience. If the feelings are negative, the risk perception increases, and if the feelings are positive (e.g. no damages suffered), it decreases. Fuchs *et al.* (2017) found no difference in risk awareness between those who experienced an event and those who did not. Another factor correlated to feelings is the trust in authority, which, on the contrary, decreases when they are negative and increases when they are positive (Wachinger *et al.* 2013). In addition, when the trust in authorities and experts is high, risk awareness tends to decrease (Grothmann and Patt 2005, Scolobig *et al.* 2012), as individuals tend to delegate their responsibilities. Fear is also seen to influence risk awareness, even though with different outcomes across studies. Grothmann and Reusswig (2006) found that it affects judgements on the severity of flood risk, leading to an increase in risk perception, while others found that it correlates positively with the adoption of protection measures (Miceli *et al.* 2008, Bubeck *et al.* 2012). Social capital indirectly affects risk awareness as people react to risk not only as individuals but also as part of a community (Kerstholt *et al.* 2017). Indeed, households with high levels of social capital were found to have a lower risk awareness (Babcicky and Seebauer 2017). Another factor that indirectly falls within this category is the so called "levee effect". It describes how the presence of structural protection measures (a levee) can trigger greater feelings of safety and trust in authority, in turn lowering hydrogeological risk awareness (White 1945, Viglione *et al.* 2014).

While the studies mentioned above undoubtedly provide an insight into people's perceptions, they fall short when it comes to understanding how the occurrence of events shapes risk awareness in the long run. Few scholars focusing on other types of natural hazards have ventured into exploring the fluctuating nature of hazard risk awareness. Logan (2017) investigated the difference in risk awareness before and after the 2011 Christchurch earthquake in New Zealand by looking at house-price differentials. His research questions were aimed at investigating two main points: (a) whether risk awareness was higher before the earthquake so that houses in risk areas were sold for a lower price; and (b) whether homeowners showed more risk awareness after the earthquake so that risk-related house-price differentials widened. The results confirmed that risk was underestimated before the event and overestimated after the event, which means that houses in high-risk areas were not sold at cheaper prices than others before the earthquake; afterwards, risk awareness increased, causing house-price differentials to widen. Drops in house prices can also be observed right after floods, but they are usually followed by a fast recovery in the following years (Atreya *et al.* 2013, Zhang 2016), indicating that the memory of the flood tends to fade away. Su *et al.* (2015) analysed the difference in risk awareness before and after a rainstorm disaster in Beijing in 2012: public risk perception significantly increased after the disaster, with double the amount of people adopting prevention measures.

Another study was conducted right after the hurricanes Katrina and Rita in the US Gulf Coast states and repeated two years later (Trumbo *et al.* 2014). The study had three hypotheses: (a) respondents will perceive less risk from hurricanes in 2008 *versus* 2006; (b) respondents will express greater optimistic bias for hurricanes in 2008 *versus* 2006; and (c) the self and other components of the optimistic bias will increase from 2006 to 2008. The results confirmed the first hypothesis: respondents present a lower risk perception in the second, later, assessment. In addition, both components of the optimistic bias changed significantly, with the estimated probability of others having to evacuate becoming more optimistic, as compared to the estimated probability for self, so the third hypothesis was also confirmed. The second hypothesis, on the contrary, was not supported (Trumbo *et al.* 2014). Narrowing the focus down to hydrogeological hazards, Bodoque *et al.* (2019) assessed participants' flash flood risk awareness before and after implementing an *ad-hoc* risk communication strategy. They found risk awareness to have improved following risk communication. To the best of the authors' knowledge, so far no study has investigated how hydrogeological risk awareness evolves over time in the absence of events occurring.

Similarly to changes in hydrogeological risk awareness, the literature on changes in preparedness is limited to a few studies. Kreibich *et al.* (2011) and Kienzler *et al.* (2015) analysed changes between two flood events in Germany and found that preparedness was higher when people faced the second flood event. The higher level of preparedness was associated with previous flood experience. Thieken *et al.* (2007) also found preparedness to be higher after a flood event. None of these studies provide evidence on how preparedness evolved over time in the absence of subsequent events.

2 General framework and specific hypotheses

The interaction between hydrogeological hazards and human societies is explained here within the broader context of socio-hydrology (Sivapalan *et al.* 2012), which aims at understanding the dynamics of human–water systems (Di Baldassarre *et al.* 2013) by treating societal processes as endogenous to the human–water system (Pande and Sivapalan 2017). Later, Di Baldassarre *et al.* (2018b) developed a framework to incorporate socio-hydrology in DRR research (see Fig. 1). As partly illustrated in the introduction (Section 1), the two-feedback mechanism works as follows: the occurrence of a hazardous event (in our case hydrogeological) has an impact on the society both economically and psychologically. The affected society, in response, can develop policies and adopt measures to address the hazard risk. In addition, other influential forces act on the overall system: socio-economic trends, at both global and local scales (e.g. economic crises, demographic changes, etc.), and environmental changes, global phenomena which often entail local consequences. Ergo, within DRR, socio-hydrology has the potential of filling the gap between the *vulnerability paradigm* and the *hazard paradigm* (Bloschl *et al.* 2013, Di Baldassarre *et al.* 2018b), which respectively focus on societal aspects and physical aspects of risk.

Building on the previous study by Scolobig *et al.* (2012), and partly following the structure of Trumbo *et al.* (2014), this study aims to fill the gap in socio-hydrology and hydrogeological hazard risk literature by capturing the changes in hydrogeological risk awareness in the absence of events. Emphasis is put on socio-psychological factors. In particular, we compared two surveys carried out in 2005 and 2018 to test the following four hypotheses:

H1: The level of risk awareness is lower in 2018 compared to 2005 (given the lack of occurrence of hydrogeological extreme events during the interim period);

H2: The perceived preparedness is lower in 2018 compared to 2005 (given the lack of occurrence of hydrogeological extreme events in the interim);

H3: The general feeling of safety is inversely correlated with risk awareness at the individual level; and

H4: The presence of protection works is associated with lower risk awareness (at both the individual and community levels).

Besides informing DRR practitioners on the dynamics of risk awareness and preparedness, these hypotheses contribute to socio-hydrological modelling (Blair and Buytaert 2016) by providing empirical data on changes in risk awareness and preparedness. In fact, by testing the above hypotheses, we can evaluate and refine the socio-hydrological models that

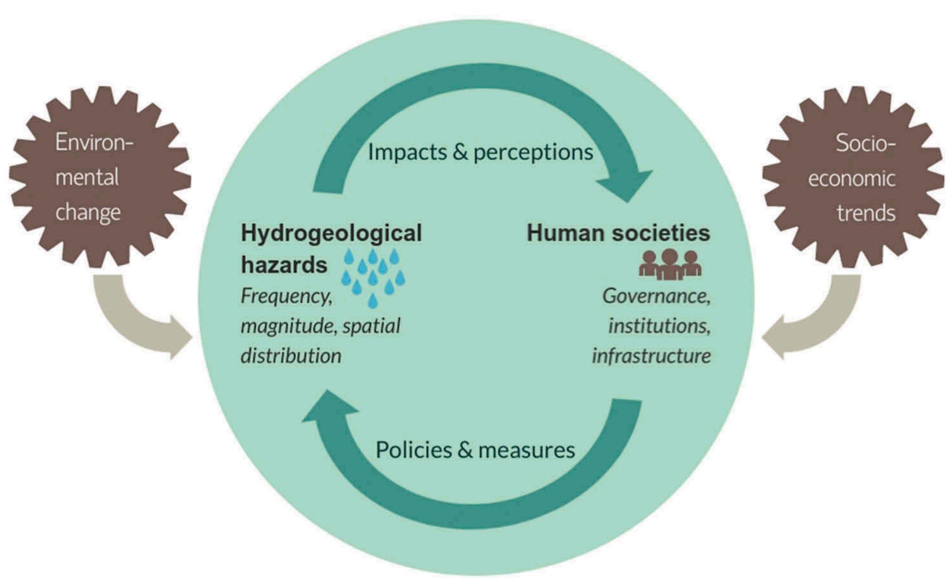

Figure 1. Interplay of hydrogeological hazards and society (adapted from Di Baldassarre *et al.* 2018b).

have been proposed in recent years (Di Baldassarre *et al.* 2013, 2015, 2018b, Viglione *et al.* 2014, Garcia *et al.* 2016, Kuil *et al.* 2016, Gonzales and Ajami 2017, Yu *et al.* 2017). These models use differential equations within a system dynamic approach to describe: (i) how awareness is built up, e.g. direct damage; (ii) how awareness changes over time, e.g. exponential decay; and (iii) how awareness relates to risk preparedness.

3 Case studies and methods

The two study areas were selected as they both experienced a hydrogeological extreme event in the early 2000s followed by a prolonged absence of events until the time of this study. This makes them suitable for testing the first and second hypotheses. Moreover, while they are both located in Trento Province, in the northeastern Italian Alps, they have contrasting features, allowing a comparative study to be made. The first study area is an alpine municipality; Vermiglio is located at 1261 m a.s.l. in the upper part of the Vermigliana torrent valley. The number of inhabitants amounts to about 1850. The village endured two debris flow events in close succession: a three-day rainfall event and debris flows in 2000, and another debris flow in 2002, which caused damages in the same area that had been hit two years earlier (De Marchi *et al.* 2007). The events caused no casualties, but the check dam built after the 2000 event to protect the village was destroyed by the 2002 event, and a considerably larger one was built afterwards. The inhabitants of Vermiglio along its three streams, Rio Cortina, Rio Fraviano and Rio Pizzano, are familiar with hydrogeological hazards. The recorded history of the municipality shows that floods (especially regarding the Vermigliana River), avalanches, heavy rainfall lasting several days and landslides have occurred regularly in the past century, often with intervals of only few years in between (Panizza 2005). The second study area, Romagnano, is an urban settlement of about 1600 inhabitants in the outskirts of Trento, the administrative centre of the homonymous autonomous province. It is located at 431 m a.s.l., between Rio Prà dell'Acqua and the Adige River. In 2000, Romagnano was affected by debris flow on the Rio Prà dell'Acqua creek, caused by a precipitation event with a return period of 100 years, after three months of continuous rain that had caused soil saturation. There were no casualties, but about 500 people had to be evacuated for about a week. The area was previously hit by a landslide in 1942 that caused a debris flow (Campedel 2007). This landslide was diverted by a massive wall, built decades before – following heavy floods in 1882 and 1885 – and hit the southern part of the village, which at the time was not heavily urbanized, causing little damage (Coali 2002).

These two communities were surveyed in 2005 in a study conducted by De Marchi *et al.* (2007), with the purpose of assaying whether risk awareness is a good indicator of risk preparedness in the context of flood risk; we surveyed them again in 2018. Since, in the first survey round, participants were kept anonymous (and therefore could not be contacted again in the second round), we used a cohort design, which allows us to have samples containing different individuals compared to 2005. A *cohort* study (or *repeated cross-sectional* study) has the characteristic of sampling individuals with a shared characteristic, which makes them part of a cohort, e.g. being born in the same year, living in the same town, having experienced a certain event, and so forth. Therefore, the two (or more) samples taken over time could contain different individuals in different points in time. While this does not allow us to make a within-respondent comparison, it still allows a comparison to be made between groups. Moreover, this type of design works around the issue of high attrition rates (i.e. participants dropping out of the study, which implies a depletion of the sample over time). Hudson *et al.* (2019) highlight high attrition rates as one of the main problems concerning longitudinal research within the flood-risk domain.

The four samples collected are representative of the local population with regards to age and gender. Regarding the sampling procedure, the methodology adopted was context-specific: interviewers were instructed to contact the inhabitants living in the areas more severely affected by the earlier events, and then proceed further away. This procedure was necessary because a random sampling, especially given the small number of inhabitants in each location, would have excluded the residents we were most interested in, those who most likely experienced the hazard in the past. The distribution of the population according to demographic variables was available through the municipal administrations. The unit of analysis was the individual, and interviewers were instructed to contact only one person per household. Descriptive statistics for age and gender of all four samples are reported in Table 1. Compared to 2005, the 2018 sample was slightly older in both Vermiglio and Romagnano. As for gender, in both locations the percentage of females slightly decreased and that of males slightly increased.

Before starting the data collection, the administrations of both areas sent out a letter to all residents informing them of the research about to be conducted. The letter included the reasons for the longitudinal study, the planned time for survey data collection and information on how the results would be given back to the community. The potential interviewees were approached at their homes and asked whether they were interested in participating in the survey, referring back to the letter received by the municipal administration. Participants did not receive a reward of any form for completing the survey. A total of 458 interviewees completed the survey: 100 in Romagnano in 2005, 100 in Vermiglio in 2005, 135 in Romagnano in 2018, and 122 in Vermiglio in 2018.

In both the first and second survey rounds, data were collected through questionnaires administered during a face-to-face interview with the respondent. The questionnaire used in the second round was built upon the first one, with some minor changes due to the slightly different aims of the two

Table 1. Descriptive statistics (age and gender) for the four samples. M: mean; SD: standard deviation.

Sample	*n*	Age				Gender	
		M	SD	Min	Max	Female	Male
Vermiglio 05	100	46.1	17.9	19	85	54.0%	46.0%
Vermiglio 18	122	50.4	17.8	18	91	51.6%	48.4%
Romagnano 05	100	47.8	16.9	18	85	55.0%	45.0%
Romagnano 18	135	50.0	17.5	18	93	52.6%	47.4%

studies. However, the questions used to assess the variables related to risk awareness were kept unchanged to allow for comparison. The questionnaire was divided into six main sections:

(1) *Community profile*: This investigates how the individual fits in the community, i.e. their length of residence in the area and their associational life.
(2) *Risk awareness*: Here, the participant's awareness is assayed regarding the general safety of the area (without mentioning hydrogeological hazards).
(3) *Hydrological hazards*: This explores the interviewee's awareness of past and potential future hazards.
(4) *Preparedness*: This assesses the individuals' preparedness in coping with the hazard and includes a self-assessment of changes in risk awareness and preparedness.
(5) *Prevention*: This investigates the knowledge of structural protection measures and risk communication.
(6) *Socio-demographics*: Age, gender, education and income level.

Three variables were selected to interpret hydrogeological risk awareness: perceived threat posed by hydrogeological phenomena relative to (a) the home, (b) the town, and (c) one's physical integrity. Specifically, participants were asked "*To what extend do you think hydrogeological phenomena are a threat to your home/town/yourself*?". For each of them, they could answer on a Likert scale from 1, minimal threat, to 5, serious threat. We also assessed a fourth variable, perceived likelihood of future hydrogeological phenomena in the area, through the question "*Do you think a hydrogeological phenomenon could happen here in the future?*". Respondents could answer "Yes", "No", or "I don't know". To explore in detail potential changes, we also asked the respondents to self-assess how their risk awareness had changed over time. Here, they could reply on a Likert scale from 1, decreased, to 5, increased, with 3 representing no change. After the self-assessment, they were asked to give an explanation of the reasons through an open question ("*Why?*").

Concerning preparedness, two variables were selected: perceived individual preparedness and perceived community preparedness. For the first, we asked participants "*To what extent do you feel prepared to face a hydrogeological phenomenon, in case it would happen?*". For the second, we asked "*To what extent do you think the town is prepared to face a hydrogeological phenomenon, in case it would happen?*". To both, respondents could reply on a Likert scale from 1, barely prepared, to 5, highly prepared. Here too, respondents were asked to self-assess changes in their level of preparedness (on the same Likert scale described in the previous paragraph) and give an explanation.

Quantitative data was analysed using the statistical software R (version 3.5.2). Given the discrete and ordinal nature of the dependent variables and the type of hypotheses we drew, chi-squared (χ^2) tests were used to assess how the above-mentioned variables differed between times and locations. In addition, we ran Spearman correlations to test the relationships among dependent and independent variables. In both cases, we assumed as significant any result within the 95% confidence interval. For qualitative data, we used qualitative content analysis, consisting in clustering similar answers. The clusters were then coded to be operationalized in R.

4 Results and discussion

4.1 Changes in hydrogeological risk awareness and preparedness

The first hypothesis to test was whether hydrogeological risk awareness decreased over time. The higher number of respondents on the lower side of the Likert scale shows that the perceived threat regarding the town significantly decreased in Vermiglio, while it remained nearly unchanged in Romagnano (see Table 2). It is also always significantly higher in Vermiglio compared to Romagnano, in both years. The perceived threat to the home also significantly decreased in Vermiglio and remained nearly unchanged in Romagnano. As for the perceived threat to one's own physical integrity, no statistically significant change was detected across time and place, but respondents in both years do not seem to be particularly worried about their own safety, given the high number of answers on the lower end of the Likert scale (see Fig. 2). These results support the first hypothesis. Overall, in 2018 too, respondents show an optimistic bias: they perceive a greater danger when they think of their entire community, compared to themselves or their home, confirming what was found by Scolobig *et al.* (2012). Both a decrease in risk awareness and the optimistic bias are also in line with the results by Trumbo *et al.* (2014), despite the difference in the type of hazard experienced. In addition, the generally low perceived threat is reinforced by the fact that respondents in both areas, when asked about the perceived threat posed by other types of hazard, show greater concern compared to hydrogeological hazards. In fact, fire (M = 2.9) and theft (M = 3.3) both rank higher than hydrogeological hazards in Vermiglio (M = 1.8) and Romagnano (M = 2.1) respectively.

Concerning perceived likelihood, our data shows that the way respondents replied to this question is again dependent on their location in place and time (see Table 3). In 2018, in both Vermiglio and Romagnano, there is a significantly higher percentage of respondents (compared to 2005) who think a hydrogeological phenomenon is likely to occur. We attribute this counterintuitive result to the fact that, while no event occurred for quite a long time in the study areas, similar extreme events happened elsewhere in the province and received significant media coverage, so that respondents might think that sooner or later it may happen again in their area too. This could be the result of a judgement shortcut

Table 2. Results of the chi-squared (χ^2) contingency table tests for the three "Perceived threat" variables (df = 4). Bold indicates significant results.

	Perceived threat		
	Town	Home	Physical integrity
Vermiglio (2005 vs 2018)	**(18.83)****	**(11.92)***	(2.27)
Romagnano (2005 vs 2018)	(3.12)	(2.85)	(1.16)
2005 (Vermiglio vs Romagnano)	**(34.18)*****	(4.68)	(0.82)
2018 (Vermiglio vs Romagnano)	**(11.56)***	(6.74)	(5.91)

χ^2 values in brackets.
***, ** and *: significance (P value): <0.001, <0.01 and <0.05, respectively.

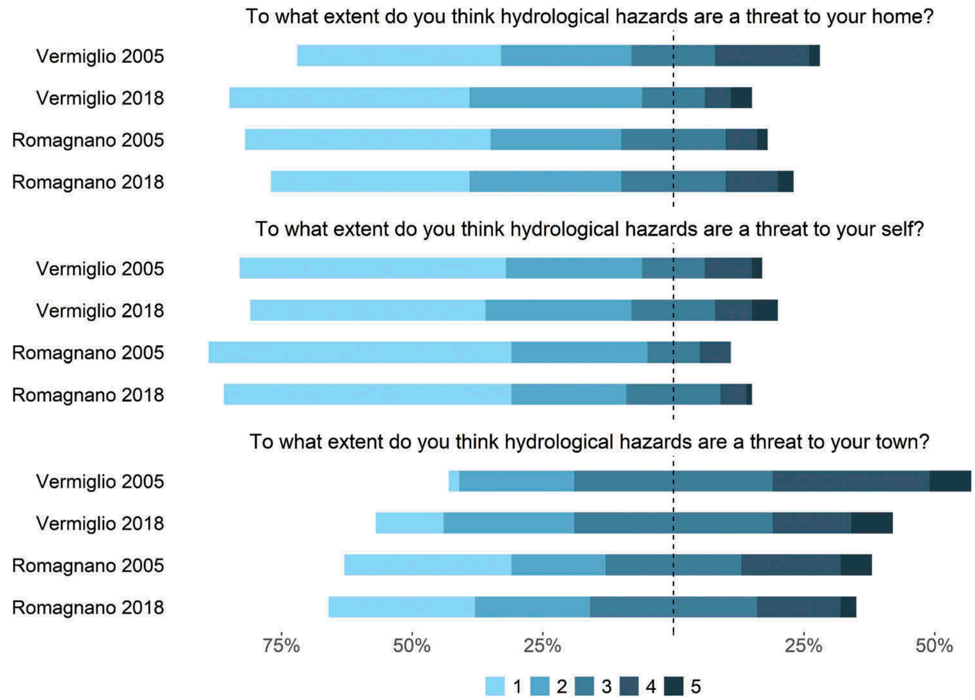

Figure 2. Results of the questionnaire regarding the perceived threat to the respondent's home, physical integrity, and town, on a scale from 1 (minimal threat) to 5 (serious threat).

Table 3. Results of the χ^2 contingency table tests for the "perceived likelihood" variable (df = 2).

	Perceived likelihood of hydrogeological phenomena
Vermiglio (2005 *vs* 2018)	**(9.28)****
Romagnano (2005 *vs* 2018)	**(34.45)*****
2005 (Vermiglio *vs* Romagnano)	**(20.06)*****
2018 (Vermiglio *vs* Romagnano)	(2.33)

χ^2 values in brackets.
***, ** and *: significance (*P* value): <0.001, <0.01 and <0.05, respectively.

known as *availability heuristic* (Tversky and Kahneman 1973, 1974), which leads our brain to think something is more or less likely according to the ease with which it comes to our mind. In this case, the occurrence of events nearby, such as the flash flood in Moena, in the same province, one month before the interviews were conducted, is likely to have triggered this mechanism. There is also a higher percentage of uncertainty (people who replied "*I don't know*") in both municipalities, compared to 2005. This could be due to the rather long time that had passed since the last occurrence. As for the differences among places, in 2005 there is a significant difference between Vermiglio and Romagnano (already highlighted by Scolobig *et al.* 2012), with the former showing a higher percentage of people who are concerned about the occurrence of hydrogeological hazards compared to the latter. This difference is no longer significant in 2018. The opinion shifts are shown in Fig. 3.

In the second round of surveys, participants were also asked to self-assess changes in their level of hydrogeological risk awareness and preparedness within the past 15 years (see Fig. 4). Both in Vermiglio and in Romagnano, the majority of respondents believe that their awareness has slightly increased (M_V = 3.57, M_R = 3.61). This is in line with the differences detected between 2005 and 2018: even though the perceived threat has decreased, the perceived likelihood of an event happening has largely increased (especially in Romagnano). After self-assessing the changes in hydrogeological risk awareness, respondents were asked to specify the reasons for such a change, or lack thereof. Among the respondents who think their awareness has

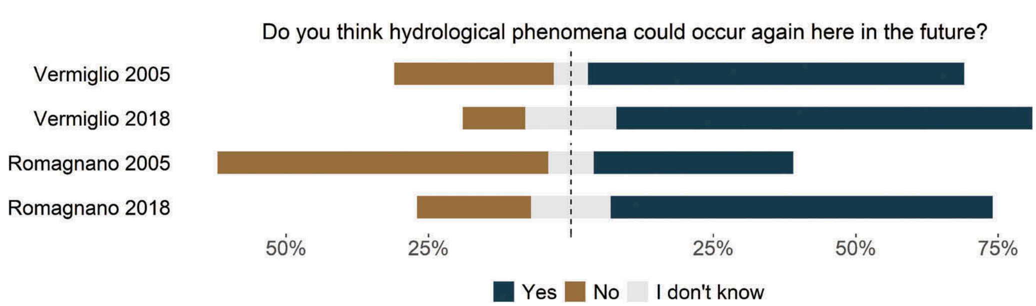

Figure 3. Results of the questionnaire regarding the perceived likelihood of hydrogeological phenomena.

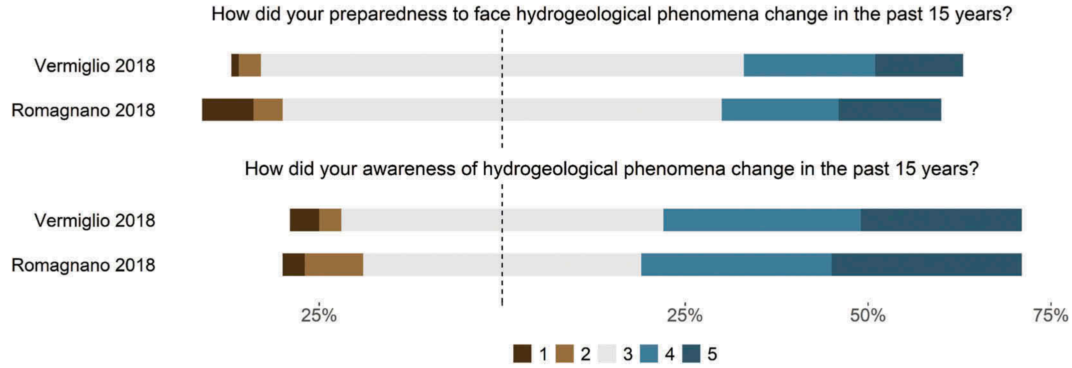

Figure 4. Results of the questionnaire regarding the respondents' self-assessed changes in hydrogeological risk awareness and preparedness, on a scale from 1 (decreased) to 5 (increased), with 3 indicating no change.

increased, the main causes specified are an increased maturity (i.e. growing older) and having experienced a hydrogeological hazard before. Even though the majority of interviewees believe that these are the main reasons for which their risk awareness has increased, the statistical analysis of survey data does not show correlations between age or previous experience with the hazard and awareness. However, these results partly find support in past research, where previous experience has been found significantly correlated with the level of risk awareness (Grothmann and Patt 2005, Burningham *et al.* 2008, Miceli *et al.* 2008, Botzen *et al.* 2009, Bubeck *et al.* 2012, Fielding 2012, Scolobig *et al.* 2012, Babcicky and Seebauer 2017). Right after these, participants also indicated the occurrence of events elsewhere and climatic changes as triggers for an increased awareness, contributing with more evidence to the availability heuristic bias. On the other hand, among those who think their awareness has decreased, the main causes are the lack of events and the lack of information regarding hydrogeological hazards. Some also pointed out that their awareness decreased due to a lack of experience with the event. This last result is in line with what was previously found in the literature.

To test the second hypothesis, that is whether preparedness decreased over time, we ran χ^2 tests for the two preparedness variables (see Table 4). Perceived individual preparedness is significantly lower in 2018 compared to 2005, in both areas. In addition, in 2018, as opposed to 2005 (where no significant differences were detected), it is also significantly lower in Vermiglio than in Romagnano. This result gives support to the second hypothesis and could be partly due to the absence of events since the early 2000s. In the study area, the administration of the Province of Trento is responsible for flood risk management. This means that the Province, through its offices, identifies areas prone to flood hazard and develops flood-risk management plans coordinated at the river basin level. Through a Civil Protection Department, the Province also has powers on flood-risk response and recovery. This may further explain a shift in responsibility from the individual to the administration when it comes to protecting one's household, given the fact that the perceived town preparedness is always higher than the perceived individual preparedness. Nonetheless, a lack of training and proper risk communication strategies may also have contributed to such a decrease in personal preparedness. Residents may also be disinterested, as they judge these events as unavoidable (*fatalism*), or unlikely to happen to them (*wishful thinking*). As for the perceived preparedness of the entire community specifically, Fig. 5 shows that a lower percentage of people think their town is prepared now, compared to 2005, but this difference is not statistically significant. In addition, even though the perceived preparedness of the community was higher in Vermiglio than in Romagnano in 2005, this is no longer true in 2018. The strong bond that the community in Romagnano has with their voluntary fire brigades might offer an explanation for this, as it could have caused the perceived town preparedness to decrease less than it did in Vermiglio. Figure 5 shows the shifts in responses.

Table 4. Results of the χ^2 contingency table tests for the two "preparedness" variables (df = 4). Bold indicates significant results.

	Perceived individual preparedness	Perceived town preparedness
Vermiglio (2005 *vs* 2018)	**(29.03)*****	(8.82)
Romagnano (2005 *vs* 2018)	**(20.07)*****	(6.90)
2005 (Vermiglio *vs* Romagnano)	(2.72)	**(13.89)****
2018 (Vermiglio *vs* Romagnano)	**(12.44)***	(5.76)

χ^2 values in brackets.
***, ** and *: significance (*P* value): <0.001, <0.01 and <0.05, respectively.

Concerning the self-assessment of changes in the level of preparedness, the majority of respondents in both areas believe that it has remained unchanged or marginally increased ($M_V = 3.16$, $M_R = 3.37$). As opposed to awareness, this result goes against the actual detected changes in preparedness, which show a decrease. Respondents who reported a self-assessed increase attribute it mainly to their personal life experiences, growing older and having experienced hydrogeological phenomena. Here too, the results are similar in both locations. In Vermiglio, however, there is a high percentage of respondents who associate it with their job. Even though this was not asked in the survey, we hypothesize that respondents who live in Vermiglio, compared to residents in Romagnano, have a stronger connection with their natural surroundings and are more likely to be employed in the field of environmental management and monitoring. Those who reported that their preparedness did not change blamed it on a lack of

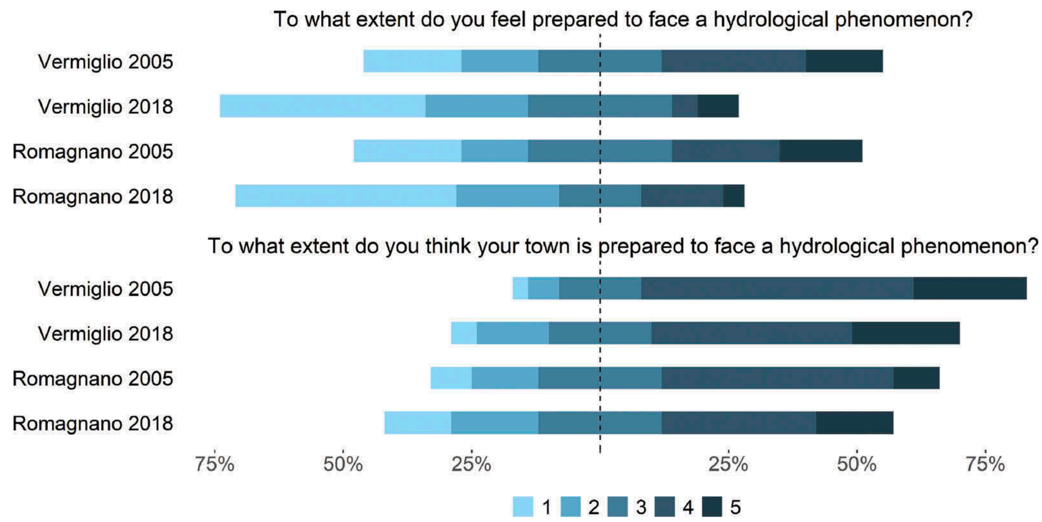

Figure 5. Results of the questionnaire regarding the respondent's perceived individual preparedness and perceived town preparedness, on a scale form 1 (barely prepared) to 5 (highly prepared).

information or training, the lack of hydrogeological events, and the lack of direct experience with the phenomena. In Vermiglio, a consistent proportion of respondents also pointed out that their preparedness did not change because nothing else in their environment changed.

From a risk management point of view, these results are telling. Even though in 2018 there is a higher percentage of respondents who feel poorly prepared, the majority still believes that their preparedness has improved, compared to 13 years ago. While this could be partially attributed to the different composition of the two samples, a mismatch in perceived preparedness and actual preparedness could have negative consequences should an event occur. Communicating the risk and specifically training people living in areas at risk on how to face different hydrogeological phenomena may help to reduce the divide. Surely, improving the knowledge on protective measures to adopt at the household level can guide respondents towards an aware assessment of their own preparedness conditions.

Concerning socio-hydrological modelling, the results presented above can significantly contribute to the conceptualization of the model itself, and to better informed estimation of parameters. Many models (Di Baldassarre *et al.* 2013, 2015, 2018b, Viglione *et al.* 2014, Garcia *et al.* 2016, Kuil *et al.* 2016, Gonzales and Ajami 2017, Yu *et al.* 2017) have used differential equations within a system dynamic approach to describe: (i) how awareness is built up, e.g. direct damage; (ii) how awareness changes over time, e.g. exponential decay; and (iii) how awareness relates to risk preparedness. Our results suggest that modelling efforts should separate the dynamics of preparedness from those of awareness, as the two are not only often influenced by different factors, but the same factor may have opposing effects on the two (see, for instance, social capital). In addition, especially regarding preparedness, our study shows that different groups within the same community may show different levels of preparedness, and generalizing the same dynamic to the entire community may lead to misleading results and projections.

4.2 Factors affecting hydrogeological risk awareness

To test the third and fourth hypotheses, we ran Spearman's correlation tests between socio-economic and socio-psychological variables and risk awareness variables. Socio-psychological factors are those most correlated with hydrogeological risk awareness variables in both areas. The *general feeling of safety* is inversely correlated with both the perceived threat to the home ($\rho_V = -0.36$, $P < 0.001$; $\rho_R = -0.27$, $P < 0.001$) and to one's physical integrity ($\rho_V = -0.24$, $P < 0.01$; $\rho_R = -0.26$, $P < 0.01$) posed by hydrogeological hazards. While this might look like a predictable result, in fact it still offers some insights. Participants might have felt unsafe for other reasons as well (e.g. social insecurity), but the fact that a correlation was found between the general feeling of safety and the perceived threat deriving from hydrogeological hazards tells us that such hazards are indeed posing a perceivable threat to the community. This brings evidence in support of the third hypothesis, that a general feeling of safety is inversely correlated with risk awareness.

Concerning protection works, the results differ slightly between the two cases. Knowing about the presence of protection works is inversely correlated with the perceived threat to the home, but only in Vermiglio ($\rho_V = 0.18$, $P < 0.05$), whereas in Romagnano no correlation was found. In addition, in Vermiglio, the respondents who report a high feeling of safety derived from the presence of protection works tend to feel less threatened by hydrogeological hazards at the individual level ($\rho_V = -0.29$, $P < 0.001$). The fact that this correlation is present in Vermiglio and not in Romagnano could be attributed to the different type of protective infrastructure in the two areas. In the former, protection works have a considerable size and are highly noticeable, while this is not true for the latter. However, in Romagnano, the greater the safety respondents feel deriving from protection works, the less likely they think an extreme hydrogeological event can occur ($\rho_R = 0.19$, $P < 0.05$). In general, the "levee effect" mechanism (Di Baldassarre *et al.* 2018a) does not seem to be at play in either location, given the prevalent lack of correlation between the presence of protection works and risk awareness variables. These could be due to the fact that, especially in Vermiglio, the engineering solution adopted after the 2000 event failed during the 2002 one. Consequently, respondents might feel that protection works cannot influence the frequency or magnitude of hydrogeological phenomena. The reasons for this missing correlation in Romagnano, on the other hand, could be attributed to the fact that structural protection measures are smaller and hidden by vegetation. This potentially prevents inhabitants from being reminded of their presence and purpose.

As regards socio-economic variables, and in line with Babcicky and Seebauer (2017), we found that the higher the income of a household, the lower is the perceived threat to the town ($\rho_V = -0.27$, $P < 0.01$) and the respondent' own safety ($\rho_R = -0.21$, $P < 0.01$), in Vermiglio and Romagnano respectively. In contrast with the literature, we found that respondents with a higher education tend to feel more threatened by hydrogeological hazards at the individual level in Vermiglio ($\rho_V = 0.21$, $P < 0.05$), and report an increased risk awareness in Romagnano ($\rho_R = 0.19$, $P < 0.05$). However, since these results contradict previous literature (Bubeck *et al.* 2012, Ludy and Kondolf 2012, Babcicky and Seebauer 2017), further research is needed to test whether it could be a pattern or just a characteristic of these two specific samples.

5 Conclusions

We performed a cohort study to explore changes in time of risk awareness and preparedness. First, we hypothesized that hydrogeological risk awareness would decrease over time in the absence of events (H1). This assumption found support in our data: the lack of hydrogeological events in a long time and poor (if no) risk communication strategies might be the cause of such decrease in awareness. Similarly, the data provides backing for the hypothesized decrease in preparedness (H2). Here too, the reasons can be attributed to the lack of events and the fact that neither of the two municipalities provided training to the citizens. Both results can also be partially explained by the fact that respondents who generally feel safe living in their area do not seem to be worried about hydrogeological phenomena (H3). This also brings evidence in favour of the third hypothesis. The fourth hypothesis, that the presence of protection works is associated with lower risk awareness (H4), is partly supported by our data, given the characteristics of structural protection measures in the two locations.

However informative a longitudinal approach is, it does not come without limitations. Two main issues can affect the results of longitudinal surveys: attrition rate and retention bias (Hudson *et al.* 2019). The former occurs when some of the participants drop out in a later round of surveys, resulting in a smaller sample size. If this drop out is not random, but due to one or more specific variables, it may lead to retention bias, which, besides the smaller sample size, may contribute to inaccurate statistical findings. In our case, limitations are not related to attrition rate or retention bias, but to the sampling methodology: we could not follow the same individuals over time, therefore we only investigated differences at the community level. This implied a loss in the statistical precision of our analysis. Further studies on the matter should focus on following the same individuals over time to gain a deeper insight into the causes of potential changes.

Nevertheless, the results from this cohort study offer meaningful insights into how awareness and preparedness change over time in the absence of events during the intervening period. Our outcomes can inform risk communication strategies for disaster risk reduction at the municipal level. Indeed, knowing how risk perceptions, in particular awareness and preparedness, evolve over time is essential to plan timely and effective policies for risk management. Moreover, our study contributes to improve our understanding of risk dynamics and provides empirical information to further develop socio-hydrological models.

Acknowledgements

This work was developed within the framework of the Panta Rhei research initiative of the International Association of Hydrological Sciences (IAHS); in particular, it is a contribution of the Working Group on Changes in Flood Risk. We wish to deeply thank Bruna De Marchi, leader of the Mass Emergency Programme at Instituto di Sociologia Internazionale di Gorizia (ISIG), for having contributed considerably to the survey design, data collection and analysis between 2004 and 2008. The same is true for Prof. Giovanni Delli Zotti and Maura Del Zotto, two of the other ISIG team members, who played a critical role in the data collection and analysis. We also thank all the other colleagues who provided us with professional advice and collaboration, the key informants in the province of Trento, who devoted their time to our interviews and focus groups to prepare the survey, the interviewers who conducted the surveys in Romagnano and Vermiglio, and the survey respondents, both in 2005 and 2018. We also want to acknowledge the municipalities of Vermiglio and Trento and the district of Romagnano for their collaboration and for providing demographic data. Special thanks go to Amelii Valeria, Bernello Giacomo, Comberlato Manuel, Libardoni Linda, Poli Elena, Taccaliti Flavio and Zanella Davide.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

GDB was supported by the European Research Council (ERC) within the project “HydroSocialExtremes: Uncovering the Mutual Shaping of Hydrological Extremes and Society” [ERC Consolidator Grant no. 771678]. The original survey was developed in the EC Sixth Framework Programme funded project FLOODsite, 2004–2008 (http://www.floodsite.net) [Contract GOCE-CT-2004-505420]. The 2005 data were also collected in the frame of the same project. At the time of the research Anna Scolobig was associated with ISIG (Institute of International Sociology of Gorizia, Italy), one of the FLOODsite partners.

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