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## Public perceptions and responses to flood risk: Evidence from the 2023 flood events in Italy

Irene Palazzoli <sup>a,b</sup>, Chiara Puglisi <sup>c</sup>, Chiara Binelli <sup>d</sup>, Raya Muttarak <sup>c</sup>,  
Serena Ceola <sup>b,\*</sup><sup>a</sup> Department of Agricultural and Food Sciences, Alma Mater Studiorum – Università di Bologna, Bologna, Italy<sup>b</sup> Department of Civil, Chemical, Environmental, and Materials Engineering, Alma Mater Studiorum – Università di Bologna, Bologna, Italy<sup>c</sup> Department of Statistical Sciences, Alma Mater Studiorum – Università di Bologna, Bologna, Italy<sup>d</sup> Department of Political and Social Sciences, Alma Mater Studiorum – Università di Bologna, Bologna, Italy

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## ABSTRACT

In 2023, Italy experienced severe flooding events with devastating environmental and socio-economic impacts. As flood hazards increase in frequency and intensity, understanding public risk perception, preparedness, and responses to communication strategies is critical. This study provides timely insights into these aspects following the May and November 2023 floods in Emilia-Romagna and Tuscany. Through an online survey submitted to a representative sample of 3,423 residents across the two regions, we collected information on socio-demographics, flood risk perception, preparedness and mitigation measures, awareness of response strategies, information sources, and expectations regarding future policies and personal risk. A unique contribution of this study is the integration of survey responses with official flood hazard data, enabling a comparison between perceived and actual flood risk.

Residents of flooded municipalities reported higher perceived flood risk than those in non-flooded municipalities, with perceptions aligning more closely with high- and medium-probability flood zones. Household preparedness was generally low, with nearly half of respondents reporting no precautionary measures. Adoption of structural measures was more common among individuals with higher risk perception, income, and education levels. Awareness of municipal flood management and evacuation plans was limited, yet more than half of respondents expressed interest in improving their flood risk knowledge. Trust in future policy interventions and perceived personal risk were moderate, with the latter varying by age, education, and prior flood experience. These findings underscore the need for targeted, community-focused interventions integrating socio-demographic factors, prior experience, and effective risk communication to promote proactive behavior, particularly for low-probability, high-impact events.

## 1. Introduction

Floods are among the most destructive natural hazards, generating considerable economic losses and social impacts [1]. According to UNISDR [2], flood risk is defined as the product of hazard (i.e., probability of occurrence), exposure (i.e., elements at risk), and

\* Corresponding author.

E-mail address: [serena.ceola@unibo.it](mailto:serena.ceola@unibo.it) (S. Ceola).<https://doi.org/10.1016/j.ijdr.2025.105981>

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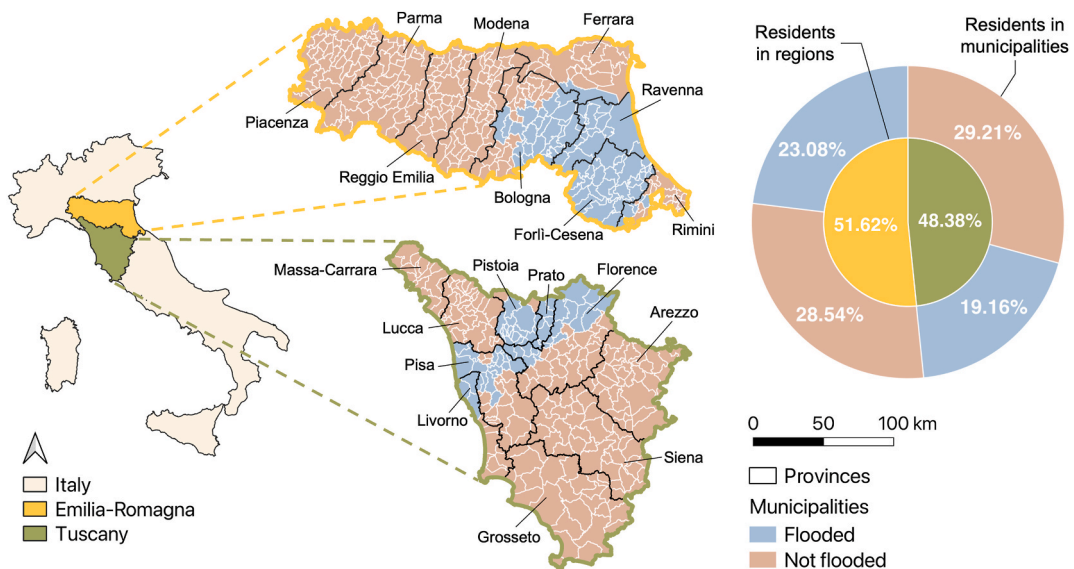
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vulnerability (i.e., the ability to cope with the event). As climate change intensifies the frequency and severity of extreme rainfall events and as more people are living in flood-prone areas, flood risk is escalating worldwide [3–6].

In Europe, the past three decades rank among the most flood-rich periods on record, with floods accounting for 81% of climate-related economic losses each year, affecting 1.6 million people annually [7]. About 77% of the floods observed in the period 1980–2025 have occurred after the year 2000, with a 25% share of total damages observed in the past five years alone [8]. Several recent episodes show this growing hazard, including the 2021 floods across Austria, Belgium, Croatia, Germany, Italy, Luxembourg, the Netherlands, and Switzerland [9–12] and widespread flooding in Italy, Slovenia, Norway, Sweden, Greece, Bulgaria, and Turkey in 2023 [9,13–15]. In 2024, Europe experienced its most widespread and destructive flooding since 2013 [16], during which locally record-breaking rainfall to eastern Spain led to catastrophic flooding in the Valencia region [16–18]. Studies reveal that flood characteristics across Europe are changing, with strong regional contrasts. Flood magnitudes are increasing in small catchments in northwestern Europe, while in the Mediterranean, floods are occurring earlier in the year, with more intense rainfall, drier soils, and more frequent flash-type events [19–23]. The spatial extent of floods has increased by about 11% over the past 70 years, driven by increases in precipitation, snowmelt, and more spatially coherent heavy rainfall [10].

Among the Mediterranean countries, Italy is one of Europe's most hazard-prone countries, frequently affected by severe inundations and hydro-geomorphological disasters [24–26]. Over the past few decades, Italy has experienced a remarkable number of flood events, with the territory across Emilia-Romagna, Tuscany, Marche, and Calabria regions repeatedly hit by floods [8,27,28]. The country's mountainous terrain, steep riverbeds, and narrow valleys amplify flood hazards [29], while urban expansion into floodplains and foothills has increased the exposure of settlements, infrastructure, and economic assets [30]. Exposure to floods remains high across Italy, particularly in the northern and central regions. According to the 2021 ISPRA report [31], millions of residents live in medium-to high-hazard zones, with the greatest regional exposures found in Emilia Romagna and Tuscany. In terms of economic losses, Italy has been the second most flood-affected country in Europe over recent decades (135 billion euros in losses, after Germany with 180 billion euros), accounting for 17% of the continent's total flood events and 38% of all flood-related deaths recorded in Europe [32].

In response to floods, the EU Floods Directive 2007/60/EC [33] requires European countries to implement flood risk management plans, which outline structural and non-structural flood protection measures and emergency preparedness strategies. Despite advances in disaster risk management, recent floods highlight the persistent vulnerability of communities and the need for more effectively designed climate risk mitigation and management strategies, that also incorporate increased public awareness and preparedness. Indeed, risk perception (i.e., individuals' beliefs or subjective judgements about the likelihood and impacts of a hazard) plays a crucial role in risk management, as it reflects communities' awareness of extreme weather events as well as their level of concern about and preparedness for potential consequences [34–36]. Studies across a range of hazards, including floods [6,35,37–39], landslides [40,41], earthquakes [42,43], volcanic unrest [44], and storms [45] highlight several recurring drivers. Prior experience is one of the most consistent predictors of risk perception and preparedness [3,36,46–49]. Trust in institutions and information sources similarly affects willingness to take protective actions [32,34,47]. Spatial factors also play a role [32,47,50]. In particular, for floods, residents in the most flood-prone areas often tend to underestimate their actual risk, posing challenges for risk management [51]. The quality of risk



**Fig. 1.** Location of the study area and distribution of survey respondents. Maps on the left show the location of the Emilia-Romagna and Tuscany regions within the Italian peninsula, with zoomed-in views highlighting municipalities classified as flooded or not flooded during the 2023 flood events (May in Emilia-Romagna and November in Tuscany). Province boundaries and names are also indicated. The pie chart on the right illustrates the distribution of survey respondents across Emilia-Romagna and Tuscany (inner pie chart), and the percentage of respondents residing in flooded versus non-flooded municipalities (outer doughnut chart).

communication, for example through targeted awareness campaigns, can reduce the existing gap between awareness and actual preparedness [32,38,46,48]. Finally, demographic factors, including age, income, and education, have likewise been documented to shape individuals' awareness, preparedness, and behavioral responses to hazards [47,52].

While much attention has been given to the assessment of flood risk and to hydrological and infrastructural aspects, there is limited evidence on how the Italian population affected by the recent flood events perceives flood risk, reacts to floods, and engages in preparedness measures. To fill this significant gap, in this study we perform a detailed assessment of flood risk perception and preparedness through an original survey submitted to a representative sample of 3,423 individuals living in the Italian regions of Emilia-Romagna and Tuscany. The survey captures multiple dimensions relevant to public response to the 2023 flood events, namely socio-demographic characteristics, awareness and perception of flood risk, individual preparedness and mitigation behaviors, perceived effectiveness of emergency response and communication strategies, expectations regarding future policy interventions, and perceived personal risk.

## 2. Data and methodology

### 2.1. Study area

The Emilia-Romagna and Tuscany regions present an important case study on risk perceptions and preparedness against floods due to the severe events they experienced in 2023 (Fig. 1a and Fig. S1). That year, floods affected 79 municipalities in Emilia-Romagna, covering about 30.75% of the region's total area (6,919.93 km<sup>2</sup>), while in Tuscany 62 municipalities were affected, accounting for 17.78% of the region's total area (4,036.76 km<sup>2</sup>). In May 2023, Emilia-Romagna, the Italian region with the largest flood-prone area [53], experienced one of its most devastating fluvial flood events in recent history [54,55]. The region was struck by two major hydro-meteorological events that occurred in close succession, on May 2–3 and May 16–17. Both events were triggered by persistent, record-breaking rainfall, which caused widespread river overflows, with 23 rivers bursting their banks and numerous landslides [14, 56,57]. The initial flood event in early May was characterized by exceptionally heavy rainfall, with Storm Minerva delivering more than 200 mm of precipitation within 48 h in several areas, particularly affecting the provinces of Bologna, Ravenna, and Forlì-Cesena. The situation was exacerbated by the even more severe second event, with rainfall reaching up to 300 mm within 48 h in some areas. The resulting flooding inundated approximately 540 km<sup>2</sup> of lowland terrain, leading to the displacement of over 36,000 people and 15 fatalities [14,57]. In the hilly and Apennine areas of the Bologna, Ravenna, and Forlì-Cesena provinces, a total of 65,598 landslides were recorded, affecting a cumulative area of 72.21 km<sup>2</sup> [57].

Later, in November 2023, Tuscany faced catastrophic flooding due to Storm Ciarán, one of the most extreme weather events impacting Western Europe in recent years. The storm, which had already caused destruction in Spain, Portugal, the U.K., and France, brought torrential rain and strong sirocco winds to Tuscany on November 2–3 [58,59]. A nearly stationary storm line produced 130–170 mm of rainfall within 5–6 h, with hourly peaks of 40–55 mm in the provinces of Pisa, Florence, Pistoia, and Prato [58]. This intense, short-duration rainfall triggered rapid river overflows in small to medium catchments causing sudden urban flooding [59]. A second storm on November 4–5 brought widespread rainfall, further stressing river channels and flood defenses [58]. Across Tuscany, the event led to 20 levee breaches, flooding of approximately 2,500 buildings, disruption of electricity and transport networks, and the evacuation of around 300 people [59,60].

### 2.2. Study design and respondents' recruitment

To investigate flood risk perception and the level of preparedness in the aftermath of the 2023 floods, we conducted an original survey on a representative sample of residents of Emilia-Romagna and Tuscany aged 18 years and over. The anonymous online questionnaire was developed using the Qualtrics platform [61] and administered between June and July 2024 by the independent survey company Demetra *opinion.net* S.r.l. [62]. Demetra provided a pool of respondents balanced by gender, age, and province of residence to reflect the demographic profile of the adult population in the two regions.

The survey was sent to 4,443 participants. Restricting the sample to individuals who completed the questionnaire and provided consent yielded 3,472 respondents. We further excluded respondents without a valid ZIP code consistent with their reported region of residence. The final dataset consists of 3,423 responses, of which 51.62% are individuals residing in Emilia-Romagna and 48.38% are individuals residing in Tuscany (Fig. 1).

### 2.3. Survey development and structure

The survey consisted of a total of 52 questions. Questions were designed based on a review of key literature on flood risk perception and household preparedness, (see, for example, [32,39,63,64]), and were complemented by questions developed by the authors to ensure clarity, simplicity, and comparability with established research. To this end, the questionnaire relied primarily on closed-ended items, established scales where available, and minimal technical terminology. The survey was organized into six thematic sections and included a mix of numerical scales (0–100%), Likert-type categorical responses, and multiple-response options.

For the purpose of this study, we focused on 20 questions addressing the following topics: respondents' socio-demographic characteristics, flood risk awareness and perception, level of household preparedness, perceived effectiveness of flood response and communication strategies, and expectations regarding future policy and personal risk (Table 1). Participants were asked about their perceived level of flood risk in their municipality of residence, the presence of emergency equipment in their homes, and whether any

risk mitigation measures had been implemented prior to the occurrence of the 2023 flood. We also examined the effectiveness of communication strategies, sources of information, and the type of additional information respondents would have liked to receive. Additionally, respondents were asked to assess the likelihood that policies and intervention strategies would be implemented at the municipal and national levels over the next five years to address future extreme weather events, and to evaluate their own personal risk of being affected by such events.

#### 2.4. Official flood-related data

We integrated additional objective information by compiling a list of municipalities affected by the 2023 flooding events in both regions, derived from official statements [65,66]. This list enabled us to classify respondents as residing in either flooded or non-flooded municipalities based on their ZIP code of residence.

In addition, we collected flood hazard data quantifying the share of each municipality's territory exposed to flooding [67], with reference to three recurrence intervals (i.e., return periods, RP) that reflect the likelihood and severity of flooding events, namely high probability (frequent floods with a 20–50-year RP), medium probability (moderately frequent floods with a 100–200-year RP), and low probability (rare floods with a  $\geq 200$ -year RP). Therefore, we measured the extent of municipal territory potentially threatened under these three hazard levels and linked this information to each respondent to indicate the extent of flood-prone areas within their municipality corresponding to these RPs.

#### 2.5. Statistical analysis

All analyses were conducted in R (version 4.4.2). We first performed descriptive statistics, including frequency distributions and cross-tabulations, to summarize socio-demographic characteristics, flood experience, preparedness actions, and communication patterns. Missing responses were treated as NA and excluded from the analysis. Data were not weighted, as the aim was to describe patterns within the surveyed sample rather than produce population-level estimates. Multi-response variables (e.g., preparedness measures) were treated as binary indicators (adopted/not adopted) for regression analyses.

##### 2.5.1. Linear and logistic regression model

To explore the influence of socio-economic factors and the effect of living in a flooded municipality on risk perceptions and flood preparedness, we estimated regression models considering the following predictors: gender, age, marital status, education level, occupation status, income level, home ownership, and a binary variable indicating whether the respondent lived in a flooded municipality. Models were defined for questions 8, 10–15, and 18–20 (referenced by their ID in Table 1). Depending on the nature of the response variable, we employed linear regression for numeric outcomes (e.g., percentage estimates or likelihood ratings) and logistic regression for categorical responses. Binomial logistic regression was used for dichotomous outcomes (e.g., yes/no), while multinomial logistic regression was applied to questions with more than two response categories (e.g., very effective/not effective/don't know).

To investigate how individuals' perception of the extent of flood-prone areas in their municipality influences their level of flood preparedness, we performed an additional linear regression. According to question 9 (Table 1), we reclassified preparedness into three levels: structural (i.e., structural repairs or improvements, home elevation, emergency power generation, or flood management equipment), soft (e.g., insurance, emergency planning, or emergency supplies), and no measures.

Statistical significance was defined at  $p < 0.05$ . Full details and complete tables are provided in the Supplementary Information.

### 3. Results

#### 3.1. Socio-demographic characteristics and exposure to 2023 flood events

Table 2 presents summary statistics for respondents' socio-demographic characteristics, derived from their ZIP code of residence and answers to questions 1–7 in Table 1. The sample displayed balanced gender representation across both the whole sample and each region, and a relatively young age distribution, with over half of participants aged under 45 years old. Approximately half of respondents were married, around half held a high school diploma, and over one-third held a bachelor's or master's degree. Nearly 70% of respondents were employed, with over 40% reporting monthly income between €2,000 and 5,000. A substantial majority of respondents were homeowners, with comparable ownership rates across the two regions. Based on respondents' ZIP code of residence and the official list of flooded municipalities in both regions, we determined whether each participant lived in a municipality affected by the 2023 flooding (Fig. 1). Approximately 42% of survey respondents resided in municipalities impacted by these events, with slightly higher rates for Emilia-Romagna (44.71%) compared to Tuscany (39.61%).

#### 3.2. Perception of flood risk

To analyze flood risk perception, we asked respondents to estimate the proportion of land at risk of flooding in their municipality of residence (question 8 in Table 1). We distinguished between respondents living in a municipality affected by the 2023 floods and those residing in a non-affected municipality (Fig. 2a). Residents of flooded municipalities reported higher perceived exposure, with a mean of 54.30% among respondents in this group compared to a mean of 44.84% among respondents in non-flooded municipalities. The linear regression analysis (Table S1) shows that respondents living in a flooded municipality estimated a substantially higher

**Table 1**

Summary of survey sections, questions, and corresponding answer options presented in the online survey. For Question 9, \* and + mark the response options classified as soft and hard measures, respectively, for the purpose of the linear regression analysis.

Section	ID	Question/Variable	Possible answers
<i>Socio-demographic information</i>	1	Gender	Male, Female
	2	Age	18-29, 30-44, 45-59, ≥60
	3	Marital status	Single, Married, Separated/Divorced/Widowed
	4	Level of education	≥ Bachelor's degree, High school, ≤ Middle school
	5	Employment status	Employed, Student, Retired, Unemployed
	6	Net monthly household income	≤ €2,000; €2,001-5,000; €5,001-10,000; > €10,000; Don't know
	7	Property ownership	Owned, Rented
<i>Flood risk awareness and perception</i>	8	What percentage of your municipality do you think is at risk of flooding?	Scale from 0 to 100%
	9	Was your home equipped for extreme weather before the flood in your area? (Select all that apply)	No Yes, I arranged for insurance against extreme weather events * Yes, I developed an emergency plan that provides instructions for household members on where to go and what to do in case of danger * Yes, I prepared emergency food supplies * Yes, I obtained a first aid kit * Yes, I have essential medication stocks * Yes, I ensured emergency drinking water supplies * Yes, other (please specify) * Yes, I elevated my dwelling + Yes, I set up emergency power generation + Yes, I equipped myself with tools to manage flooding (e.g., temporary bridges, sandbags, or flood barriers) + Yes, I made structural repairs or improvements to my home +
<i>Level of preparedness</i>	10	We would now like to ask about any flood management measures you may have taken during the 2023 flood. These measures aim to reduce flood risk/impact and can be proactive (before the flood) or reactive (after the flood). Have you ever adopted any of the following measures? (Select all that apply)	1. Secured or moved items in the basement to reduce flood risk; 2. Installed barriers or flood protection; 3. Purchased pumps or sandbags; 4. Removed hazardous trees; 5. Strengthened property against heavy rain or wind; 6. Alerted neighbors about approaching storms; 7. Encouraged others to implement protective measures; 8. Purchased or upgraded home insurance; 9. Relocated to a lower-risk home; 10. Contacted the municipality about risk issues; 11. Acquired emergency equipment (e.g., flashlights, candles, battery-powered radios)
	11	If you had known your home's flood risk, would you have acted differently during the flood?	Yes No Don't know
	12	If you had known your home's flood risk, would you have chosen to live elsewhere?	Yes No Don't know
<i>Perceived effectiveness of flood response measures</i>	13	Are there evacuation plans in place for flood risk in your city or municipality? In particular: 1. Does your city/municipality have a flood management plan? 2. Does your city/municipality have evacuation plans for flood risk? 3. Does your city/municipality implement flood risk communication strategies? 4. Are you aware of the likelihood of flooding at your home? 5. Do you think these measures would be effective in increasing preparedness and reducing flood risk?	Yes No Don't know
	14	How effective were the measures implemented during the flood event?	Very effective Not effective Don't know

(continued on next page)

**Table 1** (continued)

Section	ID	Question/Variable	Possible answers
<i>Communication strategies</i>	15	Did you receive any information about weather warnings, flood severity, preparedness, or evacuation before, during, or after the flood?	Yes No
	16	From which of the following sources did you get weather warnings and flood updates before, during, and after the flood? Television; Radio; Neighbors; Friends, acquaintances, or family; Newspaper; Authorities (e.g., Regional Civil Defense Agency, Municipality, Local Police); School; Weather bulletins or forecasts; Social media (e.g., Facebook, X, Instagram); Websites or other online sources (excluding social media); Community events or meetings; Subscription-based alerts (e.g., SMS, email, app notifications)	I did not receive any information from this source Before the event During the event After the event Before and during the event Before and after the event During and after the event Before, during, and after the event
	17	What information would help you better understand flood risk? (Select all that apply)	Live in an area flooded in the past Live in an area with low, medium, or high flood risk List of actions to manage flood events Satisfied with information I have
<i>Future policy and personal risk expectations</i>	18	What do you think is the likelihood that policies and interventions will be implemented in your municipality within the next five years to address the impacts of extreme weather events?	Scale from 0 to 100%
	19	What do you think is the likelihood that policies and interventions will be implemented in Italy within the next five years to address the impacts of extreme weather events?	Scale from 0 to 100%
	20	How likely do you think it is that you will be personally affected by extreme weather events in the next five years?	Scale from 0 to 100%

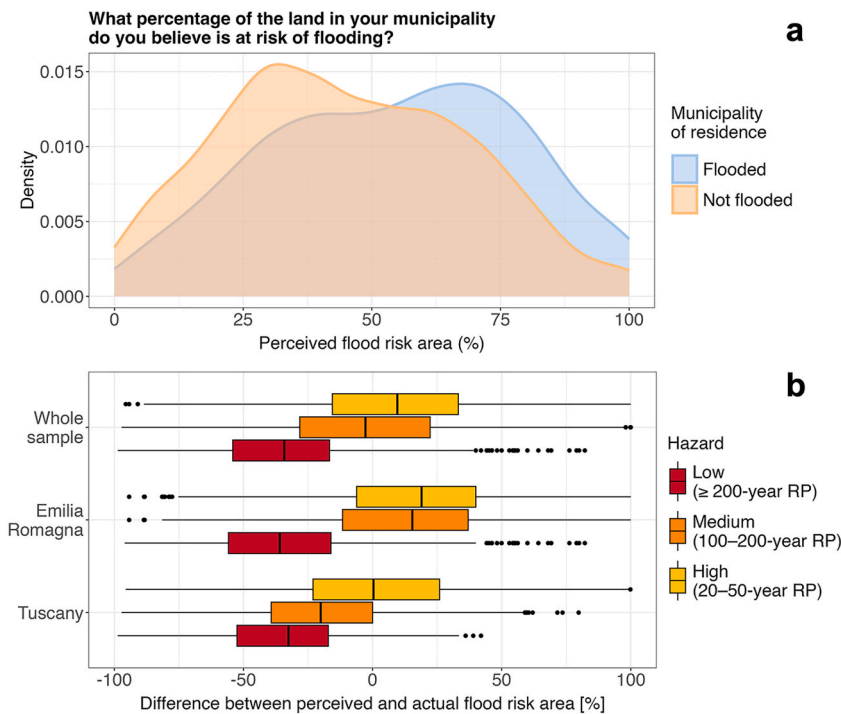
**Table 2**

Survey sample: size and socio-demographic profile.

		Whole sample	Emilia-Romagna	Tuscany
<b>Municipality</b>	Number of participants	3423	1767	1656
	Flooded	42.24%	44.71%	39.61%
<b>Gender</b>	Not flooded	57.76%	55.29%	60.39%
	Female	54.54%	54.95%	54.11%
<b>Age</b>	Male	45.46%	45.05%	45.89%
	18–29 years	19.31%	19.35%	19.26%
	30–44 years	29.24%	29.71%	28.74%
<b>Marital status</b>	45–59 years	34.94%	34.18%	35.75%
	≥60 years	16.51%	16.75%	16.24%
	Single	38.77%	39.73%	37.74%
	Married	50.95%	49.92%	52.05%
<b>Education</b>	Separated/Divorced/Widowed	10.28%	10.36%	10.21%
	≤ Middle school diploma	10.20%	9.85%	10.57%
	High school diploma	51.48%	50.03%	53.02%
<b>Occupation</b>	≥ Bachelor's degree	38.33%	40.12%	36.41%
	Employed	69.47%	69.84%	69.08%
	Student	7.42%	7.58%	7.25%
	Retired	10.69%	11.49%	9.84%
<b>Household's monthly income</b>	Unemployed	12.42%	11.09%	13.83%
	≤ €2,000	30.76%	29.94%	31.64%
	€2,001–5,000	43.59%	44.03%	43.12%
	€5,001–10,000	7.86%	8.21%	7.49%
<b>Tenure</b>	> €10,000	8.56%	8.32%	8.82%
	Don't know	9.23%	9.51%	8.94%
	Owned by a household member	76.80%	76.17%	77.48%
	Rented	23.20%	23.83%	22.52%

percentage of land at risk – 9.35% more – than those in non-flooded municipalities. Women, married individuals, employed respondents and those with a monthly income lower than €2,000 perceived higher percentages of land at risk compared to their counterparts (Table S1).

To evaluate the accuracy of public risk perception, we compared respondents' estimates with objective flood hazard data. Specifically, we computed the difference between the perceived fraction of flood-prone area in the municipality reported by each respondent and the actual percentage associated with high-, medium-, and low-probability flood hazards (Fig. 2b). Although participants were not explicitly asked to distinguish between flood hazard levels associated with specific flood recurrence frequency and provided only a general estimate, this comparison enabled us to better interpret the accuracy of respondents' awareness of flood-prone



**Fig. 2.** Flood risk perception among survey participants. **(a)** Percentage of municipal area perceived as flood-prone by respondents living in flooded versus non-flooded municipalities. **(b)** Difference between perceived and actual percentage of municipal area across flood hazard levels associated with a different return period (RP), shown for the whole sample, Emilia-Romagna, and Tuscany.

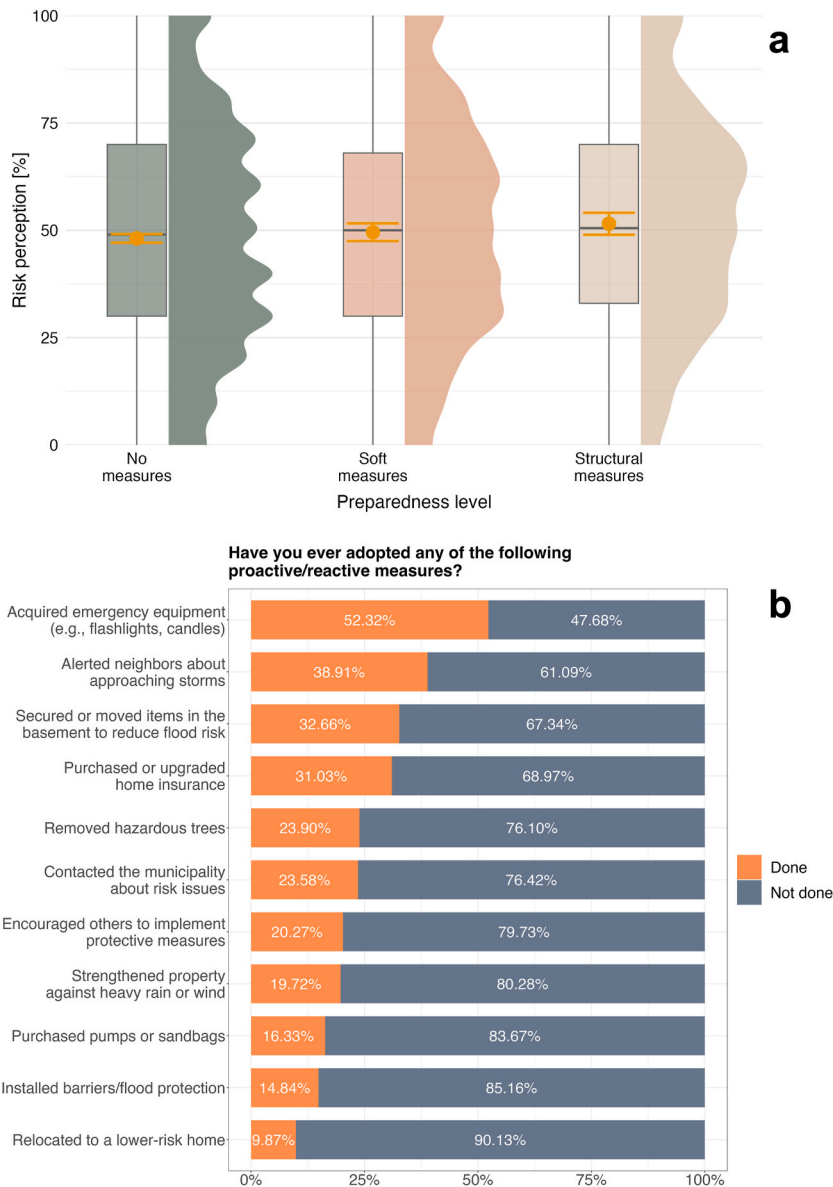
areas in their municipality, which is inevitably shaped by past flood experiences, media coverage, and official communications about events of varying probabilities. Overall, survey data suggested that participants' perceptions aligned more closely with the extent of areas affected by high- and medium-probability floods than with those impacted by low-probability events. For high-probability events, the affected area was overestimated on average by 9.53%, while for medium-probability events, respondents' estimates were fairly accurate (mean difference =  $-2.09\%$ ). Low-probability areas were considerably underestimated (on average by  $-34.53\%$ ), suggesting limited awareness of the extent of their municipality potentially threatened by such extreme events.

When analyzing these results at the regional level, distinct regional patterns emerged. Respondents in Emilia-Romagna tended to overestimate the extent of high- and medium-probability flood-prone areas in their municipality ( $+16.60\%$  and  $+13.14\%$  on average for high-probability and medium-probability floods, respectively), while they substantially underestimated the extent of low-probability flood-prone areas ( $-33.90\%$ ). Tuscany residents significantly underestimated the extent of areas affected at medium and low levels (by  $-19.23\%$  and  $-35.08\%$ , respectively), and, to a lesser extent at the high-hazard level (by  $-1.57\%$ ). These differences in perception may reflect the substantially larger share of flood-prone land area in Emilia-Romagna ( $47.31\%$ ,  $45.60\%$  and  $11.58\%$  for low-, medium- and high-flood hazard, respectively) compared to Tuscany ( $21.22\%$ ,  $12.16\%$  and  $6.15\%$  for low-, medium- and high-flood hazard, respectively), potentially influencing local awareness and flood risk assessment.

We also distinguished between municipalities affected and not affected by the 2023 floods (Fig. S2) and found that both groups exhibited similar perception patterns for high- and medium-probability events. However, for low-probability events, respondents in flooded municipalities tended to underestimate the extent of flood-prone areas more than residents in non-flooded municipalities, suggesting their perceptions were more strongly anchored to medium-probability events. This pattern was confirmed at the regional scale in Emilia-Romagna, where residents of flooded municipalities reported a stronger underestimation of low-probability areas ( $-44.11\%$  vs.  $-26.81\%$  for non-flooded municipality residents). In Tuscany, by contrast, both groups underestimated the extent of low-probability areas by nearly the same amount  $-34.26\%$  vs.  $-33.65\%$ ).

### 3.3. Preparedness and adoption of mitigation measures

We investigated respondents' preparedness for floods and found that household-level precautionary measures prior to the 2023 events were generally low (question 9 in Table 1). Overall, 48.05% of respondents reported having taken no specific precautionary measures (49.08% in Emilia-Romagna, 46.95% in Tuscany). Linear regression analysis indicated that respondents who had implemented at least one structural measure tended to perceive a slightly larger extent of flood-prone areas in their municipality ( $+3.42\%$  compared to the reference category "No measures", Table S2), whereas respondents adopting only soft measures did not show statistically significant differences (Fig. 3a).



**Fig. 3.** Flood risk perception and preparedness among survey participants. **(a)** Distribution of perceived flood risk area (%) within municipalities, stratified by flood preparedness level (“No measures”, “Soft measures”, and “Structural measures”). Boxes indicate the interquartile range (IQR), and horizontal black lines represent the median. Half-violin plots show the density of responses for each preparedness category. Points and error bars over the boxes represent the predicted values and 95% confidence intervals from the linear regression model. **(b)** Measures adopted during the flooding events in Emilia-Romagna and Tuscany. The colors of the bars indicate the fraction of respondents who reported each action as “Done” or “Not done”. Multiple answers were allowed.

When asked about the types of proactive (before the flood) or reactive (after the flood) actions they had ever undertaken to mitigate floods risks and impacts (Question 10 in Table 1), the most frequently adopted measures across the whole sample (Fig. 3b) included acquiring emergency equipment, such as candles, flashlights, battery-powered radios (52.32%), alerting neighbors about an approaching storm or weather event (38.91%), and taking basic protective actions like storing items in the basement (32.66%) or purchasing/upgrading house insurance (31.03%). A concerning finding was that over three-quarters of respondents had not adopted more robust mitigation efforts, such as installing flood barriers, improving structural resilience, or removing hazardous trees. Outcomes from the linear regression analysis suggested that younger individuals, married and separated/widowed respondents, wealthier individuals (monthly income > €5,000) and homeowners were more likely to adopt preparedness measures (Tables S3–S13).

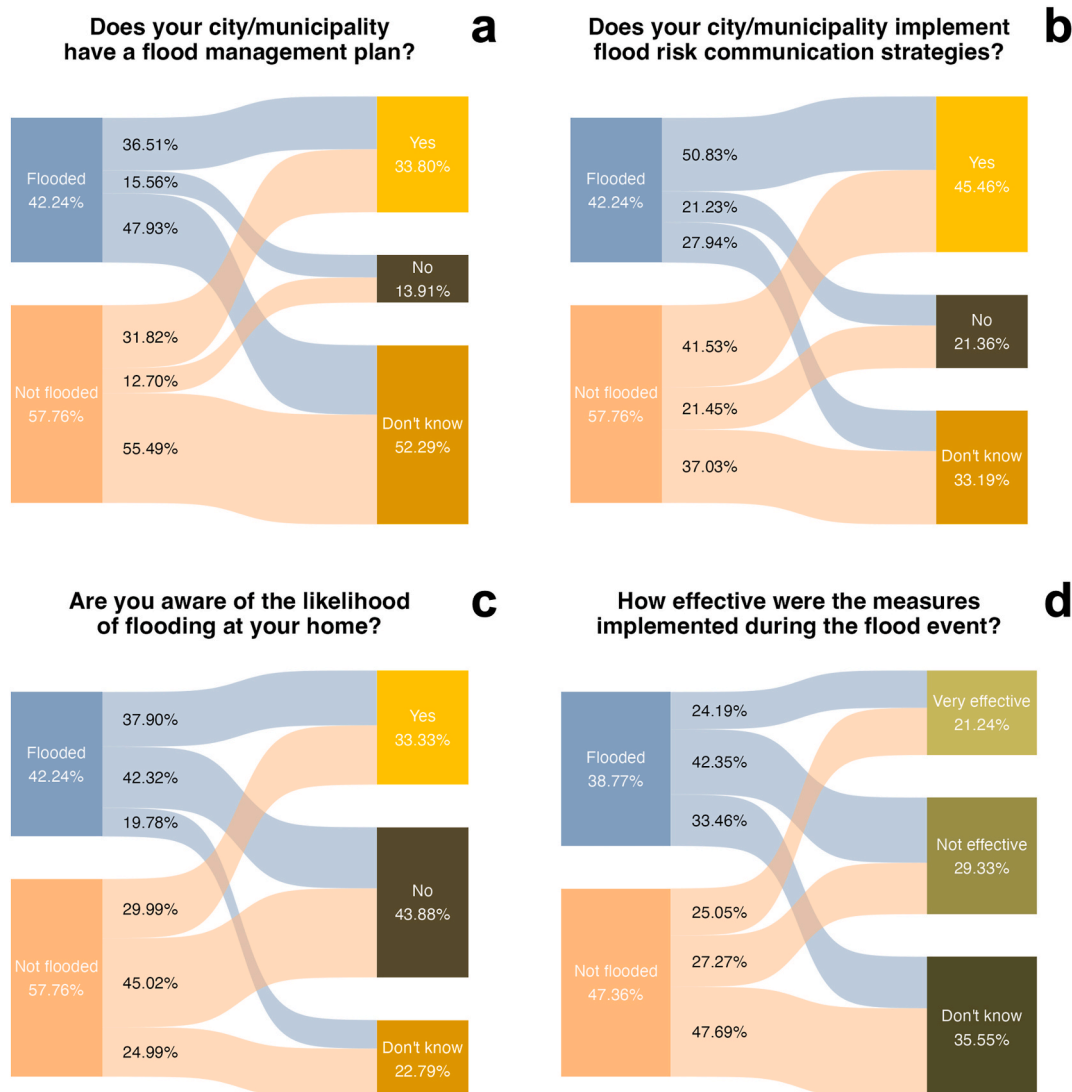
When asked whether they would have acted differently had they known the flood likelihood of their home (question 11 in Table 1), 62.78% of respondents answered affirmatively, with a similar proportion (63.76%) among those directly affected by 2023 floods. Also in this case gender, age, and income were the main predictors of responses relative to the likelihood of acting differently (i.e., saying

“yes”), while other factors, including education, occupation, homeownership, and municipality flood experience, had no significant effect (see Table S14).

The survey also included a question on whether respondents would have chosen to live elsewhere had they known the flood risk of their current home (question 12 in Table 1). Only 29.59% responded affirmatively, whereas nearly half (46.51%) reported that they would not have chosen to live elsewhere despite being aware of the flood risk. The remaining 23.90% selected “I don’t know”. Younger respondents, married individuals, and renters were more likely to report willingness to relocate or to express uncertainty, whereas participants living in flooded municipalities were less likely to express uncertainty and more likely to state that they would not move (Table S15).

### 3.4. Perceived effectiveness of flood response measures

With regard to the perception of flood response measures taken at the municipal level (question 13 in Table 1), only 33.80% and 26.76% of respondents reported knowing whether their municipality had flood management or evacuation plans, respectively; 13.91% and 18.43% answered “no”, and the remaining 52.29% and 54.81% indicated that they are unaware of the existence of these plans (Fig. S3). Despite this knowledge gap, nearly two-thirds (61.15%) believed that these plans would effectively improve preparedness



**Fig. 4.** Perception of flood response measures and awareness of flood risk. Respondents are grouped by whether they live in a flooded or non-flooded municipality. (a) Awareness of the existence of flood management plans at the city/municipality level. (b) Awareness of the implementation of flood risk communication strategies at the city/municipality level. (c) Awareness of the level of flooding risk to the respondents’ homes. (d) Perceived effectiveness of measures implemented during the 2023 floods.

and reduce flood risk, while 14.29% believed they would not.

Education, age, income, past flooding experience, gender, and employment status significantly influenced awareness and perceptions of flood risk management (Table S16–S20). Higher-educated respondents were more aware of flood management plans and evacuation plans than those with a middle school education or less, while women and those aged 45 years or older were more likely to be unsure rather than saying that there are no flood management measures compared to men and respondents aged 18–29, respectively. Greater uncertainty was found among older adults and respondents with unknown income. Interestingly, flood experience did not appear to influence awareness of municipal flood management plans: the proportion of residents in flooded municipalities who were aware of such plans was only marginally higher than that of residents in unaffected municipalities (Fig. 4a). By contrast, awareness of the implementation of flood risk communication strategies and awareness of the flood risk affecting their own home were higher among residents of flooded municipalities than among residents of non-flooded municipalities (Fig. 4b and c), highlighting that direct experience improved knowledge.

We then considered respondents living in flood-affected areas only and examined their satisfaction with the local response during the 2023 floods (question 14 in Table 1). Only 24.19% of respondents rated the measures as “very effective”, while 42.35% expressed dissatisfaction (Fig. 4d). In this case, past flood experience, age, and income were the main predictors of respondents’ evaluations (Table S21). Residents of flooded municipalities and individuals aged 45–59 were more likely to rate measures as “not effective” rather than “very effective”, whereas respondents with higher incomes (>€2,000) were more likely to consider them “effective”.

### 3.5. Information and communication strategies

We further explored whether and from which sources respondents received information related to weather warnings, flood severity, flood preparedness, or evacuation procedures before, during, or after the 2023 floods (questions 15 and 16 in Table 1). We found that 61.85% of respondents reported receiving some information, with a slightly higher share among residents of flooded municipalities (65.40%) compared to those in non-flooded municipalities (59.26%). Our results suggest that individuals with flood experience and those aged under 30 generally reported greater access to flood-related information, whereas respondents with middle-school education or below were less likely to receive such information compared to those with a bachelor's degree or higher (Table S22).

Prior to the floods, the most widely reported source was weather bulletins or forecasts (38.35%), followed by bulletins from official authorities such as the Regional Civil Protection Agency, municipalities, and local police (30.64%), and then television (25.97%). During the floods, television became the primary information source (37.49%). However, social media (35.20%), friends,

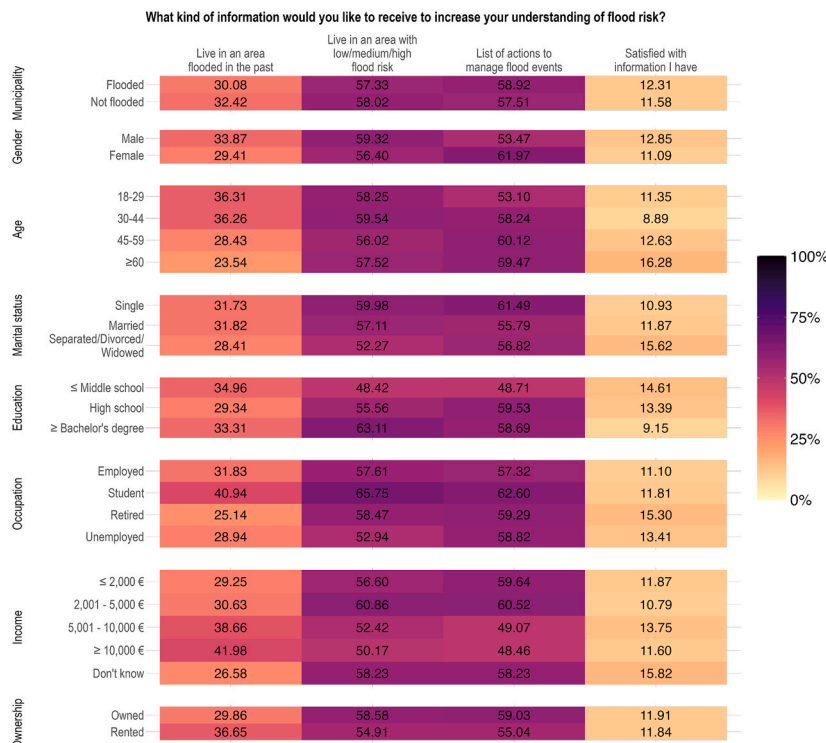


Fig. 5. Types of information on flood risk that participants would like to receive. The heatmap shows the percentage of participants within each socio-economic category and within groups of residents in flooded or non-flooded municipalities. Each participant could select multiple options; therefore, percentages do not sum to 100%.

acquaintances and family members (34.94%), official authorities (34.04%), radio (31.27%), and weather bulletins or forecasts (30.97%) were also widely used. After the floods, television remained a key channel (26.61%), along with newspapers (26.11%), social media (24.61%), friends, acquaintances, and family members (23.81%), official authorities (21.93%), and websites other than social media (21.92%). Despite this wide range of sources, more than half of the respondents reported they did not receive any information from community events or meetings (58.74%) or from schools (54.92%).

We also asked participants whether they were willing to improve their level of understanding of flood risk (question 17 in Table 1), and we examined whether this willingness varied across socio-economic groups and between respondents living in flooded and non-flooded municipalities (Fig. 5). More than half of respondents – especially those aged 30–44, holding at least a bachelor's degree, students, single respondents, and individuals with an income between €2,000 and €5,000 – expressed interest in knowing whether they live in a low/medium/high flood risk area. Similarly, interest in receiving a clear list of recommended actions to take during flood events was high across all socio-economic groups, with particularly strong interest among women, individuals aged 45–59, single respondents, high school graduates, students, and people with a household income below €5,000. Around one-third of each socio-economic category also expressed interest in knowing whether their area had previously experienced flooding, with the highest interest observed among students, individuals earning more than €10,000, and those living in rented housing. Finally, only about 9%–16% of respondents across all socio-economic groups reported being satisfied with the information they currently had, pointing to a clear need for more effective communication and information on flood risk at the community level.

### 3.6. Future risk perception and expectations

The survey also included questions aimed at investigating respondents' personal assessments of the likelihood that policy measures and interventions to address extreme weather events will be implemented over the next five years, either in their municipality (question 18 in Table 1) or at the Italian national level (questions 19 in Table 1). Across the overall sample, the average perceived probability was approximately 40%. Respondents from flooded municipalities reported higher expectations for action both at the municipal and national level (Tables S23 and S24). In contrast, individuals aged over 45 expressed lower expectations compared to the youngest group (<30). Other demographic and socio-economic factors did not show significant effects.

Finally, when asked about the likelihood of personally experiencing extreme weather events in the next five years (question 20 in Table 1), respondents reported an average perceived probability of 44.06% (first quartile = 21.00%, third quartile = 63.00%). Among residents of flooded municipalities, the range of responses was slightly broader, with the first quartile increasing to 25.00% and the third quartile to 67.75%, while the mean remained nearly unchanged at 46.41%. Respondents living in flooded municipalities and students perceived a higher personal risk than those in non-flooded municipalities and employed individuals, respectively, whereas those over 45 reported lower risk perception compared to the youngest group (Table S25). Other factors, including gender, marital status, income, and housing tenure, showed minimal or non-significant effects.

## 4. Discussion

A detailed assessment of flood risk perception and preparedness is pivotal for the effective implementation of flood risk management strategies. This study examines this issue by merging individual perceptions and behaviors with official flood hazard data to identify both discrepancies and alignments between perceived and actual risk following the 2023 events in the Emilia-Romagna and Tuscany regions in Italy.

Our results indicate that personal experience enhances awareness of frequent, lower-intensity flood hazards, but does not necessarily translate into accurate perceptions of rare, high-impact events, which remain substantially underestimated. This finding is consistent with established theories of risk perception, particularly the availability heuristic, whereby judgments about the likelihood of an event are influenced by how easily similar events can be recalled [68,69]. High- and medium-probability floods are typically more familiar to residents, either through personal experience or frequent media coverage, which makes them more cognitively accessible and leads to more accurate or slightly overestimated perceptions. Conversely, when communities have lived through long periods without major floods, memories of these past events become less salient or effectively “unavailable”, resulting in systematic underestimation of the extent of areas exposed to such extreme but infrequent hazards [70]. Empirical evidence from Germany [71] and Spain [72] likewise shows that flood experiences occurring long ago exert little influence on current levels of worry, risk awareness, or engagement in flood-mitigation behaviors. Such reduced perceived risk may, in turn, weaken motivation to undertake preparedness measures. In line with this pattern, our study finds that the adoption of structural modifications – measures that require greater effort and financial resources than soft actions – is more common among respondents who perceive a larger share of their municipality as flood-prone.

Beyond the influence of risk perception on preparedness behavior, our findings also show substantial variation across demographic and socio-economic groups. These differences highlight the ways in which people's motivations to protect themselves are shaped by their social and economic circumstances. Within the framework of Protection Motivation Theory, the decision to adopt protective behavior is driven by two sequential cognitive appraisal processes: threat appraisal and coping appraisal [73,74]. Socio-economic characteristics play a central role in shaping these appraisals, as they influence both beliefs about the usefulness of particular measures and the perceived capability to implement them. In the threat-appraisal stage, individuals evaluate the seriousness of the hazard, their own vulnerability, and any perceived benefits of inaction. In the coping-appraisal stage, they assess their confidence in being able to perform the recommended behavior (self-efficacy), their belief in its effectiveness (response efficacy), and the potential costs associated with taking action. Together, these evaluations shape overall motivation to undertake protective measures.

Socio-economic factors play a major role in shaping preparedness. Costly structural measures such as installing flood barriers, undertaking building retrofitting, or purchasing insurance are consistently more common among higher-income and home-owning households. This pattern is observed across both high-income settings, including Canada [75], Germany [76], and the Netherlands [77], and low-income contexts such as Bangladesh [78] and Myanmar [79]. Lower-income households may simply lack the financial resources needed for structural adjustments or insurance, while renters often have less incentive to invest in long-term protective measures for properties they do not own.

Age-related differences also emerge. Younger respondents (18–29 years) are consistently more likely than older groups to adopt both structural mitigation measures (e.g., flood barriers, building retrofitting, removal of hazardous trees) and undertake non-structural actions (e.g., relocating to lower-risk areas, contacting the municipality about risk issues). One possible explanation is that older individuals, particularly those aged 60 and above, may face physical or practical limitations that hinder the implementation of such measures. Evidence from the United States [80] and China [37] similarly confirms that older adults tend to undertake fewer preparedness actions, even when their perceived risk is relatively high.

Awareness of institutional measures is also limited: more than half of participants do not know whether evacuation or flood management plans exist in their municipality, and satisfaction with local response measures is mixed, especially among lower-income groups. In contrast to what might be expected, awareness of municipal plans is not substantially higher among residents with prior flood experience. These findings closely mirror those from Valente et al. [81], who describe fragmented databases, unclear evacuation protocols, and inconsistent guidance during the 2023 Emilia-Romagna floods. Sun et al. [82] reinforce this point by showing that perceived information impact is one of the strongest and most consistent predictors of risk awareness. Limited institutional trust also plays a critical role: higher trust in government can reduce perceived risk via heuristic processing, potentially undermining preparedness if communication lacks transparency [83].

Communication gaps exacerbate these challenges. Respondents rely mainly on traditional media, while schools, community organizations, and interactive channels are rarely employed. As a result, many residents remain underinformed despite a high willingness to adopt protective action, and only a minority feels sufficiently informed. Valente et al. [81] describe flood alert communication as “suboptimal”, highlighting limitations in mobile alert systems, fragmented messaging, and citizens’ reluctance to act on guidance due to mistrust and inconsistent information flows. Similarly, Henderson et al. [84] show that inadequate consultation and predominantly top-down communication approaches can polarize communities and underline resilience, particularly in rural contexts.

Looking ahead, respondents expressed moderate confidence in future policy action at both the municipal and national levels. Residents of flooded municipalities perceive a slightly higher likelihood of municipal interventions and greater personal exposure, while older adults reported lower concerns about personal risk. This persistent age-related gap in risk perception may hinder collective preparedness, especially in communities with ageing populations. Overall, these patterns align with broader evidence showing that trust and clarity in communication play a central role in shaping risk perception and preparedness [85,86].

## 5. Conclusions

This study provides a comprehensive assessment of flood risk perception, preparedness, and readiness across communities affected by the 2023 floods in Emilia-Romagna and Tuscany by uniquely combining an original survey with official flood hazard data. Our findings reveal substantial gaps between perceived and actual flood hazard, uneven preparedness across socio-economic groups, and limited awareness of institutional measures, all of which have implications for flood risk management and climate adaptation strategies. To enhance flood risk perception and preparedness and improve response to communication strategies, we recommend the following priority areas.

1. Strengthen public risk awareness, especially for rare but severe events, using clear flood maps, local hazard scenarios, and accessible tools such as interactive platforms and user-friendly visualizations [87–90];
2. Address socio-economic inequalities in preparedness capacity through financial incentives, technical assistance for household-level mitigation, targeted communication and support programs for vulnerable groups, such as older adults, renters, and low-income household [76,89];
3. Expand and diversify communication channels beyond traditional media, by incorporating schools, community and voluntary organizations, digital platforms, and neighborhood forums. Municipalities should promote community-based disaster risk reduction initiatives, including local preparedness committees and household-level training [87,91,92];
4. Improve visibility, accessibility, and usability of municipal flood plans, ensuring that residents are aware of their existence and understand how to access, interpret, and act on them. Regular community drills and participatory planning can help translate plans into actionable, context-specific knowledge [87];
5. Modernize early warning and alert systems with multi-channel (e.g., municipal apps, WhatsApp broadcasts, and localized sirens), clear, consistent, and localized alerts to reach the widest possible audience [89,91];
6. Promote participatory recovery and adaptation planning, involving residents (especially those recently affected by floods) in the co-design of municipal measures such as evacuation routes, nature-based solutions, and community preparedness actions. Such approaches strengthen trust, legitimacy, and collective ownership of risk management strategies [86,87,90,91];
7. Align local interventions with national and international frameworks, including the EU Floods Directive and Sendai Framework’s priorities on risk understanding, governance, and preparedness, to support coherent resilience strategies [93–95].

By linking individual perceptions, socio-economic disparities, and institutional communication gaps, this study highlights where policy efforts can be most effective in building trust, engagement, and community resilience to future extreme events in Italy.

### CRedit authorship contribution statement

**Irene Palazzoli:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation. **Chiara Puglisi:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Chiara Binelli:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Raya Muttarak:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Serena Ceola:** Writing – review & editing, Supervision, Methodology, Conceptualization.

### Declaration of competing interest

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

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### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ijdr.2025.105981>.

### Data availability

Data will be made available on request.

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