

# Multi-level assessment of flood risk perception and flood behaviour

## Responses to reviewers

### Response to Reviewer #1

Dear Reviewer,

We sincerely thank you for your thorough and constructive review of our manuscript. Your careful evaluation and the time you dedicated to providing detailed feedback are greatly appreciated. We are encouraged by your positive assessment of our work, particularly your recognition that our findings have the potential to improve the effectiveness of flood management strategies.

We have provided a detailed point-by-point response to all your comments alongside the revised text. We sincerely appreciate your guidance in helping us refine this study.

### Detailed responses

- 1) L26-29: The first paragraph can be made simpler by using plain language rather than technical terms. It would be helpful to elaborate the meaning of terms such as 'flood risk perception' and 'flood behavior' so that it is easier for readers to follow.

**Answer:** Thank you for the suggestion. The first paragraph was modified accordingly to: Floods are well recognized as one of the most damaging natural hazards worldwide, and the damage they cause is increasing (Adikari & Yoshitani, 2009; Blöschl, 2022). Absolute flood prevention or protection is unattainable and flood risk management is the only practicable way forward (Birkholz et al., 2014). However, risk is a complex concept that is usually quantified through technical evaluations, while risk perception can differ from risk quantifications as perception can be dominated by the hazardousness, or biased by factors such as misinformation, affecting the people behaviours previously, i.e. preparedness, during, i.e. reaction, and after a flood, including adaptations, and thus, resilience. Flood risk perception, adaptation and resilience of exposed communities has been recognized as crucial for flood risk management (Rufat et al., 2020).

- 2) L39-48: The previous paragraph mentions about risk and its three components: hazard, exposure and vulnerability. But it is not clear how flood risk perception is related to these three components. The paragraph introduces the concepts of awareness, worry and preparedness, but the authors should add a few lines on how these concepts can help in risk reduction.

**Answer:** Thank you, we modified the paragraph to include how flood risk perception is related to risk and its three components, hazard, exposure and vulnerability:

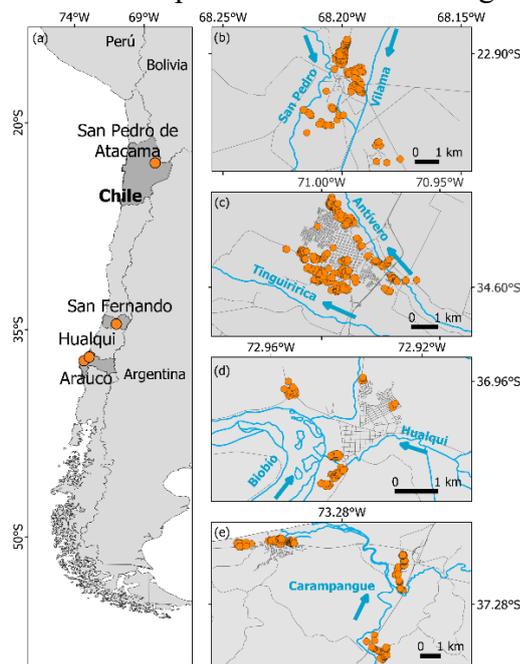
The flood risk is the product of hazard, vulnerability and value of the goods exposed (Kron, 2005). For a given discharge, the hazard is the product of the probability of occurrence by the hazardousness magnitude. The probability of occurrence of a given flood, is assumed to be the same as that of its peak discharge and is commonly determined through a frequency analysis. The corresponding hazardousness magnitude varies over the territory and is computed locally as the flow depth by the flow velocity (Martín-Vide, 2009; Díez-Herrero, Laín-Huerta, and Llorente-Isidro, 2009; Bodoque et al., 2016; Link et al., 2019). The vulnerability distinguishes between physical vulnerability, such as the vulnerability of buildings (e.g.: Mazzorana et al., 2014; Stephenson et al., 2014), vehicles (Xia et al., 2011) and people (Jonkman & Penning-Rowsell, 2008), and the social vulnerability, which is a much more complex concept, and is commonly evaluated in a simplified way through so called social vulnerability indices, SVIs (e.g., Kocks et al., 2015). The perception of such risk is shaped by the social, political, cultural, religious, and historical contexts (Lechowska, 2022), determining the attitude, i.e. the level of preparation

for a flood, and the possible behaviour of the residents when facing a flood (Bradford et al., 2012; Lechowska, 2018). Risk evaluation and risk perception can differ significantly from each other, challenging flood risk management.

Raaijmakers et al. (2008) identified three specific elements of flood risk perception, namely: awareness, worry and preparedness, and later Lechowska (2018) identified a so-called ‘clear relation’ between worry and awareness with flood risk perception, while relations between flood risk perception and preparedness was identified as an ‘unclear relation’, as well as the relation between worry and awareness with preparedness and between awareness and worry. Remarkably, Scolobig et al. (2012) showed that the link between awareness and preparedness is not at all straightforward, as in the Italian Alps, residents felt both slightly worried about flood risk and slightly prepared to face an event. There was also a clear discrepancy between the actual adoption of household cautionary measures and the willingness to take self-protection actions among the studied localities.

3) Please add the names of the four municipalities in Figure 1(a). VS

**Answer:** Thank you. The name of the municipalities was added to Figure 1(a):



**Figure 1.** Location of the study area: a) the four municipalities in Chile, and surveyed households in (b) San Pedro de Atacama, (c) San Fernando, (d) Hualqui, and (e) Arauco.

4) The two main aspects of flood risk analyzed in the study: worry and preparedness have not been defined explicitly. What was the question asked in the survey? Table 3 mentions that preparedness was calculated as a composite index. How was this index calculated?

**Answer:** Thank you for this comment. In the manuscript we included the definitions of worry and preparedness, as well as the survey questions. Additionally, the construction of the preparedness index is explained, as detailed below:

Worry refers to the *individual concern or emotional response associated with the perceived risk of flooding*, reflecting the subjective perception of flood risk (Raaijmakers et al., 2008; Lechowska, 2018). In the survey, worry was measured using the question: “On a scale from 1 to 3, where 1 means ‘Low’ and 3 means ‘High’, what do you think is the level of flood risk in your home?” and was analysed as an ordinal variable (1 = low, 2 = medium, 3 = high). Preparedness refers to *the adoption of precautionary measures against flooding and their continuity over time (whether they are permanent or non-permanent), as well as the perceived effectiveness of those measures*, and therefore reflects the extent to which households take actions to reduce potential flood impacts (Raaijmakers et al., 2008; Lechowska, 2018). Preparedness was analyzed through the survey questions: “What actions did you take during the last flood event?” and

“On a scale from 1 to 7, where 1 means ‘Not effective at all’ and 7 means ‘Very effective’, *how would you rate the effectiveness of the measures adopted during the last flood?*”. Based on the reported actions, a preparedness score was assigned to each household according to the combination of measures adopted. A maximum score of 1.0 was assigned when both permanent and non-permanent measures were implemented. When only permanent measures were adopted, the score was 2/3 ( $\approx 0.67$ ), while households that adopted only non-permanent measures received a score of 1/3 ( $\approx 0.33$ ). Households that did not adopt any measures received a score of 0. To incorporate the perceived effectiveness of the measures, a preparedness index was computed as:

$$PI = \frac{S_m * E}{7}$$

where PI is the preparedness index,  $S_m$  represents the score assigned according to the type of measures adopted, and  $E$  corresponds to the perceived effectiveness of the adopted measures reported by the respondent on a scale from 1 to 7. In this way, the resulting index was normalized on a scale from 0 to 1, where higher values indicate greater preparedness against flooding. Finally, the index was categorized into four ordinal levels to facilitate interpretation: Level 0 – No preparedness (Index = 0); Level 1 – Low preparedness (Index between 0 and 0.33); Level 2 – Medium preparedness (Index between 0.33 and 0.67); and Level 3 – High preparedness (Index between 0.67 and 1). These categories were used as the dependent variable in the ordinal regression analysis.

- 5) The definition of preparedness is particularly confusing. Table 3 defines preparedness as ‘Composite index based on actions taken during the last flood and the perceived effectiveness of those actions. So how should preparedness be interpreted? If a respondent says they have high preparedness, does it mean that they have actually taken action or it is their perception that they are well-prepared. It is possible that a respondent has not taken any action but still feels confident that they are prepared. Actual preparedness and perception of preparedness are two different things. Clarification on this aspect would be helpful.

**Answer:** Thank you for this comment, we apologize for this confusion. In this study the preparedness is measured through an index that considers: a) whether the household took actions during the last flood event, b) whether these measures were non-permanent or permanent, and c) the perceived effectiveness of those actions in the last flood event. Thus, it is not possible that a respondent has not taken any action but still feels confident that it is prepared. In the text, we included: Preparedness relates to Raaijmakers et al., 2008; Lechowska, 2018. Particularly, in this study, respondents are considered as prepared only if they undertook cautionary measures against floods.

- 6) It is not clear how the survey results are analyzed at higher levels. For example, how were household level surveys used for analysis at neighborhood levels? Were the responses simply averaged over households in a neighborhood? It is not clear how to interpret the results at the municipal level if averaging has been performed. The analysis at municipality level should refer to the response of administrators such as municipal commissioners as they are the actual decision makers at the municipal scale.

**Answer:** Thank you for this comment. The survey data includes variables that were considered at different hierarchical levels, depending on the nature of each question. Some variables correspond to the individual level, such as gender or respondent characteristics, since they refer to the person who answered the survey. Other variables correspond to the household level, such as housing quality or whether floodwaters passed outside the home, as these describe characteristics of the dwelling or household context.

For analyses conducted at the neighbourhood and municipality levels, household- and individual-level variables (e.g., worry and preparedness) were aggregated within each spatial unit, using average values. This aggregation does not represent institutional decision-makers, but rather the collective characteristics of households within each neighbourhood or municipality. In addition, some explanatory variables were already defined at higher levels and were included accordingly. For example, the Territorial Socio-Material Index (ISMT) is defined at the neighbourhood (block) level, while the Multidimensional Poverty Index (MPI), Income Poverty Rate (IPR), and Municipal Common Fund Dependency (MCFD) are defined at the municipal level using official statistics. These contextual variables were matched to households based on geographic location and included in the multilevel framework without further

aggregation. Therefore, the municipality-level results reflect aggregated household characteristics combined with contextual municipal indicators, rather than responses from municipal administrators. The objective was to analyse how household perceptions and preparedness vary across spatial contexts, not to evaluate institutional decision-making.

- 7) An important factor affecting worry for floods is perception about climate change, but I could not find any question related to climate change in the listed variables. The authors could possibly comment on the role it could have on the resident's worry about floods.

**Answer:** Thank you for this comment. You are absolutely right, indeed the survey included a question explicitly addressing climate change as a potential driver of flooding. Respondents were asked to rate the importance of "climate change increase precipitation and flooding events" on a scale from 1 (not important) to 5 (very important). 88% of respondents attributed high importance to climate change as a contributing factor to flooding. Because responses exhibited limited variability across respondents, this variable had low discriminatory power in explaining differences in individual flood worry and was therefore not included in the regression models. Nevertheless, the overall high attribution of flooding to climate change suggests that climate change forms part of the broader interpretative framework through which residents understand flood risk. This point has been clarified in the revised manuscript, after Table 3. In the survey, respondents were asked to rate, on a scale from 1 to 5, the importance of climate change increase precipitation and flooding events. 88% of respondents attributed high importance to climate change as a contributing factor to flooding. As this variable had low discriminatory power in explaining differences in individual flood risk perception and behavior, it was not included in the regression models. Nevertheless, the overall high attribution of flooding to climate change suggests that climate change forms part of the broader interpretative framework through which residents understand flood risk.

- 8) The analysis on preparedness shows that individuals from higher socioeconomic groups have higher preparedness but at the neighborhood level lower socioeconomic groups show higher preparedness. If neighborhoods of lower socioeconomic groups are more prepared, why is it not reflected at the individual level? In my understanding, individuals from higher socioeconomic groups could be perceiving more preparedness but lower socioeconomic groups may actually have taken actions. That is why it is important to clarify the meaning of preparedness in this study, as mentioned in comment 5.

**Answer:** Thank you for your comment. At the individual (household) level, higher socioeconomic status is positively associated with preparedness. This likely reflects greater access to financial and material resources, enabling households to implement more permanent and effective preparedness measures. At the neighbourhood level, areas characterised by lower socioeconomic conditions show higher preparedness. This pattern can be explained by greater exposure to flood risk and more frequent flood experience, which promote collective adaptation practices and increase the overall level of preparedness among residents. The difference between the individual level and neighbourhood level results reflects the multilevel structure of the analysis.

- 9) The discussion section can be strengthened by providing implications of the study for flood risk management. For example, which sections of the society should be targeted for more efficient flood risk management? Which type of strategies are more likely to be effective?

**Answer:** Thank you for this valuable suggestion. We strengthened the discussion section by providing some implications of the study for flood risk management, as follows:

Obtained results suggest that flood risk perception and flood behaviour should be analysed at the neighbourhood level. Consequently, flood risk communication and management should be adapted to focus on the needs of specific neighbourhoods exposed to floods. The more effective strategies are expected to vary among different neighbourhoods. For instance, neighbourhoods exhibiting the *status quo* effect should be better informed about flood risk and supported by local authorities for implementation of cautionary measures, while strategies for neighbourhoods exhibiting the levee effect, should elaborate on the persistence of the flood hazard.

## **Other comments**

- 10) L8 – Please change to “but quantitative research in this area remains challenging”.  
**Answer:** Thank you for your comment. The manuscript has been modified to address this point.
- 11) L13 – Please change to “lower economic resources at the municipal”.  
**Answer:** Thank you for your comment. The manuscript has been modified to address this point.
- 12) L17 and L51 – The meaning of “lower levels” is not clear at this stage of the manuscript.  
**Answer:** Thank you for this comment which helped us to clarify the concept in the text. In line 17, the text was modified to: Overall, worry and preparedness in the study area were intermediate, with an increasing dispersion from the municipality to the individual level. In Line 51 the text was modified to: Socio-hydrological systems are complex systems and thus, exhibit emergent properties due to the interactions between elements of the lower levels (Damper, 2000; Giorgiu, 2003; Reuter et al., 2005), e.g.: interactions between individuals produce emergent properties at the neighbourhood level, interactions between neighbourhoods produce emergent properties at the municipality level, etc.
- 13) Table 2 – Please change to “Age of respondent”.  
**Answer:** Thank you for your comment. The manuscript has been modified to address this point.
- 14) L303 – Please change “worry” to “worried”.  
**Answer:** Thank you for your comment. The manuscript has been modified to address this point.
- 15) Table 8 – Please change the title. The table does not show explanatory variables.  
**Answer:** Thank you for your comment. The manuscript has been modified to address this point.
- 16) L338 – Please change “declares” to “declared”.  
**Answer:** Thank you for your comment. The manuscript has been modified to address this point.
- 17) L477 – Please delete this line, it has been repeated.  
**Answer:** Thank you for your comment. The manuscript has been modified to address this point.
- 18) L485 – What is the meaning of the word “hydrologicalhydraulic”?  
**Answer:** Thank you for your comment. The manuscript has been modified to address this point.