

Multi-level assessment of flood risk perception and flood behaviour

Responses to reviewers

Dear Editor,

We thank you and the five reviewers for the constructive comments, and positive evaluation of our MS. In the following we provide a point by point response of each comment by each reviewer. In our opinion, the MS is now suitable for its publication in Natural Hazards and Earth System Sciences.

Sincerely yours,

The Authors

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):

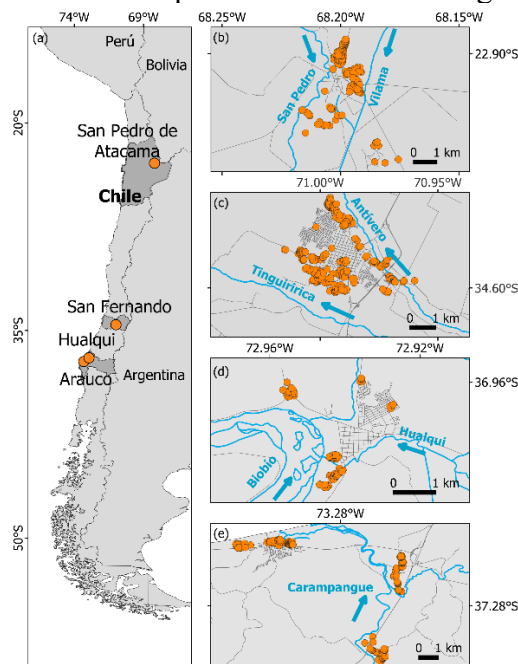


Figure 1. Location of the study area: a) the four municipalities in Chile, and surveyed households in (b) San Pedro de Atacama, (c) San Fernando, (d) Hualqui, and (e) Arauco.

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 (≈ 0.67), while households that adopted only non-permanent measures received a score of 1/3 (≈ 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.

Response to Reviewer #2

Dear Reviewer,

We sincerely thank you for your thoughtful review of our manuscript. Your expertise in statistical analysis is evident in the depth of your evaluation, and we greatly appreciate the time and effort you invested in providing a detailed feedback.

We prepared 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.

Sincerely,

The authors

Detailed responses

1) Make sure the connection between risk perception and preparedness at different levels is clearly explained. This helps readers understand how findings at one level relate to another.

Answer: Thank you for this observation, which allowed us to help readers understand how findings at one level relate to another. In the introduction, lines 41- 48, the text was modified to:

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. In particular, preparedness can occur with specific cautionary measures corresponding to the different levels (see Veloso et al. 2022), i.e. having personal protective equipment at the individual level, having a power circuit above flood depth at the household level, implementing sandbag barriers at the neighbourhood level, implementation of shelters at the municipality level. Remarkably, at each level, preparedness is not clearly related to risk perception. Indeed, Scolobig et al. (2012) showed that the link between awareness and preparedness is not at all straightforward, as e.g. 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 preparatory measures and the willingness to take self-protection actions among the studied localities.

2) Provide a brief explanation of the cluster analysis and PCoA methods in the methodology, so readers can follow these analyses without confusion.

Answer: Thank you for giving us the possibility to explain in more detail the PCoA methods. Therefore, Section 2.4.4 was expanded as follows:

2.4.4 Multilevel analysis: To explore similarities between neighbourhoods and municipalities based on the explanatory variables of worry and preparedness according to the multi-level regression, a principal coordinates analysis (PCO) was computed using Gower distance, which allows for the combination of ordinal and continuous data types. This method enabled the projection of multivariate dissimilarities into a reduced two-dimensional space while preserving the pairwise distances between observations as accurately as possible (Abdi and Williams, 2010). Subsequently, hierarchical clustering using Ward's method was conducted on the same distance matrix to identify groups of similar neighbourhoods and municipalities. For both spatial levels, the input data were aggregated by either neighbourhood or municipality, averaging the relevant variables obtained in the multilevel regressions. This was combined with biplots that held to visualise scores plots (data points) and a loading plot (variable vectors) to simultaneously analyse row-sample relationships and column-variables contribution (Gower, 1995).

Additional reference:

Gower, J. C., & Hand, D. J. (1995). *Biplots* (Vol. 54). CRC Press.

3) Correct grammar errors and spelling mistakes: For instance, "neighbourhood" (appears multiple times, it should be "neighbourhood"), "preapredness" (line 481, it should be "preparedness"), "hydrologicallyhydraulic" (line 484, it should be "hydrological and hydraulic"), "acknowledged" (line 625, it should be "acknowledged").

Answer: We apologize for these issues. The manuscript was corrected accordingly.

4) The chart numbers do not match the references. For instance, "Figure 9 illustrates the flood behavior" (line 418), but the previous text only mentions Figures 1-6, indicating a numbering error.

Answer: We apologize for these issues. The manuscript was corrected accordingly.

5) The article uses a multilevel ordinal regression model to fit the relationships between the probability that the person belongs to a category of worry and age range of the respondent, trust in the neighbourhood, etc. (Equation 5). And also uses a multilevel ordinal regression model to fit the relationships between

probability that the person belongs to a category of preparedness and the knowledge of flooding areas, the gender of the respondent, etc. (Equation 6). Has the author considered non-linear relationships? And the mutual influence among these factors, such as the socio-economic group and housing quality, etc.

Answer: Thank you for this important comment. Regarding non-linear relationships, most explanatory variables included in the multilevel ordinal regression models were specified as categorical or ordinal (e.g., age range, socioeconomic group, housing quality, trust levels). Therefore, the model does not assume a strictly linear relationship between these variables and the outcome, as each category is estimated separately. Concerning the mutual influence among variables, interaction terms were not included in the final models, as the multilevel structure already incorporates multiple variables across hierarchical levels, and adding interaction terms would substantially increase model complexity and reduce interpretability. Moreover, some variables used in the analysis (such as preparedness and ISMT) are composite indices that already integrate multiple dimensions. The primary objective of the study was to evaluate the independent contribution of variables at different levels rather than to model complex interaction effects.

6) The article employed linear methods such as Spearman coefficient analysis and Pearson's test to analyse the correlation between worry and preparedness. Did the author consider non-linear relationships?

Answer: Thank you for this comment. The relationship between worry and preparedness was analysed using contingency tables, Pearson's chi-square test of independence, and Spearman's rank correlation coefficient. These methods were selected due to the ordinal nature of the variables. Both worry and preparedness are ordinal measures, and therefore non-parametric approaches are more appropriate than linear correlation methods based on continuous assumptions. Spearman's rank correlation does not assume a linear relationship between variables, but rather evaluates monotonic associations between ordinal variables. Similarly, Pearson's chi-square test assesses statistical independence between categorical variables and does not rely on linearity assumptions. For these reasons, additional non-linear modelling approaches were not considered.

7) For the analysis of the relationship between flood risk perception and flood behaviour, the magnitude of the flood is a very important factor. Did the author consider the impact of different magnitudes of floods on the probability that the person belongs to a category of worry and the probability that the person belongs to a category of preparedness?

Answer: Thank you for this observation. We fully agree that the magnitude of the flood is a very important factor for the analysis of the relationship between flood risk perception and flood behaviour. As the available hydrological records (please see Figure 5) are insufficient for a formal frequency analysis of extreme discharges, the flood magnitude was classified between floods causing damages as reported in the news and media, and floods without reports of damages. Therefore, to estimate the recurrence of flood events in each municipality, a review of national and regional news reports was conducted for the period 2000–2025. This search aimed to identify significant flooding over the last 25 years and to calculate the frequency of occurrence of a damaging flood, i.e. a flood reported in the news. Additionally, the dates of the floods detected in the literature were verified with the available discharge measured at gauge stations in Figure 5.

Response to Reviewer #3

Dear Reviewer,

We appreciate your overall assessment of our manuscript, where you identify the main findings, and recognize its value for informed flood risk management. We sincerely thank you, for your detailed review and for raising up important concerns that helped us to improve the quality of the work.

Below, we provide point-by-point responses to each of your comments. Line numbers refer approximately to the original manuscript.

Sincerely,

The authors

Detailed answers

1) How would you define a “neighborhood”?

Answer: In this study, neighbourhoods were defined using an official Geographic Information System (GIS) layer of unidades vecinales (neighbourhood units) in Chile. These units constitute the geographical counterpart of juntas de vecinos (neighbourhood councils), which are the legally recognised base of local social organisation in the country. As such, neighbourhood units represent administratively recognised territorial subdivisions that also function as socially meaningful spaces for community organisation, participation, and local governance.

To integrate statistical information available at the census-block level (manzanas censales), neighbourhood boundaries were spatially adjusted through a GIS overlay procedure. Census blocks were aggregated according to the limits of the corresponding neighbourhood units, ensuring consistency between socio-demographic statistical data and territorially recognised neighbourhood areas.

This approach allows combining two complementary logics: the administrative–community definition embedded in neighbourhood units—particularly relevant for variables related to social cohesion, trust, and local interaction—and the statistical robustness provided by census-block data, which offer detailed socio-material information.

In the Chilean context—and more broadly in the urban studies literature—there is no single, universally accepted definition of “neighbourhood.” Rather, neighbourhoods are typically conceptualised as hybrid constructs that combine administrative delimitation and community-based recognition. The operationalisation adopted in this study follows this combined perspective, aligning territorial-administrative boundaries with socio-spatial meaning.

2) Lines 30-38: In the second paragraph of the Introduction Section, it would be better to briefly discuss the exposure factor in flood risk.

Answer: Thank you for this observation. We added a brief discussion on the exposure factor in flood risk as follows: 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 includes the exposure factor, which is usually well represented with the distance to the water (O’Neill et al., 2016), and 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 than physical vulnerability, and is commonly evaluated in a simplified way through so called social vulnerability indices, SVIs (e.g., Kocks et al., 2015).

Additional reference:

O’Neill, E., Brereton, F., Shahumyan, H., & Clinch, J. P. (2016). The impact of perceived flood exposure on flood-risk perception: The role of distance. *Risk Analysis*, 36(11), 2158-2186.

3) Line 40: Awareness is one of the three elements of flood risk perception. It seems that this study did not clearly distinguish “awareness” and “worry”.

Answer: Thank you for this observation. In this study, we distinguish between awareness and worry. However, awareness was not further investigated, because almost all of the interviewed people was aware of flood risk. Indeed, 57.9% of the surveyed people live closer than 750 m from the river, i.e. in areas with a high exposure to flood, 84.7% declare to know the flooding areas, and 55.4% experienced a flood passing outside the home. Overall, 96.2% of all respondents live closer than 750 m from the river, declare to know the flooding areas, and/or experienced a flood passing outside the home. Thus, in the present study people were assumed to be aware of flood risk.

4) Lines 44-45: Please rephrase the sentence "...as well as the relation between worry and awareness with preparedness and between awareness and worry", which is confusing.

Answer: Apologize for this confusing sentence. The text was rephrased as:

...later Lechowska (2018) identified a so-called 'clear relation' between worry and flood risk perception, and between awareness and flood risk perception. An 'unclear relation' was identified between awareness and worry, awareness and preparedness, worry and preparedness, and between preparedness and flood risk perception.

5) Lines 83-84: It is suggested to add a few references for the statement that the previous research mainly focused at the local scale.

Answer: Thank you for giving us the possibility to provide additional references to support that previous research mainly focused at the local scale. The paragraph was changed as follows: Spatial scale is crucial for understanding the relationship between risk and behaviour, as both worry and preparedness vary significantly across territories, while flood hazardousness is strongly conditioned by local factors (De Moel et al., 2015). Previous research has examined flood risk and behaviours mainly at the local scale, such as neighbourhoods (Al Assi et al., 2023) or municipalities (Becker et al., 2014; Santos et al., 2020).

Additional references:

Al Assi, A., Mostafiz, R. B., Friedland, C. J., Rahim, M. A., & Rohli, R. V. (2023). Flood risk assessment for residences at the neighborhood scale by owner/occupant type and first-floor height. *Frontiers in big Data*, 5, 997447.

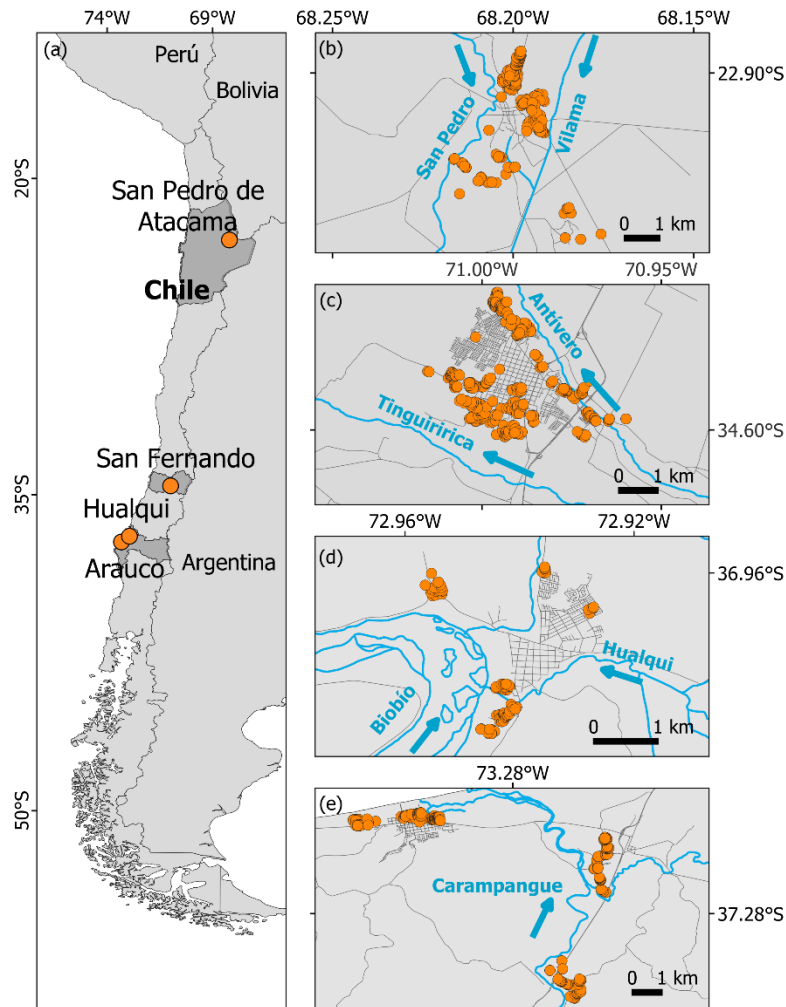
Becker, G., Aerts, J. C., & Huitema, D. (2014). Influence of flood risk perception and other factors on risk-reducing behaviour: a survey of municipalities along the Rhine. *Journal of Flood Risk Management*, 7(1), 16-30.

De Moel, H., Jongman, B., Kreibich, H., Merz, B., Penning-Rowsell, E., & Ward, P. J. (2015). Flood risk assessments at different spatial scales. *Mitigation and Adaptation Strategies for Global Change*, 20(6), 865-890.

Santos, P. P., Pereira, S., Zêzere, J. L., Tavares, A. O., Reis, E., Garcia, R. A., & Oliveira, S. C. (2020). A comprehensive approach to understanding flood risk drivers at the municipal level. *Journal of environmental management*, 260, 110127.

6) Figure 1: Please check the longitude and latitude labels, and it would be better to add municipality names in Figure 1(a). Also, it is suggested to add a scale bar to each map.

Answer: Thank you. Figure 1 was modified to address this point.



7) Lines 152, 164, 169, 173, 183, 185, and others: It is suggested to only use the acronyms after the full name appears for the first time in Lines 145-146.

Answer: Thank you, done!

8) Lines 170-172: It seems that the last sentence about the interpretation of MPI values is redundant.

Answer: Thank you for your comment. The manuscript has been modified to address this point.

9) Equations (2) and (3): What is the subscript “i”?

Answer: The subscript “i” refers to a specific household in the sample. It indicates that the poverty indicator and rate are computed for each household individually before aggregating to the overall poverty rate. This definition was included in the text.

10) Table 2: Why does the variable “socioeconomic group” belong to both the individual and the household levels? Why does the variable “territorial socio-material index” belong to the neighborhood level, while its SD belongs to the municipality level?

Answer: The variable “socioeconomic group” appears at both the individual and household levels because it captures conceptually distinct mechanisms operating at different scales. At the individual level, socioeconomic group reflects the respondent’s socio-educational and occupational position, which may influence cognitive dimensions of risk perception, access to information, and individual decision-making. At the household level, socioeconomic group represents the material and economic resources available to the household as a unit, which condition the capacity to implement preparedness measures.

Although both variables are based on the same national socioeconomic classification, their analytical role differs depending on the level of aggregation, justifying their inclusion at both levels within the multilevel framework.

Regarding the Territorial Socio-Material Index (ISMT), the average ISMT value was assigned at the neighbourhood level because it reflects the socio-material vulnerability of the immediate spatial context in which households are embedded. This contextual condition is directly linked to local social cohesion, housing quality patterns, and everyday exposure.

At the municipality level, instead of using the municipal average ISMT, we incorporated the standard deviation of the ISMT across neighbourhoods within each municipality. This indicator captures intra-municipal socio-material inequality, which reflects structural heterogeneity rather than average vulnerability. The distinction is analytically relevant: while neighbourhood ISMT represents local contextual vulnerability, the municipal ISMT standard deviation represents territorial inequality at a broader scale.

11) Table 3: Why are the ordinal values for worry 1-3, while 0-3 for preparedness?

Answer: The difference in the ordinal scales reflects the distinct nature and construction of the two variables. The variable worry is derived directly from a single survey question, measured on an ordinal scale from 1 to 3, representing increasing levels of perceived flood risk. As such, it does not include a zero category. In contrast, preparedness is a composite index based on reported actions taken during the last flood event and the perceived effectiveness of those actions. The scale for preparedness ranges from 0 to 3, where 0 represents the absence of preparedness actions, and higher values represent increasing levels of preparedness based on the type (non-permanent vs. permanent) and perceived effectiveness of the measures adopted. Therefore, the inclusion of a zero category in the preparedness scale allows the index to explicitly distinguish households that did not adopt any preparedness measures from those that reported some level of preparedness. This distinction is not applicable to the worry variable, which captures perceived risk. Further details on the construction and interpretation of the preparedness index are provided in the response to comment 4 by Reviewer#1.

12) It is suggested to combine Tables 2 and 3.

Answer: Thank you for the suggestion. Tables 2 and 3 have been combined into a single table:

Table 4. List of variables used in the univariate analysis

Level	Variable	Type	Description
Individual	Gender	Binary (1/0)	Gender of the respondent
	Occupation	Categorical (1–3)	Employment status categorized by current activity
	Residence 5 years ago	Categorical (1–3)	Place of residence five years prior
	Age respondent	Categorical (1–4)	Age range of the respondent
	Location of social ties	Ordinal (1–3)	Location of nearby social connections (e.g. within the neighbourhood, within the commune, etc.)
	Trust in neighbours	Ordinal (1–3)	Level of trust in neighbours
	Knowledge of flooding areas	Binary (0/1)	Knowledge of flood-prone areas within their locality
Household	Socioeconomic group	Ordinal (1–3)	Grouping based on education, occupation, household income and household size
	Housing quality	Ordinal (1–3)	Index based on type of dwelling and materials of walls, floor, and roof
	Socioeconomic group	Ordinal (1–3)	Grouping based on education, occupation, household income and household size
	Time living in the neighbourhood	Ordinal (1–3)	Number of years that the household has been residing in the current dwelling
	Number of age-dependent people	Binary (0/1)	Presence of at least three dependent people in the household, considering individuals under 15 and over 65 years old as “age-dependent people.”

	Flooding outside their home	Binary (0/1)	Whether floodwaters passed outside the respondent's home during the last flood event
	Hazard proximity	Ordinal (1–4)	Distance between the house and the river causing flooding in the area
	Worry	Ordinal (1–3)	Reflects the respondent's subjective perception of flood risk at their home
	Preparedness	Ordinal (0–3)	Composite index based on actions taken during the last flood and the perceived effectiveness of those actions
Neighbourhood	Neighbourhood interaction	Ordinal (1–3)	Frequency of interaction with neighbours
	High socioeconomic portion	Continuous 0-1	Proportion of households in the neighbourhood classified within high socioeconomic groups (A, B, C1a, C1b)
	Low socioeconomic portion	Continuous 0-1	Proportion of households in the neighbourhood classified in lowest socioeconomic group (E.)
	Perceived closeness to neighbourhood	Ordinal (1–3)	Respondents evaluate their sense of belonging and connection to their neighbourhood
	Territorial socio-material index	Continuous 0-1	Index capturing socio-material vulnerability based on census data
Municipality	Territorial socio-material index SD	Continuous 0-1	Standard deviation of the socio-material index across households within the municipality, reflecting the degree of internal inequality in socio-material conditions
	Satisfaction with the commune	Ordinal (1–3)	Degree of satisfaction with living in the commune
	Municipal Common Fund dependency	Continuous 0-1	Proportion of municipal revenue dependent on the Common Municipal Fund
	Multidimensional Poverty Index	Continuous 0-1	Index that assesses poverty considering household income, education, health and living conditions
	Income Poverty Rate	Continuous 0-1	Proportion of the population living below the income poverty line in each commune

13) Line 259: The Spearman's rank correlation is conventionally denoted as “ ρ ”.

Answer: Thank you for your comment. The Spearman's rank correlation is now denoted as “ ρ ” along the MS.

14) Tables 5 and 6: A lower absolute value of z-value is typically corresponding to a larger p-value. However, for example, the z-value and the p-value for “age respondent” are -0.975 and 0.009, respectively, which are not correct. Please double-check all the results in the tables.

Answer: Thank you for noting this inconsistency. We have checked the MS and corrected accordingly.

15) Equations (5) and (6): How to relate the probability of a level of worry or preparedness to the ordinal values?

Answer: Thank you for this comment. Equations (5) and (6) correspond to cumulative ordinal logistic regression models. In this framework, the ordinal values of worry and preparedness (e.g. 1, 2, 3) define ordered categories separated by threshold parameters. The model estimates the cumulative probability of an individual belonging to a given category or a lower category (i.e. $P(Y \leq k)$). The explanatory variables are related to the log-odds of these cumulative probabilities. From these cumulative estimates, the probability of belonging to each specific ordinal category is derived. In this way, the ordinal structure of the dependent variables is explicitly incorporated into the probability estimation.

16) Line 342: Maybe a typo here: “where” should be “were”.

Answer: Thank you, the word where was changed by “were”.

17) Table 7: It is suggested to highlight those p-values less than the significance level.

Answer: Thank you, done!

18) Lines 401-405: It is important to distinguish between flooding frequency and recurrence interval, as different flood magnitudes would lead to different consequences.

Answer: Thank you for this observation. Indeed, we fully agree with the importance in distinguishing between flooding frequency and recurrence interval, as different flood magnitudes would lead to different consequences. As the available hydrological records (please see Figure 5) are insufficient for a formal

frequency analysis of extreme discharges, the flood magnitude was classified between floods causing damages as reported in the news and media, and other not reported floods, presumably because they caused minor or no damages. Therefore, to estimate the recurrence of 'significant' flood events in each municipality, a review of national and regional news reports was conducted for the period 2000–2025. This search aimed to identify significant flooding over the last 25 years and to calculate the average frequency of occurrence of a damaging flood, i.e. a flood reported in the news. Additionally, the dates of the floods detected in the literature were verified with the available discharge measured at gauge stations in Figure 5. This idea was introduced in the section materials and methods, Lines 195-198: “In addition, to estimate the recurrence of flood events in each municipality, a review of national and regional news reports was conducted for the period 2000–2025, as the length of the available hydrological records is insufficient for a formal frequency analysis of extreme discharges. Assuming that floods reported in the news and media correspond to floods causing damages, the flood magnitude was classified between floods causing damages as reported in the news and media, and other not reported floods, presumably because they caused minor or no damages, and were thus, not reported in the news and media. This search aimed to identify significant flooding over the last 25 years and to calculate the frequency of occurrence of a damaging flood, i.e. a flood reported in the news. Additionally, the dates of the floods detected in the literature were verified with the available discharge measured at gauge stations”, and in section results, between lines 400 and 401: “The review of news reports between 2000 and 2025 revealed that San Pedro de Atacama experienced seven significant, i.e. damaging, flood events, in years 2001, 2012, 2013, 2015, 2017, 2019, and 2023, with an average frequency of 3.7 years; San Fernando experienced four major flood events in years 2000, 2006, 2015, and 2023, with an average frequency of 7.7 years; Hualqui experienced five floods in years 2001, 2003, 2006, 2023, and 2024, with an average frequency of 5.8 years, and Arauco experienced eight flood events in years 2001 (twice), 2003, 2006, 2008, 2019, 2023, and 2024, with an average frequency of 3.3 years.”

19) Lines 409-410: It is suggested to move the text to the caption of Figure 5. Also, in Figure 5, why were some peaks not circled, and why is the flow range of Vilama River so small?

Answer: Thank you for your comment. The caption of Figure 5 was moved to the text. Regarding the circled peaks, only those discharge peaks corresponding to flood events reported in the news were highlighted. Not all peaks were circled, as some high discharge events did not cause floods reported in the news, and at the same time, some floods reported in the news could have a different origin than the discharge of the Vilama river, i.e. a flood in the San Pedro river or a flood caused by rainstorm water rather than overbank of the rivers.

20) Line 476 is the same as Line 477.

Answer: Thank you. The manuscript has been modified to address this issue.

21) Line 517: What is the difference between “community and institution” and “neighborhood and municipality”?

Answer: In the manuscript, the terms “community” and “institution” are used conceptually to refer to social and structural dimensions of space. Empirically, however, these dimensions correspond to specific hierarchical levels in the multilevel model. In particular, “community” refers to the neighbourhood level, capturing local social interaction, cohesion, and shared socio-material conditions. The “institutional” dimension refers to the municipality level, which represents formal administrative structures and local government capacity.

Response to Reviewer #4

Dear Reviewer,

We sincerely thank you for your positive evaluation of our manuscript, especially recognizing the main findings and strengths of our work. We thank you very much for your detailed comments which helped us to improve the quality of the article.

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

Sincerely,

The authors

Minor comments:

1) While the introduction is generally well written, a clear and explicit hypothesis statement is missing. I recommend formulating and placing the hypothesis at the end of the introduction (after line 87).

Answer: Thank you for giving us the possibility to state a research hypothesis. After line 87 we included the hypothesis: Spatial scale is crucial for understanding the relationship between risk and behaviour, as both worry and preparedness vary significantly across territories, while flood hazardousness is strongly conditioned by local factors. Previous research has examined flood risk and behaviours mainly at the local scale, such as neighbourhoods or municipalities. This article goes further by incorporating individual and household characteristics, allowing us to capture the multilevel complexity of space and its consequences for flood risk perception and adaptive behaviours. The hypothesis of this work is: “Flood behaviour varies differently with flood risk perception elements across different levels”. To verify the hypothesis, the dimensions and variables that explain worry and preparedness at the different levels: individual, household, neighbourhood and municipality, and the relationships between worry and preparedness as well as the flood behaviour are analysed in four municipalities located along Chile, that represent different forms of urban agglomeration, ranging from small localities to intermediate cities within the national context.

2) Figure captions would benefit from being more descriptive. In particular, adding two to three sentences explaining what is shown in each figure and why it is relevant would improve clarity and interpretability (see detailed comments below).

Answer: Thank you. Figure captions were expanded to be more descriptive:

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 was changed to:

Figure 1. Location of the study area showing in a) the four municipalities under study in Chile, and the surveyed households marked with orange dots in (b) San Pedro de Atacama, (c) San Fernando, (d) Hualqui, and (e) Arauco together with the rivers causing floods in blue.

Figure 2. Principal coordinate analysis (PCO) of worry at (a) the municipal level and at (b) the neighbourhood level. Dendrogram showing clusters based on similarity for (c) the municipal level and (d) the neighbourhood level changed to:

Figure 2. Principal Coordinate Analysis (PCO) of worry based on the significant variables from the multilevel regression models, with biplot vectors showing the direction and relative influence of each variable (a) the municipal level and (b) the neighbourhood level.

Figure 3. Principal coordinate analysis (PCO) of preparedness at (a) the municipal level and at (b) the neighbourhood level. Dendrogram showing clusters based on similarity for (c) the municipal level and (d) the neighbourhood level changed to:

Figure 3. Principal Coordinate Analysis (PCO) of preparedness based on the significant variables from the multilevel regression models, with biplot vectors showing the direction and relative influence of each variable (a) the municipal level and (b) the neighbourhood level.

Figure 4. Heatmaps with the joint distribution of worry and preparedness for (a) the whole sample, (b) the municipality level, and (c) neighbourhood level changed to:

Figure 4. Heatmaps derived from contingency tables between worry and preparedness visualizing the cross frequency of the different preparedness (0 - 3) and worry (1 - 3) levels for (a) the whole study area, (b) the municipalities, and (c) the neighbourhoods. The cross frequency can vary from 0 to 100%. A darker colour corresponds to a higher cross-frequency.

Figure 5. Maximum instantaneous discharges recorded each month between years 2000 and 2025 measured at gauge stations San Pedro@San Pedro de Atacama, Vilama@San Pedro de Atacama, Tinguiririca@San Fernando, Biobío@Hualqui, Hualqui@Hualqui, and Carampangue@Arauco changed to:

Figure 5. Maximum instantaneous discharge recorded each month between years 2000 and 2025 measured at gauge stations San Pedro@San Pedro de Atacama, Vilama@San Pedro de Atacama, Tinguiririca@San Fernando, Biobío@Hualqui, Hualqui@Hualqui, and Carampangue@Arauco. Red circles highlight events reported in the news and social media as damaging floods.

Figure 6. Flood behaviour according to flood recurrence and preparedness, adapted from Leong (2018). Q1: forgetting effect; Q2: proactive effect; Q3: status quo effect; Q4: learning effect changed to:

Figure 6. Flood behaviour according to flood recurrence and preparedness level, adapted from Leong (2018). The flood behaviours are Q1: forgetting effect; Q2: proactive effect; Q3: status quo effect and; Q4: learning effect. Big dots correspond to municipalities. Small dots correspond to neighbourhoods. Purple dot represent the study area, red is for Arauco, blue is for San Pedro de Atacama, black is for Hualqui and grey is for San Fernando.

3) In Section 2.2 (Survey), it would be helpful to explain the rationale behind the distribution of the survey sample across households and to clarify why the selected sample size is considered representative.

Answer: The sample distribution across municipalities was proportional to the number of households located in flood-prone areas within each municipality, ensuring adequate territorial representation. Households were selected following a spatially distributed fieldwork strategy within predefined flood-exposed zones.

The total sample size ($n = 1,015$; valid responses = 1,007) was calculated assuming a 95% confidence level and a maximum margin of error of 5%, using a conservative population proportion ($p = 0.5$) to maximize variance. Given the size of the adult population in each municipality, the achieved sample allows statistically robust estimations at the municipal level and supports multilevel modelling across individual, household, neighbourhood, and municipality scales.

4) The clustering shown in Figure 2 is informative; however, similar groupings already appear evident in the PCO plots, making the dendrograms somewhat repetitive. One potential improvement would be to include biplots (vectors indicating the direction and relative influence of the variables) within the PCO plots, which would help visualize the ordination and the “pull” of individual variables - then of course discussing those further in the discussion. The same suggestion applies to Figure 3.

Answer: Thank you for your comment. We agree that the dendrograms provided information that was largely redundant with the PCO plots. Biplots help to improve and visualize the influence of the significant variables. The figures (Fig 2 and Fig 3) have been updated according to your suggestion. The results and discussion are shown below.

Figure 2 presents the Principal Coordinate Analysis (PCO) performed using the variables that are significant in the multilevel regression for worry at municipalities and neighbourhoods. The biplots include vectors indicating the direction and relative contribution of the significant variables.

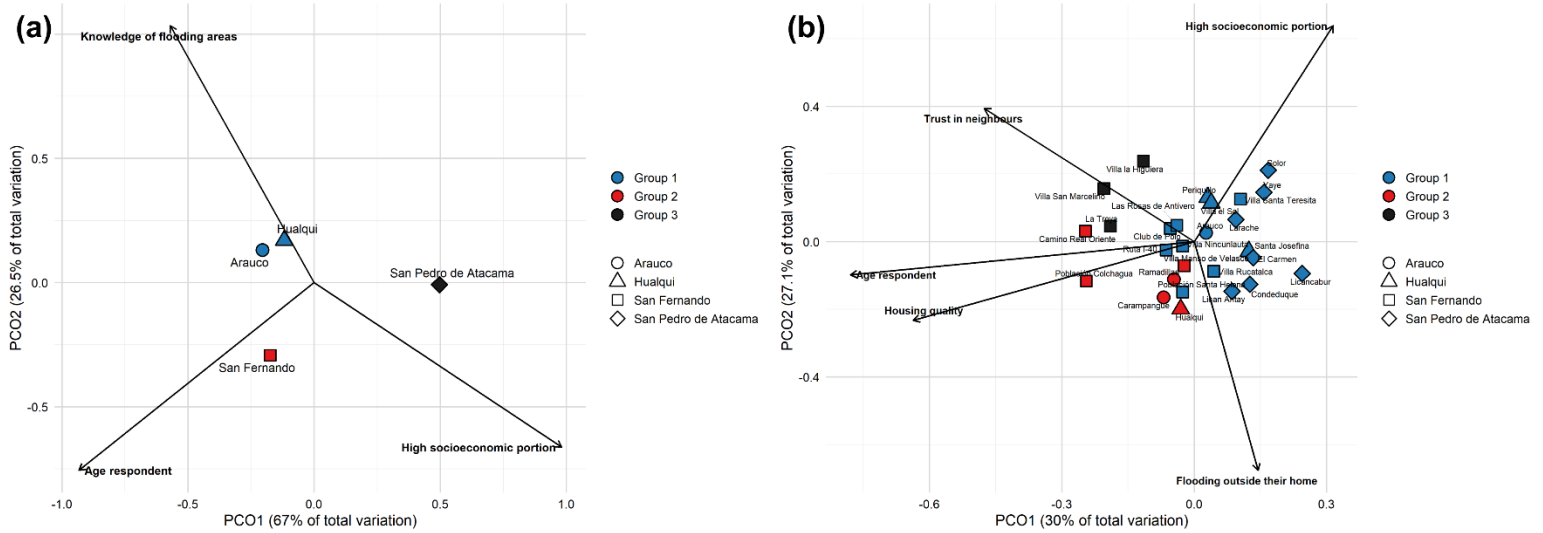


Figure 2. Principal Coordinate Analysis (PCO) of worry based on the significant variables from the multilevel regression models, with biplot vectors showing the direction and relative influence of each variable for (a) the municipal level and (b) the neighbourhood level.

At the municipal level both axes capture 67.0% and 26.5% of the total variation of worry, explaining 93.5% of the variability in the data. The biplot shows that three variables capture worry, namely age respondent, knowledge of flooding areas, and high socioeconomic proportion. Figure 2a shows that the municipalities are grouped into 3 groups. Hualqui and Arauco group together, showing similar characteristics of worry. Both municipalities are aligned with the vectors for age respondent and knowledge of flooding areas, indicating that worry in these municipalities is mainly associated with older respondents and greater awareness of flood-prone zones. San Fernando forms a separate group, although it is not completely distant from Hualqui and Arauco, as it also shares the influence of age respondent. However, it is less associated with knowledge of flooding areas, and by the contrary it is associated with socioeconomic factors. San Pedro de Atacama appears clearly separated from the other municipalities and is primarily associated with high socioeconomic proportion, indicating that worry in this municipality is linked to socioeconomic characteristics.

At the neighbourhood level (Fig 2b), the PCO shows that both axes capture 30.0% and 27.1% of the total variation of worry, explaining 57.1% of the variability in the data. The biplot shows that five variables capture worry: Age of respondent, trust in neighbours, housing quality, flooding outside their home, and high socioeconomic portion. Three different groups are formed. Group 1 is made up of neighborhoods from all municipalities, showing that neighborhoods from different municipalities can share similar worry-related characteristics. One part of the group is associated with high socioeconomic portion. The other part of the group is mostly associated with the variable flooding outside their home, indicating that worry in these neighborhoods is associated with direct experience with floods. Group 2 comprises neighborhoods in San Fernando, Hualqui, and Arauco. Worry in these neighborhoods is related to flooding outside their homes, meaning they have experienced flooding; housing quality; and the age of the residents. Group 3 consists of neighborhoods located only in San Fernando. In this group, worry is mainly associated with trust in neighbours and age of respondent. There is also an association with high socioeconomic portion, suggesting that socioeconomic characteristics play a secondary role in terms of the worry for this group.

Neighbourhoods located near the centre of the plot are not strongly related to any specific variable. This central position indicates that worry is related to a combination of factors, without one dominant variable structuring their pattern.

Figure 3 presents the Principal Coordinate Analysis (PCO) performed using the variables that are significant in the multilevel regression for preparedness at municipalities and neighbourhoods. The biplots include vectors indicating the direction and relative contribution of the significant variables.

preparedness is not straight forward, however in Fig. 6 three out of four possible flood behaviours proposed by Leong (2018) were identified in the study area as a function of preparedness and flood recurrency, namely the *status quo*, the learning, and the proactive effects. Dispersion in the observed behavior increased when reducing the level. The variables controlling preparedness and flood behaviour in critical places were related to the knowledge of flooding areas and the economic resources available for implementation of measures to prevent flood damages. This information suggests that the neighbourhood is the appropriate spatial scale at which preparedness should be promoted in the frame of risk management. Similarly, risk communication should focus on the neighbourhood level to inform residents the precise flood prone areas, especially in neighbourhoods exhibiting a *status quo* effect such as those pertaining to San Pedro de Atacama. Aim should provide households with the necessary financial resources for improvement of the cautionary measures, especially in neighbourhoods with low preparedness, such as those in San Pedro de Atacama, Arauco and Hualqui.

Other comments:

6) Line 38: add more references

Answer: Thank you for this comment. Social vulnerability indices have been extensively used and developed for accounting risk in the natural hazards context. We added key references on SoVIs:

Cutter, S.L., Carolina, S., Boruff, B.J., Shirley, W.L., 2003. Social Vulnerability to Environmental Hazards. Soc. Sci. Quart. 84 (2) 242–261.

Cutter, S.L., Emrich, C.T., Morath, D.P., Dunning, C.M., 2013. Integrating social vulnerability into federal flood risk management planning. J. Flood Risk Manag. 6, 332–344

7) Line 48: emphasize here the importance of social vulnerability.

Answer: Thank you. The text was extended after line 48 to: “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 preparatory measures and the willingness to take self-protection actions among the studied localities, emphasizing the importance of social vulnerability on flood risk perception.”

8) Line 52: three different methods - briefly explain

Answer: Thank you for giving us the opportunity to explain each of the three methods that have been used for the analysis of the long-term interactions between the human and social systems. The text was changed to: Such interactions have been studied through three different methods (di Baldassarre et al., 2015): one of the most common methods in the social sciences is based on statistical analysis of empirical research data, such as surveys and interviews combining the strengths of qualitative and quantitative data. This method relies on extensive and robust empirical data, which can be expensive and time consuming to collect. A second method is agent-based modeling which operate by prescribing rules on how individuals and/or institutions (the agents) interact, and therefore allow heterogeneity to be included. They compute the interactions at the microlevel which leads to observed behavior at higher levels. The disadvantage of these models is that they can become extremely complex, results might be difficult to interpret, and they are often not generalizable. In a third method, a number of hypotheses about the fundamental processes and interactions driving the behavior of the system are explicitly formalized using a set of differential equations. This type of modeling has proved to be useful where empirical data are limited. Moreover, differential equations for dynamic modeling have been recognized as being appropriate for understanding complex systems and it has been widely used in neoclassic economic models.

9) Line 54-55: briefly explain levee and adaptation effect

Answer: Thank you for giving us the opportunity to explain the learning and the forgetting effects. The text was expanded as follow: In particular, the socio-hydrology of floods recognized already different flood

behaviour types that emerge from the interactions between the social and the hydrological system during floods, such as the so-called “forgetting or levee effect” and the “learning or adaptation effects”. The forgetting effect relates to the observation that the rare occurrence of flooding (possibly caused by protection measures, such as levees) is often associated with increasing vulnerability. In the learning effect, the frequent occurrence of flooding is often associated with decreasing vulnerability. It can be attributed to enhanced coping or adaptation capacities gained by individuals and communities during their flood experience. (di Baldassarre 2017).

10) Line 93-95: combine these sentences and consider rephrasing it

Answer: Thank you. Please see also the Ans. to your comment 1). Line 93-95 were modified according to your suggestion:

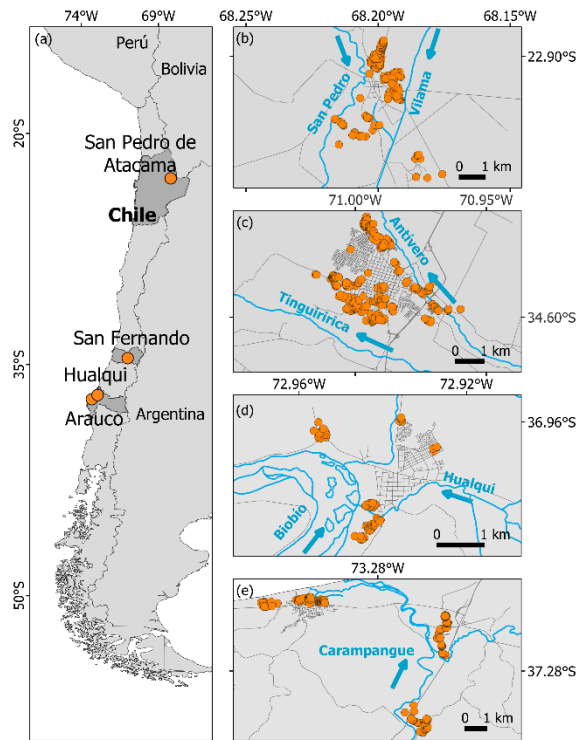
Spatial scale is crucial for understanding the relationship between risk and behaviour, as both worry and preparedness vary significantly across territories, while flood hazardousness is strongly conditioned by local factors. Previous research has examined flood risk and behaviours mainly at the local scale, such as neighbourhoods or municipalities. This article goes further by incorporating individual and household characteristics, allowing us to capture the multilevel complexity of space and its consequences for flood risk perception and adaptive behaviours. The hypothesis of this work is: “Flood behaviour varies differently with flood risk perception elements across different levels”. To verify the hypothesis, the dimensions and variables that explain worry and preparedness at the different levels: individual, household, neighbourhood and municipality, and the relationships between worry and preparedness as well as the flood behaviour are analyzed in four municipalities located along Chile, that represent different forms of urban agglomeration, ranging from small localities to intermediate cities within the national context. The next section describes the study area, and statistical analysis. Section 3 presents the obtained results on variables explaining worry and preparedness, their correlations and distribution among the neighbourhoods and municipalities.

11) Line 95-96: the word “discussed” is used twice

Answer: Thank you. The text was corrected accordingly.

12) Figure 1: explain the rationale in 2 sentences about the selected households. Also, can you mark flow directions on maps b-e?

Answer: Thank you for your comment. The explanation of the selection of household was added in the Section 2.2. of the manuscript: Across the study areas, zones for survey application were pre-selected based on their flood exposure within the four municipalities. The household was defined as the unit of analysis. Surveyors selected households where an adult resident agreed to participate, typically following a non-consecutive pattern of household. Additionally, flow directions were added in the Figure 1 (b) (c) (d) (e):



13) Line 113: ...which reduces temperature extremes.... - need reference

Answer: The description of the specific climate classes was taken from Sarricolea et al. (2017). The reference was included in the text after Line 113.

14) Line 115: National Weather Agency -put a link of your source

Answer: Thank you, done!

15) Line 115-120: round all precipitation numbers

Answer: Thank you, done!

16) Line 124: Census Data - need reference

Answer: Thank you. The reference is: Chilean National Institute of Statistics (INE). Population and Housing Census 2002, 2017 and 2024. Instituto Nacional de Estadísticas, Chile.

17) Line 150: GIS - what version?

Answer: Thank you. The GIS version is QGIS v3.40.0

18) Line 167: what weights?

Answer: The weights refer to the official indicator weights defined in the construction of the Multidimensional Poverty Index (MPI) used in the CASEN survey, following the Alkire and Foster (2007) methodology. These weights are predefined by the CASEN methodology and are not estimated or modified in this study.

19) Line 200: The survey answers what?

Answer: Thank you for your comment. The survey answers related to flood risk perception, preparedness, worry, and sociodemographic characteristics, together with complementary data. The sentence has been revised and clarify in the manuscript.

20) Line 267-269: it is a bit hard to follow what percentage belongs to what. Consider rephrasing it.

Answer: Thank you. We fully agree with this comment. The sentence was reformulated to: Interestingly, 57.9% of the surveyed people live closer than 750 m from the river, i.e. in areas with a high exposure to flood, 84.7% declare to know the flooding areas, and 55.4% experienced a flood passing outside the home. Overall, 96.2% of all respondents live closer than 750 m from the river, declare to know the flooding areas, and/or

experienced a flood passing outside the home. Thus, in the present study people were assumed to be aware of flood risk.

21) Line 398: "...who are not worried." - Do you have an explanation why?

Answer: Thank you for this comment. One possible explanation is that preparedness does not necessarily imply high levels of worry. Even if flood events are not highly recurrent in this neighbourhood, previous experience with flooding may have led residents to adopt certain preparedness measures, which can increase their sense of capacity to manage future events. As a result, respondents may report medium levels of preparedness while not expressing high worry, consistently with the findings by Scolobig et al. (2012).

22) Line 401-405: show flood frequency in flood/yr and not average.

Answer: Thank you for the observations. Flood occurrence has been revised as suggested. Table 8 now presents flood frequency (floods per year) and the corresponding mean recurrence interval for each municipality.

23) Line 419: Table 8 caption: These are preparedness level values not expl variables. Correct table title and give explanation and meaning in 2 sentences.

Answer: Thank you. Table 8 presents the average predicted level of preparedness for each municipality, as estimated by the multi-level ordinal regression model. The outcome variable is measured on an ordinal scale from 0 (non-preparedness) to 3 (high preparedness). The Table was corrected accordingly.

24) Line 423: "...we assumed a threshold of 7 years..." - based on what?

Answer: Thank you for giving us the possibility to justify this assumption. The 7-years threshold comes from antecedents summarized by Lechowska (2018): According to The International Commission for the Protection of the Rhine (ICPR), flood risk perception usually decreases 7 years after flooding while catastrophic disasters are remembered much longer (Egli & Wehner, 2002). The literature also suggests that the positive influence of experiences on private mitigating behaviours may disappear several years after the flood. Hence, the time of the previous flood (time of the experience) plays a major role, since it can be expected that the experience of the flood that occurred a long time ago has little influence on current risk perception and mitigating behaviours. Long floodless periods result in a decrease in the level of worry and awareness." Further, Barendrecht et al. (2019) based on Egli & Wehner (2002) and Bornschein & Pohl, 2014) adopted 7 to 10 years as the time after which awareness is halved, and related it to a so-called forgetfulness.

References added to the text:

Bornschein, A., & Pohl, R. (2014). Hochwasserbewusstsein 10 Jahre nach dem "Jahrhundertereignis" im Osterzgebirge und an der Elbe. In *Vorsorgender und nachsorgender Hochwasserschutz* (pp. 19–29). Wiesbaden: Springer Vieweg.

Barendrecht M. H. Viglione A. Kreibich H. Merz B. Vorogushyn S. Blöschl G. 2019 The value of empirical data for estimating the parameters of a socio-hydrological flood risk model. *Water Resources Research* 55, 1312–1336. <https://doi.org/10.1029/2018WR024128>.

Egli, T., & Wehner, K. (2002). *Non structural flood plain management: measures and their effectiveness*. International Commission for the Protection of the Rhine (ICPR), Koblenz.

25) Line 508: "exhibited" used twice in the same sentence.

Answer: Thank you. The sentence was changed to: Municipalities exhibited different flood behaviours, and flood behaviours at some neighbourhoods were different to those of the corresponding municipalities, evidencing important differences across the analysed levels, according to several urban scales.

Response to Reviewer #5

Dear Reviewer,

We thank you for your dedicated comments and observations that helped us to enhance the quality of our MS. Below, we provide point-by-point responses to each of your comments. Line numbers refer approximately to the original manuscript. Some of your comments overlap with those from the other reviewers; where applicable, we intended to satisfy concerns raised by all reviewers to ensure a cohesive and integrated final manuscript.

Sincerely,

The authors

Detailed comments

1. Line 90: I miss the main objectives of the paper.

Answer: This observation is related to observation 5) by Reviewer#3, and to observation 1) by Reviewer#4. The text was modified to support statements with additional references, and to include both, a hypothesis and the main objectives of the paper as follows:

Spatial scale is crucial for understanding the relationship between risk and behaviour, as both worry and preparedness vary significantly across territories, while flood hazardousness is strongly conditioned by local factors (De Moel et al., 2015). Previous research has examined flood risk and behaviours mainly at the local scale, such as neighbourhoods (Al Assi et al., 2023) or municipalities (Becker et al., 2014; Santos et al., 2020). This article goes further by incorporating individual and household characteristics, allowing us to capture the multilevel complexity of space and its consequences for flood risk perception and adaptive behaviours. The hypothesis of this work is: “Flood behaviour varies differently with flood risk perception elements across different levels”. To verify the hypothesis, the dimensions and variables that explain worry and preparedness at the different levels: individual, household, neighbourhood and municipality, and the relationships between worry and preparedness, as well as the flood behaviour, are analysed in four municipalities located along Chile, that represent different forms of urban agglomeration, ranging from small localities to intermediate cities within the national context. Thus, the main objectives of the study are: (1) to determine what are the variables explaining the elements of flood risk perception: worry and preparedness, (2) to explore the possible correlations between worry and preparedness at the different levels, and (3) to investigate what are the different flood behaviours that emerge from the interaction between the social and hydrological systems along the studied localities.

2. Line 102: Specify when exactly in the particular municipalities.

Answer: Thank you for your comment. The sentence has been revised to specify the years in which each municipality experienced flooding. Additional details are provided in Section 3.4 (Flood behaviour) and summarised in Table 8. The paragraph has been modified as follows: The study area corresponds to four Chilean municipalities that experienced flood events between 2000 and 2025: San Pedro de Atacama (2001, 2012, 2013, 2015, 2017, 2019, 2023), San Fernando (2000, 2006, 2015, 2023), Hualqui (2001, 2003, 2006, 2023, 2024), and Arauco (2001 [twice], 2003, 2006, 2008, 2019, 2023, 2024).

3. Line 115: Organize this data into a table.

Answer: Thank you for your comment. The data is now organized in a table and presented in the manuscript as follows:

Table 1. Average annual precipitation, flood-prone rivers, watershed areas, and average annual discharge by municipality.

Municipality	Average annual precipitation (range) (mm)	Rivers prone to flooding	Watershed area (km ²)	Average annual flow (m ³ /s)
San Pedro de Atacama	42 (12 – 112)	San Pedro	933	0.8
		Vilama	379	0.2
San Fernando	670 (147– 1,230)	Antivero	443	7.6
		Tinguiririca	4,730	50.2
Hualqui	1,019 (269 – 1,664)	Biobío	24,264	955.0
		Hualqui	65	0.5
Arauco	1,143 (704 – 1,643)	Carampangue	1,262	61.5

4. Line 124: Organize this data into a table and standardize it for 2024.

Answer: Thank you for your comment. The data organized and standardized is presented in the manuscript as follows:

Table 2. Population, grow rate and housing units by municipality.

Municipality	Population (2002)	Population (2017)	Population (2024)	Total population growth (%)	Housing Units (2017)	Housing Units (2024)
San Pedro de Atacama	1,938	10,996	9,843	408%	4,144	5,071
San Fernando	63,732	73,973	75,585	19%	24,695	31,420
Hualqui	18,768	24,333	26,746	43%	7,754	10,881
Arauco	34,873	36,257	38,941	12%	11,663	13,185

5. Line 134: The characteristics of respondents and the method of their selection. Are these respondents whose homes were flooded? What is their experience and relevance to the floods? How was the data collected? At what level? What specific data was obtained? Was its reliability verified in any way?

Answer: Thank you for your comment. Section 2.2 has been revised and modified to:

The survey consisted of both open- and closed-ended questions and was structured around nine thematic dimensions: respondent characteristics, household characteristics, housing characteristics, location of the social network, experience during the most recent flood event, perception and knowledge of flood risk, collaboration networks, flood preparedness, and head-of-household characteristics.

Across the study areas, zones for survey application were pre-selected based on their flood exposure within the four municipalities. The household was defined as the unit of analysis. Surveyors selected households where an adult resident agreed to participate, typically following a non-consecutive pattern of household.

The questionnaire was administered in 2024 using Pen and Paper Personal Interviews (PAPI). A total of 1,015 surveys, each comprising 80 questions, were conducted. After data cleaning and validation, 1,007 responses were retained for analysis. The final sample distribution was as follows: 252 households in San Pedro de Atacama, 380 in San Fernando, 100 in Hualqui, and 275 in Arauco. Considering the population size and the homogeneity of residents aged 18 and over in each municipality, the sample design ensured a 95% confidence level with a maximum margin of error of 5%.

6. Line 150: How were respondents selected according to this factor? Were they divided into uniform clusters for all municipalities?

Answer: Thank you for this observation. We have clarified the household selection process in Section 2.2. The distance from each household to the nearest overflowing river was used for further statistical analysis. In addition, respondents were not divided into uniform clusters.

7. Line 155: Why are you using some census data from 2024 earlier?

Answer: The population figures reported for 2024 correspond to the most recent official projections available from the National Institute of Statistics (INE), and are used only for descriptive purposes to characterize the current demographic context of the municipalities.

In contrast, structural socio-material variables such as the Territorial Socio-Material Index (ISMT) were computed using the 2017 Census, which is the most recent full census dataset available at the block level. These indicators capture relatively stable structural conditions (housing quality, overcrowding, education level of the head of household, etc.), which are not expected to change substantially in the short term.

The combination of updated demographic projections with census-based structural indicators ensures both temporal relevance and methodological consistency.

8. Line 267: What is interesting on this? It strongly depends on the respondents selection of the authors. This is not a result, this is a characterization of respondents and their selection.

Answer: Thank you for this observation. We agree, therefore the text was rephrased as follows:

According to our results, 57.9% of the surveyed people live closer than 750 m from the river, i.e. in areas with a high exposure to flood, 84.7% declare to know the flooding areas, and 55.4% experienced a flood passing outside the home. Overall, 96.2% of all respondents live closer than 750 m from the river, declare to know the flooding areas, and/or experienced a flood passing outside the home. Thus, in the present study people were assumed to be aware of flood risk.

9. Line 396: What does it mean neighbourhood?

Answer: In this study, neighbourhoods were defined using an official Geographic Information System (GIS) layer of *unidades vecinales* (neighbourhood units) in Chile. These units constitute the geographical counterpart of *juntas de vecinos* (neighbourhood councils), which are the legally recognised base of local social organisation in the country. As such, neighbourhood units represent administratively recognised territorial subdivisions that also function as socially meaningful spaces for community organisation, participation, and local governance.

To integrate statistical information available at the census-block level (*manzanas censales*), neighbourhood boundaries were spatially adjusted through a GIS overlay procedure. Census blocks were aggregated according to the limits of the corresponding neighbourhood units, ensuring consistency between socio-demographic statistical data and territorially recognised neighbourhood areas.

This approach allows combining two complementary logics: the administrative community definition embedded in neighbourhood units. Particularly relevant for variables related to social cohesion, trust, and local interaction, and the statistical robustness provided by census-block data, which offer detailed socio-material information.

In the Chilean context and more broadly in the urban studies literature there is no single, universally accepted definition of “neighbourhood.” Rather, neighbourhoods are typically conceptualised as hybrid constructs that combine administrative delimitation and community-based recognition. The operationalisation adopted in this study follows this combined perspective, aligning territorial-administrative boundaries with socio-spatial meaning.

10. Line 438: What does "close to the river" mean? How are the results affected by this distance? And how about experience with floods?

Answer: Thank you. In this case, "near the river" means that the house is located less than 750 m from the main river that overflows. Distance to the river was considered as a proxy for exposure and visibility of the hazard. As noted in the manuscript, proximity to rivers has been associated with increased awareness due to greater hazard visibility (Gray-Scholz et al., 2019; Ali et al., 2022). Furthermore, knowledge of flood-prone areas is widely recognised as an indicator of awareness (Mondino et al., 2020; Bradford et al., 2012). In this context, households located closer to the river are assumed to have greater exposure to flood dynamics and therefore higher likelihood of awareness.

11. Line 475: Doubled.

Answer: Thank you. The issue was corrected in the MS.

12. Line 508: How are these results affected by the number of floods and their intensity?

Answer: Thank you for this observation which is in line with comment 8) by Reviewer#2 and comment 18) by Reviewer#3. As the available hydrological records (please see Figure 5) are insufficient for a formal frequency analysis of extreme discharges, the flood magnitude was classified between floods causing damages as reported in the news and media, and floods without reports of damages. Therefore, to estimate the recurrence of flood events in each municipality, a review of national and regional news reports was conducted for the period 2000–2025. This search aimed to identify significant flooding over the last 25 years and to calculate the frequency of occurrence of a damaging flood, i.e. a flood reported in the news. Additionally, the dates of the floods detected in the literature were verified with the available discharge measured at gauge stations in Figure 5. After Line 508 we added: This study provides an innovative multilevel perspective on flood risk perception and behaviour, yet some aspects should be noted. Flood risk perception and flood behavior were analyzed in relation to damaging floods that occurred in the past and were reported in the news and social media. Future research could study more deeply the effects of flood magnitude on the obtained results.