

Multi-level assessment of flood risk perception and flood behaviour

Responses to reviewers

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.

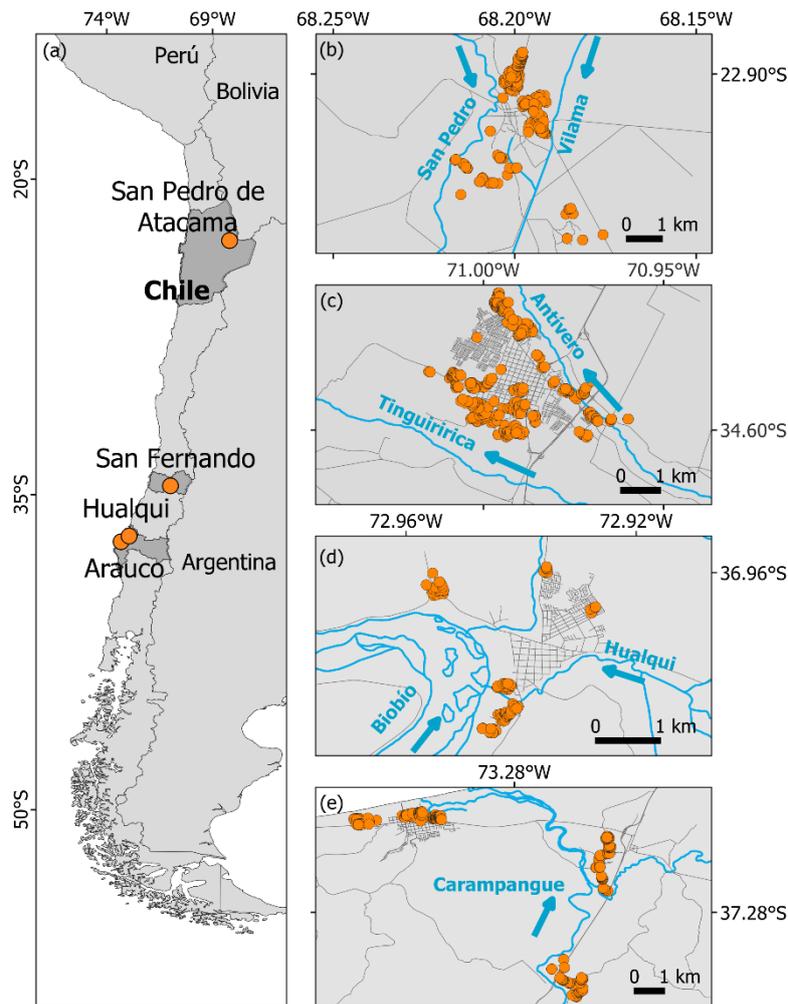
Becker, G., Aerts, J. C., & Huitema, D. (2014). Influence of flood risk perception and other factors on risk-reducing behaviour: a survey of municipalities along the Rhine. *Journal of Flood Risk Management*, 7(1), 16-30.

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
	Socioeconomic group	Ordinal (1–3)	Grouping based on education, occupation, household income and household size
Household	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.