RC1: Anonymous Referee #1, 27 Sep 2024

I have now read the manuscript titled:" Assessing flood risk: identifying indicators and indices for period-specific flood measures". In my opinion, the article has many significant drawbacks that undermine its clarity and overall quality.

General comments:

- The aim is not clear
- There are many inconsistencies in the presentation of the method and results
- Significant references are missing
- Critical view is missing from discussion and conclusions

Thank you for your useful suggestions. All comments are great and have been addressed below point by point, with the corresponding line numbers (in the version with tracks) marked.

Specific comments:

Title: The title does not represent the content. This is a "Review of indicators and indices for flood risk assessment".

Thank you for your suggestion.

It is true that this paper is a review of indicators and indices for flood risk assessment. However, the primary focus is on identifying and analysing these indicators and indices, as a wide variety of them – related to flood factors such as hazard, vulnerability, and their combinations (e.g., vulnerability + hazard) – are employed in flood risk assessment. For example, some studies use only flood hazard mapping to identify potential flood-prone areas, while others incorporate both hazard and vulnerability maps to assess flood risk (please refer to Table 1 in the manuscript). Additionally, similar or even identical indicators and indices are often applied to assess different flood risk factors. We have discussed this point in the Discussion as well.

Flood risk assessment becomes particularly valuable when potential measures are defined in relation to different flood periods. As is well known, distinct approaches and measures are required before (e.g., public awareness and preparedness), during (e.g., emergency planning and evacuation routes), and after flood events (e.g., recovery and reconstruction). In our study, we interpreted the results with these flood periods and corresponding measures in mind.

For these reasons, we would prefer to retain the current title of the manuscript.

Abstract: The problem with review papers is that they have to be very well-focused (clearly delimited) and to have a specific purpose. Neither of the two is clear in the manuscript in my opinion. In the abstract, the gap that the authors are "bridging" (line 14) is not clear neither are the findings.

Thanks for this valuable comment.

As outlined in *Introduction*, the study aims to understand the ambiguity among risk factors and identify indicators and indices that can help determine appropriate measures for different flood periods. Specifically, we aim to bridge the gap in understanding why flood risk assessments are often inconsistent in their use of factors such as hazard, exposure, and vulnerability. For instance, if risk is defined as a combination of hazard, exposure, and vulnerability, why do some studies rely solely on hazard mapping or vulnerability maps to assess risk? Furthermore, the concept of "susceptibility" adds to this ambiguity: if it is considered part of vulnerability, why is it sometimes treated as an

independent factor of risk or even as risk itself? This is particularly perplexing given that similar indicators are used for both hazard and susceptibility.

This lack of clarity in conceptual and methodological approaches is the gap we aim to bridge. Our review dives deeply into existing studies to identify common approaches and indicators that can contribute to more consistent and effective flood risk assessments in the future. Additionally, we extend our analysis to consider the different flood periods (pre-, during, and post-floods), as this temporal perspective is crucial for developing effective mitigation strategies.

By focusing on both the methodological inconsistencies and the temporal dimension of flood risk management, our study provides valuable insights to enhance the coherence and applicability of flood risk assessments. We hope this clarifies our purpose and findings in the manuscript. However, we have revised the Abstract as well considering your comment. (**Lines 6 – 27**)

Introduction: This is a very good place to make some things clear. What do you mean with floods? Is this only river flood or also flash flood (or dynamic flooding) or even coastal flood? What do you mean by "flood periods"? This becomes clear in page 19 (too late).

Thanks for this comment. We have revised this section as follows:

"Floods are natural disasters that occur when there is an overflow of water that exceeds the capacity of the area to absorb it, and in this paper, the term encompasses all types, including river floods (caused by overflowing rivers), flash floods or dynamic flooding (caused by intense rainfall over a short period), and coastal floods (resulting from storm surges or high tides)." (**Lines 32 – 35**)

…"In this context, *flood periods* refer to the three distinct phases of a flood event: pre-flood, during-flood, and post-flood. A number of actions and measures can be taken during flood periods to help mitigate their impacts. The pre-flood period focuses on awareness, preparation and mitigation measures to reduce risks (O`Grady et al., 2019), such as early warnings and infrastructure reinforcement. The during-flood period involves emergency responses to minimize harm, including evacuations and crisis management. Post-flood period is about not only recovering but also measures and management considering lessons learned. (**Lines 38 – 43**)

Introduction: what do you mean by "alternative approaches" in line 32? What are their advantages and disadvantages? You can get some ideas/refer to this publication:

Papathoma-Köhle, M.: Vulnerability curves vs. vulnerability indicators: application of an indicator-based methodology for debris-flow hazards, Nat. Hazards Earth Syst. Sci., 16, 1771–1790, https://doi.org/10.5194/nhess-16-1771-2016, 2016

Thanks for your comment. As referenced in the paper by Nasiri et al. (2019), alternative approaches include vulnerability curves, disaster loss data, and computer modelling. We have revised this section as follows:

"An indicator-based approach provides a detailed assessment of flood risk and vulnerability and serves as a valuable policy-making tool compared to alternative approaches such as vulnerability curves, disaster loss data and computer modelling (Nasiri et al., 2019). Each of these approaches has distinct strengths and weaknesses. Vulnerability curves, widely used by practitioners, provide general physical vulnerability assessments by illustrating hazard-damage relationships (Papathoma-Köhle, 2016). However, they often fail to incorporate essential characteristics, such as the specific attributes of buildings, which are critical for a comprehensive assessment of physical vulnerability (Papathoma-Köhle, 2016). In contrast, indicator-based approaches allow for tailored and flexible evaluations, enabling the inclusion of these characteristics. Nonetheless, the effectiveness is often hindered by challenges related to standardization, weighting, and aggregation (Nasiri et al., 2019). Additionally, methods such as disaster loss data offer broad insights, lacking the adaptability and presicion of

indicator-based approaches. Meanwhile, computer modelling, though comprehensive, can be complex and data-intensive (Nasiri et al., 2019). To address these limitations and leverage the strengths of each method, combining approaches can provide a more integrated and holistic assessment (Birkmann, et al., 2013; Papathoma-Köhle, 2016). For example, combining methods, particularly indicators and vulnerability curves, or integrating indicator-based methods with computer modelling, could enhance precision while addressing data gaps and uncertainties. Similarly, coupling disaster loss data with indicator-based approaches might offer both broad historical context and detailed, context-specific insights. While this paper focuses exclusively on the indicator-based approach, the potential of a combined framework remains significant. Such an integrated methodology would allow practitioners to better exploit the complementary nature of these methods, ultimately improving flood risk and vulnerability assessments and supporting more robust decision-making." (**Lines 78 – 95**)

Introduction: (lines 38-40). Is this your own definition? These criteria (measurable, observable etc.) can be found in the book of Birkman *Measuring Vulnerability to natural hazards*. In my opinion, a quality check of your indicators through this criteria would be beneficial for the paper (see previous publication of Papathoma-Köhle). What is also missing is the definition of (vulnerability) indicators from Birkman. The reference is here:

Birkmann, J.: Indicators and criteria for measuring vulnerability: Theoretical bases and requirements. In J. Birkmann (Ed.),Measuring Vulnerability to Natural Hazards: Towards disaster resilient societies (S. 55-77). UNU Press, 2006.

Moreover, valuable information on indicators can be found here:

OECD. Handbook on Constructing Composite Indicators: Methodology and User Guide. (OECD Publications, Paris, 2008).

Thanks for your comment. We added recent version of the (vulnerability) indicator definition by Birkmann et al. (2013). We have added the references to this section as well:

"The OECD (2008, p.13) defines an indicator "*as a quantitative or qualitative measure derived from a series of observed facts that can reveal relative positions (e.g., of a country) in a given area*". According to Birkmann et al. (2013, p.87), a vulnerability indicator for hazards of natural origin can be defined as "*a variable which is an operational representation of a characteristic or quality of an object or subject able to provide information regarding the susceptibility, coping and adaptive capacity and resilience of a system to an impact of an albeit ill-defined event linked with a hazard of natural origin."*

Starting from this point of view, an indicator regarding a risk assessment is a variable that can be qualitative, quantitative, rank, measurable, observable or changing local conditions to determine or define the presence, likelihood or impact of a particular risk (Gallopín, 1997; Birkmann et al., 1999; OECD, 2003, 2008; Birkmann, 2006; Heink & Kowarik, 2010; Birkmann et al., 2013). (**Lines 99 – 107**)

A reflection on the quality criteria for vulnerability indicators is provided in Section 4 (Discussion), as follows. Since we did not explore these criteria in detail, we did not elaborate on them for hazard and exposure. We focused on explaining the key indicators identified in the review and discussing which criteria they fulfil briefly.

"Birkmann (2006) provided standard criteria for developing vulnerability indicators. However, an indicator does not need to fulfill all quality criteria, as the selection and use of indicators depend on the specific needs, priorities, and practical constraints of the assessment. Instead, indicators should align with the purpose and context of the study, with certain criteria prioritized based on objectives and available resources. In this study, quality criteria for flood vulnerability indicators ensure their relevance and effectiveness in capturing key aspects of flood impacts. Indicators such as population

density, income level, and vulnerable population emphasize sensitivity, relevance, and policy relevance, highlighting their connection to coping capacity and harm susceptibility. Measurability, validity, and reproducibility, as seen in indicators like education level and basic health facilities, enhance analytical soundness and practical applicability. Transportation networks are evaluated for relevance, sensitivity, and policy relevance, given their role in evacuation and accessibility during floods. Land use, imperviousness, and slope demonstrate sensitivity and reproducibility, reflecting the influence of urbanization, building design, and terrain stability on vulnerability. Elevation, drainage density, and flow accumulation highlight measurable and analytically sound criteria, helping the identification of flood-prone areas and runoff challenges. Finally, soil characteristics, rainfall, and the Topographical Wetness Index (TWI) emphasize the importance of data availability and cost-effectiveness in developing actionable and context-specific flood vulnerability assessments." (**Lines 630 – 644**)

Introduction: you refer to the ambiguity among risk factors (line 95) that you do not really discuss in the manuscript. You should definitely refer to this paper-they do exactly that:

https://link.springer.com/article/10.1007/s11069-024-06643-9

Thanks for your comment. Our research does not focus on the ambiguity surrounding the definitions of risk factors, which are outlined in the IPCC's risk diagram. Instead, our work emphasizes how these factors are practically applied and integrated to assess flood risk. By focusing on their application, we aim to improve the understanding and evaluation of flood risk, rather than revisiting the conceptual distinctions between them. However, to provide clarity, we have added a paragraph addressing this issue as follows:

"This paper does not examine the ambiguity in defining risk factors, as outlined in the IPCC's risk diagram. Instead, it focuses on how these factors are practically applied and integrated into flood risk assessment. While the IPCC diagram effectively illustrates key components of risk, it also raises concerns about whether it sufficiently balances conceptual clarity for academic audiences with practical relevance for policymakers and practitioners (Fuchs et al., 2024). To address this, our research takes a different perspective, emphasizing the practical use of risk factor indicators and their integration into flood risk assessment. By refining and applying these concepts, we aim to improve risk assessments and support more targeted measures." (**Lines 157 – 163**)

Introduction: you focus on AHP. Why? What about other methods? What is better in AHP? Maybe saying "participatory methods" in general would be better. A reference about AHP should be added for the readers that do not know what it is.

Thanks for your valuable comment. We have revised this section as follows:

"Multi-criteria decision-making methods (MCDM) are useful for evaluating multiple; often conflicting, criteria in decision-making processes. Several MCDM methods such as Analytical Hierarchy Process (AHP), Analytic Network Process (ANP), and Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), have been established for risk assessment to identify and prioritize indicators based on their relative importance. These methods provide a systematic framework that enables decision-makers to compare multiple factors and support informed decision-making (de Brito & Evers, 2016, Abdullah et al., 2021, Sousa et al., 2021). Among them, AHP, developed by Saaty (1977), is one of most commonly used MCDM approaches for flood risk assessment. It offers a structured methodology that allows decision-makers to evaluate and prioritize various indicators contributing to flood risk. AHP can be applied to assess both risk indicators and indices while considering the relationships between vulnerability components. By using pairwise comparisons, AHP quantifies subjective judgments and provides a clear framework for assessing factors such as flood severity, occurrence, vulnerability, and potential consequences. This structured approach makes it particularly useful for developing effective flood risk mitigation strategies. Beyond AHP, participatory approaches (Maskrey et al., 2016; Ardaya et al., 2019; Tiepolo et al., 2023) offer

additional value in risk assessment by incorporating local knowledge and stakeholder perspectives, leading to a more inclusive decision-making process. Effectively identifying and understanding the challenges and impacts of floods on people and ecosystems requires the active involvement of decision-makers, planners, and affected communities. For instance, the Delphi method involves iterative rounds of expert judgment to reach a consensus on the prioritization of indicators (Linstone & Turoff, 2002; de Brito et al., 2017). AHP can incorporate stakeholder input, contributing to the weighting of indicators and enhancing its relevance to specific contexts. Nevertheless, AHP is advantageous in contexts where objective prioritization and structured decision-making are essential for effective risk assessment and management (Saaty & Vargas, 2012), but it has certain limitations. The subjectivity involved in assigning weights through pairwise comparisons may introduce biases, particularly in multi-stakeholder settings. Additionally, its scalability is a challenge, as the number of comparisons increases exponentially with more criteria, making the process time-consuming (Dhawale et al., 2024). Furthermore, AHP assumes independence between criteria, which can oversimplify decision-making when interdependencies are significant, potentially affecting the accuracy of results." (**Lines 124 – 147**)

Material and method: you explain in the conclusions why you limit the review to these years (2017 to 2022). The reason you give is limited resources which is not good enough to explain this limitation. What about recent papers (2023?). What has this with resources to do?

Thanks for your valuable comment. As our review was conducted in 2023, we decided to exclude publications from that year to ensure a consistent analysis of the selected timeframe. We have revised the paragraph about the limitations as follows:

"Due to limitations in resources and time, the scope of the review was constrained, focusing on a limited number of publications released between 2017 and 2022." (**Lines 670 – 671**)

Material and methods: the title of 2.2 is wordy and not to the point.

Thanks for your comment. We have renamed the chapter into "Definitional analysis". (**Line 198**)

Material and methods: (line 129) "an assessment was conducted", which assessment? How? Which method did you use? Not clear.

Thanks for your comment. We have revised this section as follows:

"A flood period-specific indicator evaluation was conducted to examine the impacts, roles, and utility of various indicators related to vulnerability, hazard, and exposure during different flood periods. The systematic review of the literature was undertaken to identify the indicators most relevant to each specific period of the flood event, exploring their applicability and effectiveness. This approach helps clarify how these indicators contribute to flood risk management at various stages, providing valuable insights for targeted decision-making." (**Lines 207 – 211**)

Results: (line 140) you already wrote a lot about definitions in the introduction. Maybe you should move some text here and use the introduction to set the scene.

Thanks for your comment. 3.1 The Definitional Analysis of Flood Factors includes only the definitions used in the papers reviewed in this study, along with those from the IPCC AR6 for comparison. However, we agree that adding the UNDRR definitions could further clarify the concepts. In this case, we would like to keep the general definitions in the Introduction.

Results: Definitions from the UNDRR (2017) are totally missing! Here is the reference:

https://www.undrr.org/drr-glossary/terminology

Thanks for this insightful comment. 3.1 The Definitional Analysis of Flood Factors includes only the definitions used in the papers reviewed in this study, along with those from the IPCC AR6 for comparison. However, we agree that adding the UNDRR definitions could further clarify the concepts. We have revised those sections as follows:

3.1.2 Vulnerability

"According to UNDRR (2017), vulnerability is defined as "*the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards*"." (**Lines 261 – 263**)

3.1.3 Hazard

"According to UNDRR (2017), hazard is defined as "*A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation*"." (**Lines 297 – 299**)

3.1.4 Exposure

"According to UNDRR (2017), exposure is defined as "*The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas*"." (**Lines 308 – 310**)

Results: there is no critical view of the definitions. E.g. definitions of risk Ologunorisa and Maskrey- why are they different? Are they?

Thanks for your comment. Section 3.1 The Definitional Analysis of Flood Factors includes only the definitions used in the papers reviewed in this study, along with those from the IPCC AR6 for comparison. We added the UNDRR definitions, as you suggested, to help clarify the concepts. In the Discussion section, we further address the process of defining and selecting indicators. As previously stated, this paper does not focus on the ambiguity surrounding the definitions of risk factors, as outlined in the IPCC's risk diagram. Instead, our work emphasizes how the practical application and integration of these factors in flood risk assessment. The definitional analysis we conducted focuses on key indicators, examining their relevance to flooding. In addition to highlighting differences in key indicators, we aimed to illustrate the variations in how the factors themselves are defined. This is why Section 3.1 includes the various definitions from the reviewed papers.

Both Ologunorisa (2001) and Maskrey (1989) define flood risk as a function of hazard and vulnerability (or probability and potential loss). However, they are using different equations than each other. Ologunorisa (2001) uses an approach that risk is the result of both the hazard and vulnerability interacting in a multiplicative way. In this case, overlay analysis would involve multiplying the hazard and vulnerability layers, with areas of higher hazard and vulnerability resulting in significantly higher risk. This approach emphasizes that vulnerability amplifies the hazard, leading to greater risk, particularly in areas with high exposure to hazards. Maskrey (1989) uses a more traditional approach where risk is considered the sum of the hazard and the vulnerability. In overlay analysis, different layers representing hazard and vulnerability are combined to produce a risk map. This approach treats risk as the combined influence of hazard and vulnerability, typically with a simple additive relationship. Here, risk increases with both factors, but not necessarily in a proportional or amplified way. Even if one of the factors is low, risk can still be elevated if the other is high.

In order to make it clearer, we added a sentence as follows:

"In this case, regarding overlay analysis, flood risk can be defined either as the multiplicative interaction between hazard and vulnerability, where higher risk results from both factors being high, or

as the additive combination of hazard and vulnerability, where risk increases with both factors but without amplification or proportionality." (**Lines 250 – 253**)

Results: vulnerability (lines 167-169): "damage curves for physical assets and indices for human well-being". I do not agree. There are plenty of studies using indices for physical assets e.g.

Papathoma-Köhle, M., Schlögl, M. & Fuchs, S. Vulnerability indicators for natural hazards: an innovative selection and weighting approach. *Sci Rep* **9**, 15026 (2019). https://doi.org/10.1038/s41598-019-50257-2

Thanks for your comment. You are absolutely right, we expressed the sentence incorrectly. Indeed, the sentence about damage curves and indices is a bit away from the focus of the section. Therefore, we decide to remove this sentence anyway.

Results: Vulnerability: a discussion on the different vulnerability dimensions is needed here.

Thanks for your comment. We have added our findings on vulnerability dimensions in this section as follows:

"Reviewed papers highlight various dimensions of vulnerability, with a primary focus on physical vulnerability, which addresses the susceptibility of infrastructure and physical assets to flood damage, and socio-economic vulnerability, which reflects disparities in resources, income, and social inclusion that exacerbate risk. Other dimensions, such as institutional vulnerability, which relates to governance and institutional responses, and environmental vulnerability, which examines the sensitivity of ecosystems and natural resources to flood impacts, were not emphasized as key areas of analysis in the reviewed papers. Each dimension offers valuable insights, and flood risk assessments often integrate multiple dimensions for a more comprehensive understanding of vulnerability. However, physical and socio-economic vulnerability are analysed most frequently due to their significant influence on flood risk and recovery capacity, as well as the relatively easier availability of relevant context-specific data. Notably, none of the reviewed papers includes sensitivity and adaptive capacity as explicit components of vulnerability." (**Lines 274 – 283**)

Results: Susceptibility/sensitivity. According to line 123 there are three factors of risk (vulnerability exposure and hazard) and vulnerability incorporates susceptibility/sensitivity and adaptive capacity. If this is part of vulnerability why is it in a separate subchapter, and where is adaptive capacity.

Thanks for your comment. The subchapters of the Section 3.1 The Definitional Analysis of Flood Factors includes only the definitions used in the papers reviewed in this study, along with those from the IPCC AR6 for comparison. We added the UNDRR definitions, as you suggested, to help clarify the concepts. Since susceptibility/sensitivity is sometimes used independently to assess flood risk (as shown in Table 1) rather than as part of vulnerability, we decided to address it under a separate heading. Adaptive capacity is not included because none of the randomly selected 30 reviewed papers assesses adaptive capacity in the context of flood risk.

Table 1. the table would be better with a column providing the reference of each paper and a column showing the aim of each paper. The first column is not clear (what is this about?-I think it is about the aim of the study but it is not clear). An interesting piece of information would be to indicate whether the study is quantitative or qualitative and what is the risk metric.

Thank you for your comment. We have separated the cells to make it clear that the second column represents the aim of the study. While we collected information on methodology and risk metrics during our review, we initially chose not to include it due to the scope of the paper. However, we have now incorporated all our findings into the Table 1, and added a brief explanation. We added the reference of each paper as well.

3.3 Indices and indicators: what are the differences? The authors have to explain (we get an explanation in the figure caption-Fig 1). Yet, although according to the figure caption the indices are left, in the text they are called indicators (lines 229-230).

Besides the caption of Figure 1, although indicators are defined in Section 1 (Introduction) and **line 75** mentions that indices are combinations of indicators, we have added a definition of "index" after the definition of "indicators" as follows:

"An index is a composite measure that combines multiple variables or indicators into a single numerical value (OECD, 2008)." (**Lines 107 – 108**)

In order to explain each index, we explained indicators for each index in the text below the Figure 1.

Figure 1: on the right side we can see the risk factors. However, the risk factors according to line 23 are 3 (hazard, vulnerability, exposure). Now they are five. Susceptibility is supposed to be part of the vulnerability (lines28). What about the "flood potential"? What is the difference to hazard? Where is the definition of flood potential in the "definition analysis" part?

Thanks for your comment. The subchapters of the Section 3.1 The Definitional Analysis of Flood Factors includes only the definitions used in the papers reviewed in this study, along with those from the IPCC AR6 for comparison. We added the UNDRR definitions, as you suggested, to help clarify the concepts. Since susceptibility/sensitivity is sometimes used independently to assess flood risk (as shown in Table 1) rather than as part of vulnerability, we decided to address it under a separate heading.

We deleted the word "potential" – left only "flood risk". There were two publications that approached flood susceptibility differently: one assessed flood susceptibility to evaluate flood risk, while the other assessed flood risk without referencing specific risk factors. We covered the methodologies of both publications and explained their approaches in the subchapter. Interestingly, the assessment of flood risk closely resembles hazard assessment, as it uses similar indicators such as rainfall, distance to rivers, land use, and elevation. This overlap is particularly notable given that such indicators are also sometimes applied to evaluate flood risk itself.

We have renamed the subsection as follows:

"3.1.1 Flood risk" (**Line 232**)

Figure 1: Are these indices from specific publications or have you developed them yourselves? It is not clear.

Thanks for your comment. We added a sentence in the Section 2.1.2 Classification scheme as follows:

"The number of papers was counted for each indicator, considering its associated index and risk factor in order to determine the relationship between each indicator and flood risk factors. The most frequently used indicators for each index and risk factor were determined. During the review, we created tables to highlight the impacts of these critical indicators on floods and combined individual indicators to form indices, treating them as composite measures." (**Lines 180 – 183**)

Table 3. Is imperviousness an indicator? Is it measurable and observable? (see comment about quality criteria above). I think impreviousness is actually the result of a number of indicators (e.g. building material, building height, position of openings etc.).

Thanks for your comment. A reflection on the quality criteria for vulnerability indicators is provided in Section 4 (Discussion), as mentioned above. Since we did not explore these criteria in detail, we did

not elaborate on them for hazard and exposure. We focused on explaining the key indicators identified in the review and discussing which criteria they fulfil briefly. In this paper, imperviousness refers to building areas, buildings, urbanization ratio, impervious area ratio, and the extent of impervious surfaces. These aspects are commonly used in the reviewed papers to assess flood risk, and we collectively refer to them as "imperviousness." The transportation network, road density, and road length are treated separately, as transportation network, as reflected in the reviewed literature. Additionally, some studies use land use as an indicator, which may include impervious areas as part of the broader land use classification. We distinguish land use/land cover (or land cover, as some studies call it) as a separate indicator, particularly when the paper considers it in ranking different land uses, including imperviousness as one of the components. This clarification helps to ensure that we properly categorize and assess the different factors contributing to flood risk.

Land use and imperviousness demonstrate sensitivity and reproducibility, reflecting the influence of urbanization and building area on vulnerability. Sensitivity refers to how well an indicator responds to changes in the environmental or social conditions that influence vulnerability. Reproducibility means that the indicator can be applied consistently in different contexts and yield similar results. In the case of land use and imperviousness, these indicators demonstrate sensitivity because they react to urbanization and land development (e.g., increasing impervious surfaces or changes in land use). As urbanization increases, impervious surfaces like roads and buildings reduce water absorption, which enhances flood risk and vulnerability. They also exhibit reproducibility because these factors can be measured across different locations or over time, allowing for comparisons of vulnerability based on similar urbanization patterns and land-use changes.

Table 8. What is direct and inverse proportion? I do not agree that population density has a neutral effect during the response phase (by the way, I think that “phase” is a better word than period). Evacuation possibilities and methods are related to the population density. I also do not agree that the number of households is neutral in the pre-flood phase. It is very relevant for the total authorities and how they are going to prepare.

Thanks for your comment.

As shown in Table 8 and explained in the text (**Lines 512 – 516**), among the socio-economic vulnerability indicators, population density and the presence of vulnerable populations exhibit a negative effect and a direct proportion relationship before, during, and after a flood. In other words, the increase in population density and vulnerable populations directly correlates with negative impacts by floods, signifying a proportional relationship – higher (vulnerable) populations can face inherent challenges during these periods. As shown in Table 9 and Table 10 and further explained in the text, population density, when considered as both a hazard and an exposure indicator, also demonstrates a negative effect and a direct proportional relationship, but only during flooding. Table 2 presents the impacts of population density for each factor and includes a column indicating whether the reviewed papers support the defined impacts of the indicator (incl. evacuation possibilities).

We are simply referring to the entire duration of the event and its impacts before, during, and after a flood. The term “phase” is also fine, but we prefer to use “period” in the paper, as it is a well-known and widely used term in hydro-meteorological contexts.

As an indicator, the number of households is considered neutral in the pre-flood phase, as we could not find evidence to support either a negative or positive effect. However, most socio-economic vulnerability indicators are highly relevant for authorities and their preparedness strategies. Our argument is that a higher number of households at risk can either strain emergency response efforts or, conversely, facilitate it in certain circumstances. Moreover, after the floods, the close proximity of households within the affected area increases the likelihood of negative health impacts spreading from one person to another. Three of the papers we reviewed, which used the number of households as an indicator for vulnerability assessment, support our argument during the flood and post-flood periods.

Regarding Table 8, which shows vulnerability indicators, for instance, when the statement mentions a "direct proportional relationship" between population density and responses during a flood, it means that as population density increases, vulnerability as a flood factor also increases. In this case, the impact of population density on flood risk is negative, meaning that the effects of floods worsen as population density increases. Higher population density means more people are vulnerable, leading to greater flood-related damages or challenges. We have added an explanation of the definitions of direct and inverse proportions in Section 2.3, as follows:

"In addition to their effects, the relationships between the indicators and flood periods were further assessed as either direct or inverse proportions. In direct proportions, the values of both the indicator and flood risk moved in the same direction (e.g., an increase in population density leading to higher flood risk). Conversely, in inverse proportions, the values moved in opposite directions (e.g., an increase in vegetation cover reducing flood risk)." (**Lines 224 – 228**)

Table 9 and table 10: why the socio-economic index has now less indicators than before?

Thanks for your comment. Tables 2–7 show the common indicators for each index that contribute to flooding, considering the impacts of each indicator on the respective risk factor, while Tables 8–10 illustrate the effects of the key vulnerability, hazard, and exposure indicators during the flood periods, respectively. In this context, the socio-economic index includes indicators such as population density, education level, vulnerable populations, number of households, income level, and the availability of basic health facilities/number of doctors and nurses (see Table 2). However, only population density was used as an indicator for vulnerability, hazard, and exposure in the reviewed papers. The other socio-economic indicators are shown in Table 8, which outlines the effects of key vulnerability indicators during flood periods.

Table 9 is for the hazard, table 10 is for the exposure. What about vulnerability?

Thanks for your comment. Table 8 shows the effects of key vulnerability indicators during flood periods.

Discussion: parts of the discussion talk about the methodology. New information is coming in but there is no critical view of the findings which is what the discussion would be about. Also, limitations could be discussed here and not in the conclusions.

Thank you for your valuable comments. We have revised the subsection 4.1 and 4.2, and added a new subsection (4.3 Implications for policymakers and practitioners) to the Discussion section to reflect the findings of this study, providing recommendations on selecting risk indicators and indices that align with specific actions and measures for different flood periods.

Additionally, we moved the paragraph about the limitations from the Conclusion to the Discussion section:

"While this study aimed to provide a comprehensive review of the relevant literature, it is essential to acknowledge certain limitations, particularly pertaining to the time constraints imposed on the research process. The review, while integral to the depth and accuracy of the study, posed a challenge in terms of time consumption. Due to limitations in resources and time, the scope of the review was constrained, focusing on a limited number of publications released between 2017 and 2022. As a result, there may be a possibility that some valuable contributions, relationships and perspectives on indicator-based flood risk assessment were not included in this analysis." (**Lines 668 – 673**)

Discussion: according to the abstract, there should be some recommendations at the end, but there are not.

Thank you for your valuable comments. We have added a subsection (4.3 Implications for policymakers and practitioners) to the Discussion section to reflect the findings of this study, providing recommendations on selecting risk indicators and indices that align with specific actions and measures for different flood periods.

Conclusions: "the paper seeks to understand the ambiguity among risk factors". I do not think that it does that. There is not enough discussion on this matter.

Thanks for your comment. We revised the first paragraph of the Conclusion to make the aim clearer as follows:

"This paper seeks to address the ambiguity surrounding risk indicators and factors, and identify indicators and indices in terms of their practical application and integration for flood risk assessment, thereby enhancing the understanding and evaluation of flood risks. Specifically, the study aims to bridge the gap in understanding the inconsistencies in the use of indicators for risk factors in flood risk assessments. Clarifying and operationalizing these concepts is essential for developing effective strategies to manage disasters and foster climate change adaptation. By incorporating a temporal perspective -examining pre-, during, and post-flood periods - it highlights the critical role of timing in designing effective mitigation strategies. Through its dual focus on methodological inconsistencies and the temporal dimension of flood risk management, this research offers valuable insights to improve the coherence and practical applicability of flood risk assessments." (**Lines 740 – 747**)

Conclusions (lines 461-462): "it was necessary to build a clear concept"-it is also not clear what is this concluding clear concept that has been developed. Lines 466-467: "the exhaustive definitional review"-it is not exhaustive since the terminology of the UNDRR is missing. Lines 474-476: "By focusing on…nature of flood risk". This is not something new. There are plenty of studies focusing separately on hazard, vulnerability and (less) exposure. Finally, the last paragraph is about participatory methods and stakeholders, a topic that it is not adequately approached in the manuscript.

Thank you for your comments.

About building a clear concept, we have revised first two paragraphs of Conclusion.

In this study, we reviewed 30 publications using the keywords "AHP" OR "analytic hierarchy process" combined with "flood" OR "floods", and found 115 indicators used in a different way to assess flood risk. Section 3.1 The Definitional Analysis of Flood Factors includes only the definitions used in the papers reviewed in this study, along with those from the IPCC AR6, for comparison. As suggested, we have also added the UNDRR definitions to further clarify the concepts. However, one of our aims is align the use of risk factors with the IPCC definitions. That was the reason we explained IPCC framework in detail in the Introduction. Sections 3.2, 3.3 and 3.4 present the findings from these 30 publications, highlighting conceptual and methodological approaches. Our review dives deeply into existing studies to identify common approaches and indicators that can contribute to more consistent (addressing the inconsistency in the use of factors such as hazard, exposure, and vulnerability) and effective flood risk assessments in the future. The sentence about "the exhaustive definitional review" was in the "limitations" paragraph, and we have moved it to the Discussion, and delete the word "exhaustive", even though it was for those 30 publications and IPCC assessment reports.

"By focusing on…nature of flood risk". This is certainly not something new. However, we believe that this paper will help clarify the nuanced dynamics of each component used in flood risk assessments for different flood periods – especially since people often rely on the same indicators, using them in the same way and with the same definitions to assess hazard and vulnerability, or only sensitivity, or hazard and sensitivity, etc. We have revised that part to make it clearer.

Since participatory methods and stakeholder involvement are crucial for flood risk assessment, we would to keep this as one of our future research endeavours. However, we have made it shorter and clearer.