

NHESS-2024-178 R2 Review comments

RC1

Thank you for taking into account my previous comments and giving me a chance to review again your manuscript “Review article: Towards multi-hazard and multi-risk indicators – a review and recommendations for development and implementation”.

First, I want to stress the excellent work from the authors in addressing Reviewer 2 and my comments. The new classification of the literature reads much better and the recommendations are now well aligned with the content of the review. While the article is very much improved, I have some concerns about Section 3.2. and in particular the parts addressing hazard indicators. Beside this point, I provide a few minor comments.

Response:

Thank you for taking the time to re-review our manuscript, *"Towards Multi-Hazard and Multi-Risk Indicators – A Review and Recommendations for Development and Implementation"* and for your positive comments about the R1 revision. We note the reviewer's additional minor comments, especially with regards to section 3.2, which we address in turn below.

Comment related to Section 3.2:

Sections 3.2.1 and 3.2.2 discuss the usage of multi-hazard indicators for multiple types of hazard interactions. I find these sections very lengthy, and sometimes confusing, as they mostly enumerate indicators used in previous studies addressing several hazards. The length of these sections contrasts with one of the main conclusion of the article: “there are few studies that explicitly develop indicators for multi-hazards”. Notably, several indicators enumerated are single hazard indicators (combined to create multi-hazard indicators) and two paragraphs are dedicated to one hazard interaction: hot-dry. The other paragraph of Section 3.2.1 is dedicated to compound flooding. I believe that this highlights the lack of compound hazard indicators, and that three paragraphs may not be necessary to make that point. Section 3.2.2 introduces more single hazard indicators, while it is not clear what indicators are discussed in the two last paragraphs (l. 351-l. 362). On the other hand, the Global Delta risk Indicator (Section 3.3) would maybe deserve more discussions. I would therefore suggest to shorten Sections 3.2.1 and 3.2.2 and focus on existing multi-hazard indicators.

Response:

We appreciate the reviewer's insightful comment. In response, we have substantially revised Sections 3.2.1 and 3.2.2 to reduce length and improve clarity. These sections now focus more directly on categorising the types of multi-hazard indicators used in the literature—specifically, composite, frequency, intensity, and probability-based indicators—as they relate to compound and triggering/amplification multi-hazard events. The revised text places greater emphasis on the methodological characteristics and limitations of existing multi-hazard indicators, rather than enumerating single-

hazard metrics or detailing specific hazard combinations (e.g., hot-dry). Please refer to the revised tracked changes in Sections 3.2.1 and 3.2.2.

We also agree with the reviewer that the Global Delta Risk Index (GDRI) deserves further discussion. In response, we expanded its treatment in Section 3.2.3 to highlight its conceptual depth, multidimensional nature, and applicability across delta regions. The revised paragraph reads as follows:

“Composite risk indicators were also widely adopted across multi-risk studies. A notable example is the Global Delta Risk Index (GDRI), which provides a comprehensive framework for assessing risks in vulnerable delta regions exposed to multiple hazards such as cyclones, floods, storm surges, and droughts (Hagenlocher et al., 2018; Gallina et al., 2016; Depietri et al., 2018; Zhang et al., 2023). The GDRI is designed to evaluate social–ecological systems holistically, capturing the interplay between environmental hazards and human wellbeing. It enables spatial analysis of risk components (e.g., exposure, ecological and social susceptibility, and the robustness of ecological systems as coping mechanisms) at the sub-delta administrative scale, supporting both cross-delta and inter-delta comparisons (Cremin et al., 2023). Another application of composite indicators was observed in Gotangco and Josol (2022), which developed the Physical Service Index (PSI) framework to evaluate the combined effects of urban development, flooding hazards, and chronic deprivation at the regional scale in Manila, Philippines.”

Specific comments (1-13)

Box1, paragraph 2, l.1 environmental variables?

Response:

We have changed “environmental parameters” to “environmental variables” on the first line of paragraph 1 in Box 1.

L.93 p5: The development of multi-hazard and multi-risk indicators for disaster risk assessment and management has, however, not kept pace with the development of multi-hazard DRR approaches and the use of indicators more generally. Repetition of sentence in Box1.

Response:

We thank the reviewer for pointing out the repetition. To address this, we have rephrased the sentence in line 93 to better reflect the motivation for this study and to avoid redundancy with Box 1. The revised sentence now reads:

“However, the development of indicators that specifically address multi-hazard and multi-risk scenarios has lagged behind the broader advancement of multi-hazard DRR strategies and the general growth of risk indicators”.

L. 116-118 p5: Sentence feels like a rewording of the clearer sentence in L.229-230 p7

Response:

We appreciate the reviewer's observation. Upon review, we believe the intended reference was to lines 134–136 on page 7 in the previous version of the manuscript. To address the redundancy, we have removed the sentence previously located at lines 116–118 on page 5 in the revised manuscript.

L.141 p7: Third time you mention that you used a systematic review.

Response:

Thank you for pointing out this redundancy. As the Introduction already states that a systematic review was conducted, we have revised the opening sentence of the Methods section to avoid repetition. The revised sentence now reads:

“This study employed a structured approach to identify peer-reviewed literature that either use indicators or analyse their applications in multi-hazard and multi-risk contexts. The process was guided by the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) protocol (Page et al., 2021).”

L. 166 p8: Is it the number of sources obtained after post 2015 reduction?

Response:

Yes, the duplicate removal process was applied to the dataset after excluding pre-2015 articles, as well as non-English and inaccessible records. To clarify this sequence, we have revised the paragraph accordingly. The updated text now reads:

“The initial search returned 1,468 articles that met the search criteria. A publication date filter was then applied to include only studies published from 2015 onwards in alignment with the release of the Sendai Framework for Disaster Risk Reduction and its emphasis on multi-hazard approaches. After excluding the pre-2015 publications, non-English articles, and inaccessible records, 1,140 articles remained. A duplicate removal process, conducted using the R programming language, identified and eliminated 515 duplicates from this set. Figure 1 provides a flowchart detailing the screening process, including the number of articles at each stage of the review.”

L. 175-177 p9: Specify here that you detail the exclusion criteria just below.

Response:

Thank you for the suggestion. To clarify that the exclusion criteria are detailed immediately after, we have revised the sentence as follows:

“Relevance was primarily assessed manually based on the use of multi-hazard and multi-risk indicators in evaluating natural hazards across diverse research domains, with detailed exclusion criteria outlined below.”

L. 263-265 p13: refer to Table S3 here

Response:

Done.

L. 278 p14: most common what?

Response:

Thank you for the comment. We have clarified that the sentence refers to hazard interactions. The revised sentence now reads:

“Compound interactions were the second most common hazard interactions, representing 30% (n=149) of all hazards.”

L.281 p14: why complex?

Response:

Thank you for the comment. To clarify the use of the term “complex,” we revised the sentence to better explain the nature of these interactions. The updated sentence now reads:

“Most compound events stemmed from meteorological and hydrological hazards—particularly drought, extreme temperatures, floods, storms, and extreme precipitation—highlighting their tendency to co-occur and interact across different temporal and spatial scales, which contributes to their complexity.”

L. 303 p16: Figure number missing

Response:

Thank you for pointing this out. We have corrected the text by including the appropriate figure reference—Figure 4a—at the relevant location in the revised manuscript.

L.303 p16: Unclear what are primary hazards here, are we only looking at triggering and amplification interrelation?

Response:

Thank you for this comment. We believe the confusion likely arose due to the previously missing figure reference, as noted in the reviewer's earlier comment. In this context, the term "primary hazards" refers to those shown in Figure 4a.

Table 3: Coastal exposure index is an example of vulnerability indicator?

Response:

Thank you for the question. In Table 3, the category "Exposure/Vulnerability indicators" encompasses both exposure and vulnerability measures. The Coastal Exposure Index is listed as an example under the "Exposure Index" sub-type, reflecting its role in quantifying exposure rather than vulnerability alone.

L.485-488 p23: Three categories for 8 recommendations, either you group the recommendations or your remove the numbering from categories.

Response:

Thank you for your suggestion. The 8 recommendations, which had previously been reworked from the original submission, don't neatly fit into the 3 categories. Indeed, we don't view these as categories but rather high-level themes that the 8 recommendations address collectively. To avoid confusion, we have removed the (i) to (iii) numbering, but have left the recommendations numbered 1-8, which we prefer to keep.

RC2

I thank the authors for their detailed reply and commend their substantial revisions to the paper which make it much clearer. The new figures and tables really help to break things down. This paper will be an excellent addition to the literature.

I have a few further minor comments - these are mainly suggestions to add in a few additional sentences to help with clarity, plus a few minor typos. The main point that should be addressed is that in the results section, some of the paragraphs read a bit like a 'telephone directory' approach to a literature review - basically describing a set of papers sorted into themes - several paragraphs here could do with a final sentence or two to tell us what that set of papers collectively tell us. This will not require any re-analysis or significant time.

Response:

Thank you very much for taking the time to re-review our manuscript, *"Towards Multi-Hazard and Multi-Risk Indicators – A Review and Recommendations for Development and Implementation"* and for your positive comments about our R1 revision. We note the reviewer's additional comments, which we address below.

Comments

It is unclear why articles that discussed no hazards and no interaction mechanisms were still included within the scope of the study. A sentence in section 3.1.2 or the methods to give an indication of what types of article this encompasses would be helpful.

Response:

We thank the reviewer for highlighting this important point. To clarify, articles that did not discuss any hazards or interaction mechanisms were not included in the analysis of multi-hazard and multi-risk indicators. However, in Section 3.1.2, we explain why some articles categorised as having "no hazards" still appear in Figure 3. Specifically, the following sentence provides clarification:

"The review noted that although some articles discussed hazards in general, no specific hazard types according to the UNDRR's HIPs classification were addressed."

Additionally, we have clarified that articles without explicit interaction mechanisms (i.e., "no interactions") were excluded from the analysis of multi-hazard and multi-risk indicators. This is noted in Section 3.2, where we state:

"This study only considered interactive multi-hazard events to identify multi-hazard and multi-risk indicators, as discussed in Section 3.2."

Line 314 you set up the argument that the 'design and application of indicators varied' and then go on to describe a range of indicators. This paragraph could do with a final sentence to come back to the argument about the design/application based on what

you have described - e.g., why does this matter or what do we now know from your synthesis of these studies?

Response:

Thank you for the insightful suggestion. Following the revision of Sections 3.2.1 and 3.2.2 in response to RC1's review comments above, which now focus on key categories of multi-hazard indicators (composite, frequency, intensity, and probability) related to compound, triggering, and amplification events, we have added concluding sentences that explicitly synthesize the implications of the diversity in indicator design and application. This clarifies why these differences matter and what insights can be drawn from the range of studies reviewed.

Generally throughout section 3.2.2, each paragraph could do with a final sentence of summary or synthesis. At present, the structure of the paragraphs is an opening signposting sentence indicating the theme of the indicators you are looking at, followed by a descriptive list of a range of papers. It doesn't come across very clearly what these examples collectively show, or what the insight is from your analysis.

Response:

As part of the restructuring mentioned above, the revised Section 3.2.2 now incorporates summary sentences at the end of each paragraph to clearly articulate the collective insights derived from the examples. This improved structure better highlights current practices and gaps in the development and use of multi-hazard indicators, grouped under the categories of composite indicators, hazard frequency, hazard intensity, and hazard probability.

Bullet point starting on line 420 feels like it slightly contradicts your findings that 51% of the articles account for interactions between hazards (I was surprised it was this high!). This also appears in conclusions on line 528. Consider adding another sentence around line 420 to be more specific about what you think is missing from these studies.

Response:

Thank you for this comment. To clarify, the 51% number relates to papers that assessed multi-hazards (n = 89 of 174 in total) and included a reference to or a mention of indicators (see Methods for a more complete description). However, this number doesn't necessarily mean that 51% of these papers developed or used multi-hazard indicators – rather it means that indicators are mentioned, referenced and, in some cases used, in the context of multi-hazards. This was an important step in the review methodology that enabled us to then get to the few papers that did indeed develop and/or use indicators in this context, which we show progressively from Figures 2 to 4. We therefore elected to not highlight the 51% number as a key finding or takeaway from the paper. Instead, we focus on highlighting the relatively few examples of multi-hazard (and later multi-risk) indicators, which is the focus of this first key finding bullet point. With this added clarity, we believe this bullet point is therefore not contradictory and as

such we haven't made any further changes. However, noting the following reviewer's comment, we have added references back to the text for each key finding so the reader can now more easily link back to the relevant section that has led to it. In addition, we have amended the first line of Section 3.1.1 to reiterate the methodology used in the review to avoid confusion later on, as follows:

"This review analysed papers that assessed multi-hazards and/or multi-risks and included reference to or mention of indicators..."

Bullet points starting on line 420, it would be helpful to refer back to either sections of your findings or figures to help tie this together (just by section/figure number in brackets). I say this as the fourth and fifth bullet points are interesting but I don't think came across particularly clearly in your results. You might want to think about this with regards to my comment above that some of the paragraphs could do with a final sentence to synthesise/reflect and more explicitly make statements related to terminology and stakeholder engagement.

Response:

Thank you for this comment. We have added in references to the relevant sections / figures / tables at the end of each key finding. We have also taken the opportunity to slightly refine the text in a couple of these bullet points for clarity.

Writing on lines 461 - 466 feels more like results (and then if moved to results, possibly would answer my point above about the key finding of lack of stakeholder engagement not being that clear in the results section).

Response:

Thank you – this is a good observation and suggestion. We have moved this text to the second-to-last paragraph of Section 3.2.3, which now provides this information as a result, enabling the findings and recommendations to follow on from this.

Sentence on line 478 about EU funded projects - would be nice to reference a few of these projects or calls.

Response:

Thank you for this suggestion. We have added in a couple of examples.

Recommendation 3 in section 4.2 did not come through very clearly in the results or discussion. Consider how you could bring this through more clearly in the results section (or if it is already there, perhaps refer to the section it appears in).

Response:

Thank you. We agree that this did not come across that clearly in the results. However, the revision of Section 3.2.3 in response to one of RC1's review comments above now include a more detailed discussion of composite indicators with reference to regional contexts and socio-economic settings. However, we note that the final part of this recommendation is perhaps unsubstantiated in the results, hence we have removed the final "including policymakers, emergency planners, and affected communities" wording.

Line 133 - typo 'section 33'.

Response:

Corrected.

Line 238 need a space after studies, line 301 need a space after study.

Response:

Corrected.

Line 303 figure number is missing.

Response:

Corrected by including Figure 4a.