

Response to reviewer 1

Dear Authors,

I found the article original and, in my opinion, the paper addresses relevant scientific and/or technical questions within the scope of NHESS. I believe that the introduction provides a broad and comprehensive overview of the current state of knowledge, with appropriate references to the relevant literature.

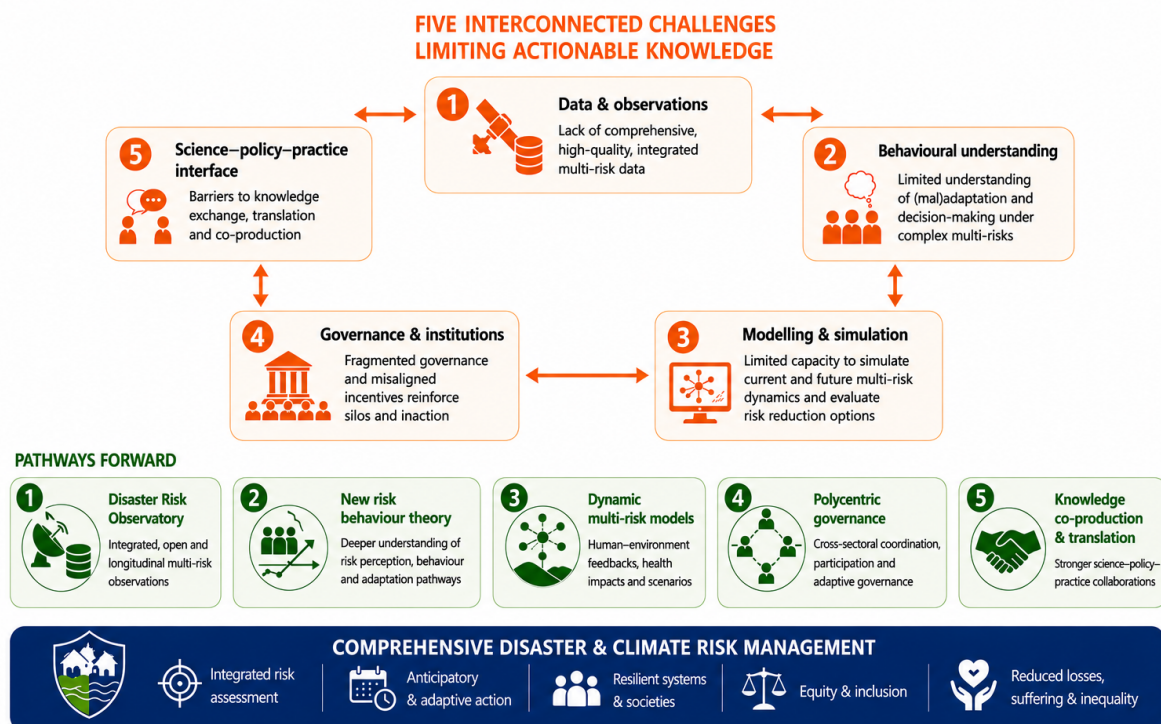
Many thanks for the generous words and for acknowledging the scientific value for the scope of NHESS. We thank the reviewer for the suggestions, which we will use to improve the manuscript - we reply to each of the suggestions point-by-point below.

Some suggestions, offered with humility:

First of all, I would recommend that the authors include some figures or graphics in the text, in order to break up the long written sections. A flowchart could be considered.

We thank the reviewer for the suggestion. We have designed, with the assistance of Generative AI, an overview figure that tries to bring the different elements of the paper together in one overview - please see the suggested figure below.

Towards Comprehensive Disaster and Climate Risk Management (CRM)



Furthermore, to improve clarity and ease of understanding, it would be more appropriate to adopt the conventional structure with Introduction, Materials and Methods, Results, Discussion, and Conclusions.

We thank the reviewer for the suggestion. However, we note that this paper was submitted as an Invited Perspective, described by NHESS as a perspective paper that aims to *present new ideas, views, or perceptions on a topical aspect of natural hazards*. We therefore do not feel that a classical research paper style would fit the perspective manuscript type, as we do

not aim to report original empirical research. Instead, after the introduction, we first set out to describe key challenges facing the development of comprehensive disaster risk management as well as outlining concrete ways forward (Section 2), and then provide an overcoupling outlook - our perspective - of how to achieve this.

Lines 35–36: in the introduction (why is the first paragraph written in italics?)

We wrote this in italics in order to provide a real-world example that brings together many of the various elements of our study. The italics were meant to show that this is a scene-setting, thought-provoking, example before coming to the core scientific text. However, if the editorial office prefers to put this paragraph in regular font we would be happy to change the style.

The example of Haiti is well explained, and when referring to the August 2021 earthquake, it would be useful to mention the number of fatalities, injuries, and missing persons (since it is extremely high and conveys the scale of the tragedy). Moreover, the risk associated with the concurrent COVID-19 pandemic has been overlooked: was this a deliberate choice? Is there a specific reason? Did the Government of Haiti also have to cope with this issue?

We thank the reviewer for this constructive feedback and for highlighting these important points, and we agree to strengthen the depth of the Haiti case study.

We completely agree that including these figures is essential to convey the true scale of the tragedy. In the revised manuscript, we explicitly add that the August 2021 earthquake resulted in at least 2,248 fatalities, over 12,000 injuries, and more than 300 missing persons (CDEMA, 2021; Government of Haiti, 2021).

The omission of the COVID-19 pandemic was not a deliberate choice to downplay its significance, but rather an oversight due to our primary focus on the immediate compounding physical hazards associated with the earthquake and/or Tropical Storm Grace. However, the reviewer is entirely correct that the pandemic was a major compounding stressor. We will add the following text: *“Moreover, at the same time the ongoing COVID-19 pandemic was a major compounding stressor: the Government of Haiti had to cope with the combined events of the aforementioned hazard shocks at a time that the healthcare system was already severely strained by the ongoing pandemic (Government of Haiti, 2021).”*

Lines 72–73: regarding rapid-onset hazards, our research group has discussed the experience following the 2016–2017 earthquakes in central Italy (when people were forced to relocate far from the epicentral areas) in several papers “Farabollini, P., Bendia, F., & Luger, F. R. (2023). Revitalizing the Wounded Territory: The “Geo-Hiking’s” Potential. In Disaster Resilience and Human Settlements: Emerging Perspectives in the Anthropocene (pp. 259-281). Singapore: Springer Nature Singapore” and also here “Farabollini, P., Aringoli, D., Bendia, F., Bufalini, M., Cingolani, R., Fuffa, E., ... & Prati, S. (2022). Geomorphology of the geo-itinerary of “Anello della Sibilla” between sciences, history and myth: a vehicle for the renaissance of the territories affected by the earthquake using GIS technologies. Rend. Online Soc. Geol. It, 58, 28-33”.

Thanks for the useful suggestions. We will add a reference to Farabollini et al. (2022), also adding “For example, hazards can lead to the immediate displacement of people as well as depopulation (e.g. Farabollini et al., 2022)”

Line 81: If the authors consider it appropriate, I would like to point out some papers that discuss the increase in the use of substances and drugs during and after disasters:

- North, C. S., Kawasaki, A., Spitznagel, E. L., & Hong, B. A. (2004). The course of PTSD, major depression, substance abuse, and somatization after a natural disaster. *The Journal of nervous and mental disease*, 192(12), 823-829;
- Beaglehole, B., Bell, C., Frampton, C., Hamilton, G., & McKean, A. (2015a). The impact of the Canterbury earthquakes on prescribing for mental health. *Australian & New Zealand Journal of Psychiatry*, 49(8), 742-750;
- Beaglehole, B., Bell, C., Beveridge, J., & Frampton, C. (2015b). Psychiatric admissions fall following the Christchurch earthquakes: An audit of inpatient data. *Australian & New Zealand Journal of Psychiatry*, 49(4), 346-350;
- Kanehara, A., Ando, S., Araki, T., Usami, S., Kuwabara, H., Kano, Y., & Kasai, K. (2016). Trends in psychological distress and alcoholism after The Great East Japan Earthquake of 2011. *SSM-Population Health*, 2, 807-812;
- Koyama, S., Tabuchi, T., Aida, J., Osaka, K., & Miyashiro, I. (2021). Determinants of increased tobacco consumption following a major disaster. *Disaster Medicine and Public Health Preparedness*, 15(1), 20-24;
- Lavery, A. M. (2018). Notes from the field: pharmacy needs after a natural disaster—Puerto Rico, September–October 2017. *MMWR. Morbidity and mortality weekly report*, 67;
- Amiri, H., Riyahifar, S., Nakhaee, N., & Nekoei-Moghadam, M. (2022). The long-term impact of the earthquake on substance use. *International journal of emergency medicine*, 15(1), 44.

Thanks for the useful suggestions. We will add references to North et al (2004), Beaglehole et al. (2015), and Kanehara et al. (2016).

Finally, it could be interesting to include one or two case studies or simulations in which the priorities identified in the paper are applied in a concrete way.

Thank you for the suggestion: we will add lines to the introduction (see below) to clarify that our paper intends to serve as an inspiration for future research endeavours by bringing together perspectives from a wide range of relevant disciplines, rather than demonstrating the application of the various aspects. Actually applying these approaches in real life would take major research efforts from across disciplines, and we aim to provide insights that can help to develop new integrative research programmes to achieve this in the future.

To stress this in the manuscript, we will add the following to the Introduction: *“Our paper aims to inspire future research endeavours by bringing together key perspectives from a wide range of relevant disciplines”*.

We will also add the final paragraph of the outlook section, to make this explicit, *“Our paper aims to inspire future research endeavours by bringing together key perspectives from a wide range of relevant disciplines, rather than demonstrating the application of the various aspects. Addressing these cross-cutting challenges requires concerted efforts that go beyond the traditional 1-4 year project cycle. To achieve the paradigm shift towards comprehensive disaster risk management, research efforts require time, resources, collaboration, and the creative space required to truly bridge silos, build trust, study both context-specificity and address generalisability, and engage in a meaningful way with ongoing political agendas such as the Sendai Framework for Disaster Risk Reduction, the*

WHO Health Emergency and Disaster Risk Management Framework, and the climate change agendas. We call for funding mechanisms that facilitate such a concerted and needed effort.”

Response to reviewer 2, Rodrigo Calderon

Dear Authors,

I found the manuscript to be a valuable and timely contribution to the discussion of current challenges in comprehensive climate risk management, particularly within the context of increasingly interconnected and multi-risk societies. The paper addresses relevant conceptual and methodological issues and highlights several important directions for future research and practice. In my opinion, the manuscript represents a meaningful contribution to the broader understanding of risk governance and multi-risk dynamics, especially through its integrative perspective across disciplines and hazard contexts.

Overall, the manuscript is generally well written, and most arguments are supported by relevant literature. The scientific discussion is clear and balanced in most sections, and the topic itself is highly relevant for the natural hazards and disaster risk reduction community. I also appreciated the effort to connect climate risk management with broader systemic and societal dimensions.

Many thanks for the kind words and for acknowledging the scientific value for the scope of NHESS. Indeed, it is one of our key hopes with this perspective to try to link the various communities that the reviewer mentions. We thank the reviewer for the constructive suggestions, which we will use to improve the manuscript - we reply to each of the suggestions point-by-point below.

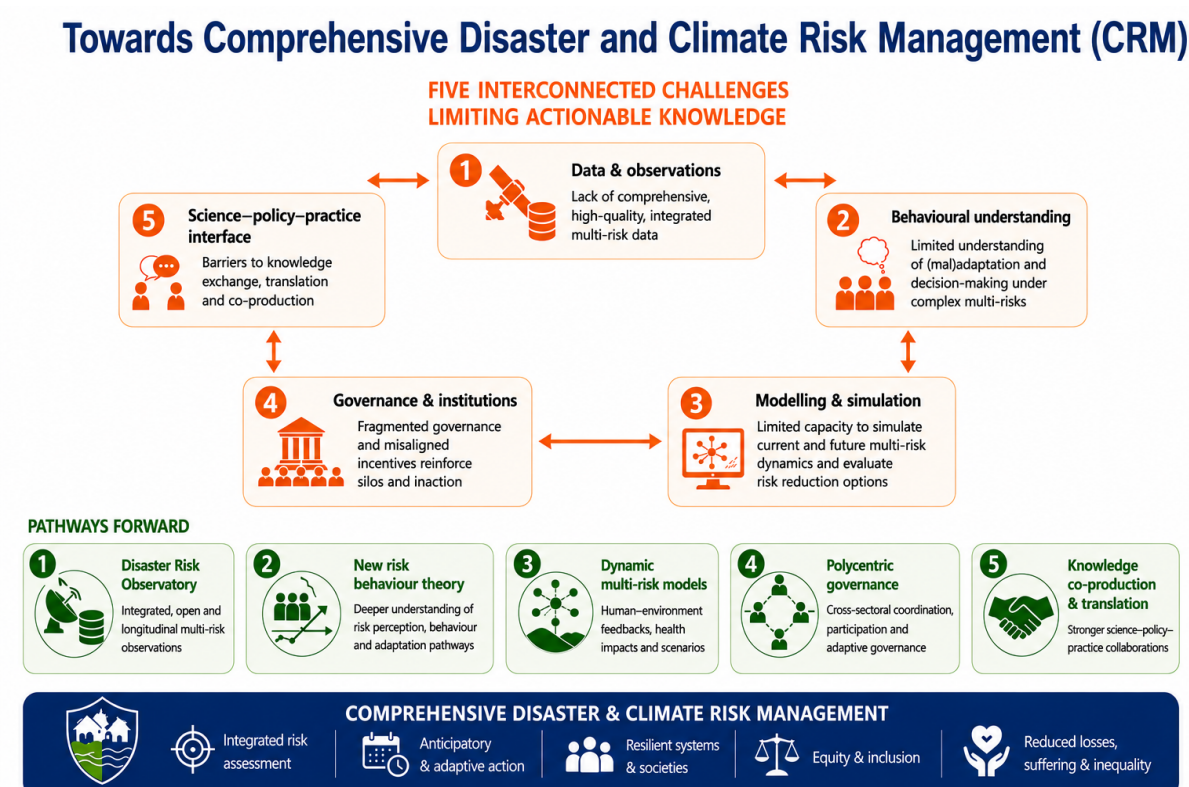
However, I believe the manuscript could be further strengthened in terms of methodological clarity and conceptual organization. In particular, the main limitation is the lack of a clearer explanation regarding how the identified topics were selected and categorized as key challenges. It would be useful for the authors to clarify whether these themes emerged from a systematic review, expert consensus, conceptual synthesis, or another methodological approach. The inclusion of a conceptual figure or integrative diagram showing the relationships and interconnections among the identified challenges could significantly improve the presentation and readability of the manuscript.

Thank you for both comments. With regards the former, we thank the reviewer for pointing out this omission. In fact, the challenges are based on the lived-experience of our wide team of authors through our work on this team, rather than a systematic approach. We will clarify this at the start of Section 2, by adding the following text:

“In the following sub-sections, we explore each of the aforementioned five core challenges, followed by concrete suggestions on ways forward to address them. The challenges were identified using the expert judgement of the interdisciplinary author team. This team consists of experts who have been working on the topic from different angles and disciplines, including climate risk, geophysical risks, biological hazards that

cause infectious diseases, social and behavioural science, disaster governance, public health, development studies, crisis management, societal resilience, and climate adaptation. The challenges are by no means exhaustive. Instead, the five challenges discussed represent key challenges that we regularly face through our multi-, inter-, and transdisciplinary endeavours in different contextual settings.”

With regards the latter point, we very much appreciate the suggestion. A similar comment was received from reviewer 1. As such we propose to add the following conceptual figure:



In addition, while the manuscript successfully highlights several relevant challenges, some complementary perspectives from social sciences, risk perception research, participatory governance, and community resilience studies could be incorporated more explicitly to broaden the discussion and reinforce several of the paper’s arguments.

Thank you for your suggestions. We discuss perspectives from social sciences in each of the sections 2.1-2.5, and believe that the need to integrate across domains is a key aspect of the paper. In particular, in Section 2.2 we discuss theories from economics, behavioural sciences, and related fields. We also discuss risk perception research on how risk perceptions affect behaviour. And in Section 2.4 we discuss participatory governance and community resilience.

Nevertheless, in the revised manuscript we bring the social sciences even more to the forefront - examples of some additions proposed are:

“It also neglects important feedback loops between behaviour and risk perception; for example, in theory, high risk perception may encourage adaptive responses, and resulting protective behaviour may result in lower risk perception, and one could theorize more such feedback loops based on models that exist (van Valkengoed et al., 2025). Current literature is unable to verify such hypotheses, because of the lack of longitudinal data and the lack of theoretical and empirical base on long-term development and interactions between the key constructs related to risk perceptions and behaviours. Longitudinal studies that monitor risk perception and behaviour over time are needed to identify such feedback loops.”

“An increasingly urgent question relates to citizens’ own capacity and willingness to mitigate and deal with multi-risks, as established institutions may no longer guarantee the same security in the face of cascading risks (e.g., insurance companies stopping insuring homes in areas prone to climate change risks). Moreover, public and/or community participation so far has limited structural and institutional embedding in multi-risk governance. Even where advisory groups (Baxter, 2019), participatory governance mechanisms (Barquet et al., 2017; Barton et al., 2020; Bierens, et al., 2020), and community-engaged risk management processes including living labs (Boersma et al., 2022) and citizen observatories (e.g. Cobweb¹, Safecast²) have emerged, they often suffer from limitations owing to semi-formalisation, as well as administrative, financial, and sectoral barriers. Additionally, political and budgetary cycles favour short term actions making it difficult to incentivise (and hold accountable) institutions for long term multi-risk funding and planning”

“A challenge is that simulating these interlinked processes at large scales yet high granularity requires a solid empirical foundation; this applies to all of the aforementioned dimensions, including the physical and socioeconomic processes, as well as socio-psychological aspects relating to behaviour and perception.”

“Integration of social sciences variables in datasets and models dominated by technocratic and cost-effectiveness-led approaches is urgently needed but remains challenging (Trutnevyte et al., 2019; van Valkengoed et al., 2025).”

Overall, I consider the manuscript to have strong scientific significance and a good overall scientific and presentation quality. With some additional clarification and expansion in specific areas, I believe the paper could become an even stronger contribution to the field.

Many thanks for the kind and encouraging comments.

Specific comments

Line 181:

Are these crises addressed through anticipatory approaches, including the use of counterfactual analyses or scenario-based studies?

Indeed, one of the ways in which we could better anticipate these kinds of crises could be through such approaches, which can be informed through learning from past experience. We will amend the text to reflect this:

“This information could also be used to allow us to better anticipate and prepare for future crises before they happen, for example using counterfactual studies. For example, in climate sciences the concept of climate storylines has become popular over the last decade (Shepherd et al., 2018; Sillmann et al., 2021; Cocuccioni et al., 2025). Climate storylines refer to “physically self-consistent unfolding of past events, or of plausible future events or pathways” (Shepherd et al., 2018), and they have recently been extended to the multi-risk context by Crummy et al. (2025), but more exploration could unlock their potential.”.

Line 240: The discussion would benefit from references to risk perception studies examining adaptive responses at the individual level. Relevant examples include Siegrist and Arvai (2020), Slovic (1987), and Wachinger et al. (2013).

Section 2.2 focuses on how and when risk perceptions affect risk protecting behaviour, and not on factors influencing risk perceptions that are the focus in the papers by Siegrist and Arvai, and Slovic, respectively. We will add the reference of Wachinger when referring to the protection motivation theory, which also emphasises the role of efficacy beliefs, and advantages of risky behaviours.

Line 257: This is an interesting point regarding risk perception. What insights do existing risk perception studies provide in this context? Additional references would help strengthen the argument.

This is an example of how one could theorise based on models that exist. The Protection Motivation theory states, for instance, that a perceived certain level of risk is one component for action. Yet, what do we know about what happens if people actually take action - how does that affect their risk perception and subsequent actions?

Longitudinal data are largely absent, so is theorising and evidence based for feedback loops between key constructs. We will add a reference to van Valkengoed et al. (2025) where more such possible feedback loops are presented with the emphasis that current literature is unable to verify those, forming urgent gaps in knowledge. We will also extend and add the text to read: *“It also neglects important feedback loops between behaviour and risk perception; for example, in theory, high risk perception may encourage adaptive responses, and resulting protective behaviour may result in lower risk perception, and one could theorize more such feedback loops based on models that exist (van Valkengoed et al., 2025). Current literature is unable to verify such hypotheses, because of the lack of longitudinal data and the lack of theoretical and empirical base on long-term development and interactions between the key constructs related to risk perceptions and behaviours. Longitudinal studies that monitor risk perception and behaviour over time are needed to identify such feedback loops”.*

Line 270: It may be useful to briefly define longitudinal data here as reinforcement of this important concept, beyond its earlier mention in Section 2.1.

Thank you for your suggestion. We will add the following sentence: *“Longitudinal studies that monitor risk perception and behaviour over time are needed to identify such feedback loops”*.

Line 275: The manuscript recognizes the growing need for greater integration of social sciences within climate risk management studies. Could the authors provide examples of current initiatives or interdisciplinary efforts addressing this gap?

We will add the following: *“The importance of better understanding the root drivers by better integrating social science knowledge is being taken up by UNDRR. For example, its Global Assessment Report Special Report 2024 (UNDRR, 2024) focused on how forensic insights from past disasters can shape future resilience. An example at project-level of bridging this divide is the UNITY project, which has the goal to develop an integrated assessment framework for pandemic preparedness and response in which biomedical, societal and economical perspectives are brought together to provide actionable, evidence-based advice for policymakers.”*

Line 284: The section title appears somewhat unclear or possibly incorrect. Perhaps “Risk simulation” or a similar term would better reflect the content of the section.

Thanks for pointing this out - it was indeed a typo. We will amend to “Simulating risk”

Line 294:

What characteristics are necessary for an effective multi-risk simulation framework? Is the inclusion of multiple hazards and longitudinal data sufficient, or should these simulations also incorporate dimensions such as physical vulnerability, health vulnerability, social vulnerability, and resilience?

These should absolutely be included. We aimed to cover this with the following sentence in the original manuscript: *“We propose a research shift towards simulations that include multiple hazards and their interactions, and also the dynamic interactions with exposure and vulnerability across time, while accounting for different societal groups.”*

However, in the revised manuscript we make this more explicit by including the following immediately after aforementioned sentence: *“This includes broadening the scope of analysis to include dimensions such as physical vulnerability, social vulnerability, health vulnerability, resilience, and agency/coping potential.”*

Line 307: It may be helpful to define what is meant by “dynamic vulnerability” in this context. Does this refer to temporal changes in social indicators and vulnerabilities resulting from cascading or multiple hazards?

Thanks for this important point. We will add the following: *“Here, we refer to changes in vulnerability in both space and time. Following De Ruiter and Van Loon (2022), these*

could be either: (1) underlying dynamics of vulnerability; (2) changes in vulnerability during long-lasting disasters, and (3) changes in vulnerability during compounding disasters.”

Line 324: It may be worth reinforcing the importance of local validation by acknowledging that disasters are inherently local processes, particularly from a disaster risk management perspective, and that locally grounded approaches are fundamental for strengthening community resilience. See, for example, Davies and Davies (2018).

Thanks for recommending this paper. We will add the following text: *“In reality, disasters are inherently local processes, with impacts taking place at the local scale, and therefore locally-relevant data are fundamental (Davies and Davies, 2018) for validating our models and allowing them to be used for strengthening community resilience”*.

Line 351: The objective of establishing an empirical foundation is highly relevant. However, how do the authors envision incorporating empirical methodologies that also integrate socio-psychological dimensions and data?

Indeed, this is what we would envision, bringing in all of those aspects covered earlier in the subsection. We will amend this sentence to be more explicit: *“A challenge is that simulating these interlinked processes at large scales yet high granularity requires a solid empirical foundation; this applies to all of the aforementioned dimensions, including the physical and socioeconomic processes, as well as socio-psychological aspects relating to behaviour and perception”*.

Line 363: What about experiences involving advisory groups, participatory governance, and community-engaged risk management approaches? Relevant examples could include Barton et al. (2020).

We proposed to address this comment by first adjusting the argument that there is “no” structural/institutional embedding for public/community participation to “limited”. We will also qualify the statement with some examples of these mechanisms: *“An increasingly urgent question relates to citizens’ own capacity and willingness to mitigate and deal with multi-risks, as established institutions may no longer guarantee the same security in the face of cascading risks (e.g., insurance companies stopping insuring homes in areas prone to climate change risks). Moreover, public and/or community participation so far has limited structural and institutional embedding in multi-risk governance. Even where advisory groups (Baxter, 2019), participatory governance mechanisms (Barquet et al., 2017; Barton et al., 2020; Bierens, et al., 2020), and community-engaged risk management processes including living labs (Boersma et al., 2022) and citizen observatories (e.g. Cobweb¹, Safecast²) have emerged, they often suffer from limitations owing to semi-formalisation, as well as administrative, financial, and sectoral barriers. Additionally, political and budgetary cycles favour short term actions making it difficult to incentivise (and hold accountable) institutions for long term multi-risk funding and planning”*

Line 446: What types of data derived from underrepresented voices would be most relevant to include as a fundamental basis for risk assessment and management? In

particular, how should the balance between the relevance, representativeness, and accuracy of risk-related information be addressed and evaluated?

We will extend the manuscript suggesting examples of data that could capture under-represented voices as a basis for risk assessment. We argue that integration of data into risk assessments requires an open, transparent, and contextual relevant approach. We propose to add the following: *“Under-represented voices can be captured through, for example, locally grounded accounts of hazard exposure, coping capacities, risk perceptions, lived experiences of cascading impacts, informal support mechanisms and collective action, and community-defined priorities that are often absent from conventional datasets. Formats for expression can vary depending on the under-represented group, context and location, and could include tacit knowledge dimensions, video, photo, and visual accounts (Anthonj et al., 2025). Evaluation of data in integrated risk assessments should go beyond statistical representativeness and empirical validity. There is a need for openness, transparent, contextually relevant triangulation and transferability.”*

Examples of references

Davies, T. R. H. and Davies, A. J.: Increasing communities' resilience to disasters: An impact-based approach, *Int. J. Disaster Risk Reduct.*, 31, 742–749, <https://doi.org/10.1016/j.ijdr.2018.07.026>, 2018.

Barton, T. M., Beaven, S. J., Cradock-Henry, N. A., and Wilson, T. M.: Knowledge sharing in interdisciplinary disaster risk management initiatives: Co-creation insights and experience from New Zealand, *Ecol. Soc.*, 25(4), 1–18, <https://doi.org/10.5751/ES-11928-250425>, 2020.

Siegrist, M. and Arvai, J.: Risk perception: Reflections on 40 years of research, *Risk Analysis*, 40, 2191–2206, <https://doi.org/10.1111/risa.13599>, 2020.

Slovic, P.: Perception of risk, *Science*, 236, 280–285, <https://doi.org/10.1126/science.3563507>, 1987.

Wachinger, G., Renn, O., Begg, C., and Kuhlicke, C.: The risk perception paradox: Implications for governance and communication of natural hazards, *Risk Analysis*, 33(6), 1049–1065, <https://doi.org/10.1111/j.1539-6924.2012.01942.x>, 2013.

New references cited by the authors above and in the revised manuscript (excluding those provided by the reviewers)

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- Cocuccioni, S., Pittore, M., Zebisch, M., Schneiderbauer, S., Shepherd, T. G., Casartelli, V., Crummy, J. and Pedde, S.: Risk Storylines: A Community-Led Discussion between Disaster and Climate Science, *B. Am. Meteor. Soc.*, 106, E1717–E1723, <https://doi.org/10.1175/BAMS-D-25-0155.1>, 2025.
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- Davies, S. R.: Participation as pleasure: Citizenship and science communication, in: *Remaking Participation*, edited by: Chilvers, J. and Kearnes, M., Routledge, London, UK and New York, USA, 2015, 162-177.
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