Response to Review Comments of Referee #1

Dear Editor and Referee,

Thank you for offering us an opportunity to improve the quality of our submitted manuscript (**egusphere-2025-2706**). We appreciate very much the referee's constructive and insightful comments, which are helpful for our current submission and future research. We fully acknowledge the referee's concerns regarding the relatively narrow time window and the exclusive reliance on a ≥50 fatalities threshold, which may potentially limit the robustness and representativeness of a global multi-disaster risk assessment index. In the following, we would like to respond to these concerns from two perspectives: methodological intent and practical data considerations.

1 Response to the issue of a narrow time window

We sincerely thank the referee for acknowledging the contributions of our study and for raising important concerns regarding the relatively narrow time window adopted in our analysis. We fully understand and respect the referee's view that a limited temporal scope may constrain the representativeness and generalizability of the results. This concern is indeed valid and is one of the reasons why we clearly stated in the manuscript that the present work is a preliminary and exploratory study. We would like to provide further clarification on the rationale and considerations behind our selection of the 2013-2023 time window.

First, we fully recognize the well-established principle in disaster risk research that the occurrence frequency of natural hazards tends to decrease as their intensity increases. This has led many risk assessment studies to adopt longer temporal spans in order to capture a greater number of high-intensity, low-frequency extreme events. However, time window selection must also strike a careful balance between data reliability and contemporary relevance. The core objective of our study is to establish a framework for assessing the recent accumulative impacts of multiple natural hazards across global regions, and to provide a data foundation for future long-term analyses. Our decision to focus on the 2013-2023 period was based on the following key considerations:

1) Data consistency and completeness: Earlier disaster records often suffer from missing entries, inconsistent reporting standards, and definitional ambiguities. These issues are particularly prevalent in developing countries, which are the primary focus of our study. As explicitly stated on the EM-DAT website, "Pre-2000 data is particularly subject to reporting biases" (https://www.emdat.be). Since the early 21st century, EM-DAT has made significant improvements in data standardization, event classification consistency, and geolocation accuracy (Delforge et al., 2025). As such, the 2013-2023 dataset offers a higher level of global comparability and reliability, which is essential for grid-based spatial analysis.

2) Disaster pattern shifts driven by climate change: In recent years, disaster frequency, intensity, and spatial distribution have been undergoing noticeable changes, largely influenced by global warming and other climatic anomalies. An increasing body of literature has documented a significant upward trend in both the frequency and severity of natural hazards over the past decade (e.g., Hussain et al., 2023; Wen et al., 2023). We observed that mainstream global disaster risk indices have not yet fully incorporated this recent dynamic phase. A much longer time window could dilute or obscure these climate-induced trends, thereby undermining the development of risk indicators that reflect the current and evolving risk landscape. We therefore believe that a shorter but higher-quality time window is more appropriate for capturing the emerging spatial patterns and intensity shifts under a changing climate regime.

3) Complementarity with existing risk indices: Our proposed Accumulated Risk Index (ARI) is not intended to replace existing tools such as the World Risk Index (WRI), but rather to serve as a complementary indicator that focuses on the accumulative effects of recent major disaster events, which are often overlooked by long-term averaged risk metrics. From a

methodological standpoint, ARI emphasizes the short-term concentration and accumulation of disaster impacts, which distinguishes it from frameworks like WRI that emphasize structural vulnerability and long-term exposure. We observed that many developing countries suffer from repeated disaster losses not because of the severity of a single event, but because new events occur before communities have had time to recover from previous ones. The World Risk Report (WRR) has also stressed that the structural vulnerability of high-risk countries often stems from accumulative impacts rather than one-off disasters (Frege et al., 2023). Therefore, identifying high-frequency, high-impact zones within a shorter time window is essential for informing emergency response planning and humanitarian aid prioritization.

We acknowledge that the referee's suggestion to extend the time window is of great scientific value, and we agree that including a longer temporal span may enhance the statistical robustness of the results. However, doing so may also dilute the distinctiveness of recent accumulated risk patterns, thereby weakening the expressive power of the ARI in capturing recent hazard concentrations. At present, we have not yet arrived at a perfect balance between capturing "recent accumulative effects" and "long-term average risk". To address this tension, we plan to explore the integration of temporal weighting coefficients in future research, which would allow us to differentiate between historical hazard frequency and recent disaster impact intensity, thereby achieving a more nuanced temporal representation of risk. Furthermore, we also intend to extend the temporal coverage to include disaster events from 2000 to 2023 in future studies. We will conduct sensitivity analyses using different time windows (e.g., 2000-2023 vs. 2013-2023) to assess the spatial stability and variability of the ARI across scenarios. These efforts will help enhance the adaptability, transparency, and scientific rigor of the proposed framework.

2 Response to the issue of a ≥50 fatalities threshold

We sincerely thank the referee for raising this important and fundamental issue. The selection of representative and reliable impact indicators remains a key challenge in the field of disaster risk assessment (Yarveysi et al., 2023; Marin et al., 2021). In our study, the proposed ARI integrates two components: the number of major disaster events occurring within each geographic grid as the primary statistical basis; and a country-level weighting factor derived from the WRI, which incorporates dimensions of exposure and vulnerability, further encompassing variables such as population density, hazard intensity, and governance capacity. In response to the referee's concern, we would like to specifically clarify the rationale for selecting "Total Deaths" as the criterion for identifying major disaster events.

We fully acknowledge and agree with the referee that "Total Deaths" is not a flawless risk measure. Its magnitude can be influenced by various extrinsic factors, such as the time of event occurrence, the effectiveness of hazard warnings, or the resilience of local infrastructure. For this reason, we carefully reviewed the full suite of impact indicators recorded in EM-DAT, prior to establishing our selection threshold. EM-DAT records 11 types of disaster impact indicators, broadly grouped into two categories: 1) Population-based indicators: Total Deaths, No. Injured, No. Affected, No. Homeless, Total Affected; 2) Economic-based indicators: Reconstruction Costs, Reconstruction Costs (Adjusted), Insured Damage, Insured Damage (Adjusted), Total Damage, Total Damage (Adjusted).

Despite this comprehensive structure, it is important to note that these indicators are not uniformly complete. In particular, economic indicators suffer from severe data gaps, especially in less developed countries, which are the primary focus of our study. These gaps are often attributable to the limited administrative capacity and underdeveloped statistical systems in such regions. Using economic-based indicators as a filtering criterion could therefore introduce significant selection bias and reduce the reliability of the overall risk assessment (Peduzzi et al., 2009). Similarly, population-based indicators such as "No. Affected" or "No. Homeless" are known to carry a high degree of subjectivity and estimation error, as their definitions and measurement methodologies vary considerably between countries (Newman and Noy, 2023; Peduzzi et al., 2009). In contrast, "Total Deaths" remains the most consistently recorded and objectively defined indicator across regions, particularly in data-scarce environments. It offers the highest level of global comparability among all available impact metrics.

To further ensure the statistical reliability of our selected events, we applied a stricter selection threshold: only disaster

events with fatalities ≥50 were retained. This is well above the minimum criteria used by EM-DAT for event inclusion (e.g., 10 deaths or 100 people affected), and was adopted to filter out small-scale or marginal events that may introduce analytical noise. By concentrating on high-severity, high-impact events, we aimed to improve the robustness and representativeness of the ARI results.

Additionally, our decision to set this threshold was also informed by the need to ensure compatibility with remote sensing applications. The 3H Dataset introduced in our study is constructed based on ARI-identified high-risk grids. In these zones, disasters resulting in large death tolls often correlate strongly with observable physical destruction, such as collapsed buildings (Ceferino et al., 2024), facilitating effective integration with satellite imagery for future disaster detection and classification models.

That said, we are fully aware that using this threshold may result in the exclusion of some moderate or small-scale events, and may limit sensitivity in certain regions. However, the objective of the ARI is to capture the short-term accumulative effects of large-scale disasters with significant societal impact, rather than to catalog all hazard occurrences. This aligns with our methodological design and resonates with insights from the WRI, which has emphasized that many high-risk countries are characterized by recurrent or compounding disasters that continually erode their response and recovery capacities (Frege et al., 2023). These accumulative effects, not just the intensity of single events, form the structural basis of their long-term vulnerability.

As also stated in the manuscript, the current work is intended as a preliminary study that draws scholarly and policymaker attention to the layered risks faced by developing countries, particularly under conditions of frequent, overlapping natural hazards. We hope this framework can support more equitable and needs-based global humanitarian planning. Looking ahead, we plan to refine the ARI methodology by introducing composite severity indicators to better reflect the multifaceted impacts of disaster events. We also intend to explore distribution-based weighting schemes to dynamically adjust the contribution of different events according to severity, thereby enhancing the model's precision and flexibility.

This concludes our point-by-point response to the referee's comments. Thanks to these insightful suggestions, we have come to recognize that the current manuscript did not sufficiently elaborate on certain methodological boundaries of the study. Accordingly, in the revised version of the manuscript, we have added a forward-looking statement at the end of **Section 4** to attempt to address these limitations and outline directions for future work. This newly added content is highlighted in blue font to facilitate review by both the referee and the editor:

Looking ahead, future studies will aim to further improve the ARI framework by expanding the temporal scope of disaster events beyond the 2013-2023 time window and incorporating additional severity indicators, such as affected population and economic loss, where data quality permits. These enhancements are expected to improve the comprehensiveness and robustness of multi-hazard risk assessments, particularly in underdeveloped regions. Moreover, dynamic weighting schemes that distinguish between recent and historical disaster impacts may be explored to better capture the temporal layering effects of hazard exposure.

Once again, we sincerely appreciate your positive comments and valuable suggestions on our manuscript. We hope this clarification addresses the referee's concern and illustrates the careful balance we sought to achieve between methodological rigor and data reliability. We are grateful for the opportunity to improve the manuscript and will continue expanding the index toward broader temporal and indicator coverage in future work.

Kind Regards,

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