

Response to Reviewer 2

We are grateful to the reviewer for her observant attention and dedicated time invested in the thorough review of the manuscript. We dutifully engaged in responding to each of the meticulous comments in order to meet the rigorous academic requirements set forth by the reviewer.

Please find below the point-by-point responses. The line numbers correspond to the updated manuscript with track changes.

The reviewers' comments are written in italics, and our responses are in regular font. We chose blue and italic formatting for citations from the manuscript. All of the line numbers refer to the reviewed version of the manuscript.

R2: *The work presented in this manuscript delves into the challenging and forward-looking realm of assessing vulnerability dynamics arising from multi-hazard risks. It does so by introducing a novel application of Impact Chains within a multi-hazard framework. For these reasons, **this work holds significance and potential for publication following substantial restructuring.***

Response: We greatly appreciate the interest and positive feedback from the reviewer. Indeed, the manuscript was substantially restructured and contracted, as explained below. Overall, we reduced the size of the paper to 78% of its initial size and massively restructured the Methodology and Results sections according to the contraction of the aim. Furthermore, we revised the approach to center around a single Impact Chain (the enhanced version) to facilitate clarity and comprehension.

R2: *I report hereafter the major issues that I strongly encourage the authors to fix before publication:*

The final aim of this work is not well explained in the introduction. Is the analysis of multi-hazard pandemic-floods vulnerability dynamics in Romania the main goal, or is it the development of an "enhanced" multi-hazard Impact Chain approach? The authors should pay more attention in framing their research question.

Response: We clarified the aim of the paper at lines 102-109, contracting it to focus on the dynamics of vulnerability in the selected multi-hazard context. This goal was achieved by developing an enhanced Impact Chain. The confusion attentively noted by the reviewer was addressed at lines 102-109: *This study aims to address the research gap regarding the dynamics of vulnerability in a multi-hazard context by analysing the increases in vulnerability that stem from hazard impacts and adaptation options, taking as a case study the co-occurrent extreme river flood events and the COVID-19 pandemic in Romania in 2020 and 2021. The proposed methodological framework relies on an enhanced version of the initial Impact Chain developed within the Paratus Project (PARATUS Deliverable 1.1 202) to document the two-year unfolding of the two independent but co-occurrent hazards. This was upgraded to capture the shifts in vulnerability by enriching it with additional elements and connection types.*

R2: Lines 93-94: It is not explained which specific transformation has been performed to the original Impact Chains approach. Clarifying this from the outset of the paper would be advantageous, as it would better underscore the novelty of the approach and its advancement beyond the current state-of-the-art. Additionally, it would be beneficial to provide a brief explanation of what are Impact Chains in the introduction, outlining their typical development purpose and traditional field of application.

Response: We thank the reviewer for this valuable suggestion. We added a brief definition of Impact Chains in the Introduction (lines 110-113): *Impact Chains are conceptual models designed to visualise, document, and analyse the interconnections between hazards, vulnerability, and exposure that ultimately give rise to a specific risk (IPCC 2014, Zebisch et al. 2017). In this study, we refined the model to focus on the vulnerability dynamics in a multi-hazard context.*

This is followed by a paragraph with a presentation of the merits and novelty of this approach (lines 113-130). Furthermore, the state-of-the-art details are given in Methodology, at lines 274-287, and the enhancement of the chain is thoroughly presented in the new Section 3.2. Enhancing the Impact Chain.

R2: The paper is very long and sometimes difficult to follow. I invite the authors to consider shortening some sections. More specifically, I suggest shortening Sections 2 and 4.

Response: Truly, the initial length of the paper hindered the following of the read thread and the easy understanding of the ideas. We thank the reviewer for having the patience to go through the paper and highlight what we have to change to make this a more pleasant experience for future readers. The size of the manuscript was reduced by 22%. Section 2 (Setting the scene) was shortened to 70% of its prior length, and Section 4 (Results) to 62% of its prior length. As the objective of the paper was contracted, Section 4.1. (presenting the multi-hazard impacts) was removed altogether.

R2: Lines 152-154: warnings do not always result in actual floods. It's unclear how you linked warnings to real flood events. Did you incorporate data from other sources, as indicated in line 158? This aspect lacks clear elucidation. If mentioned, it should be elaborated upon, including details of the validation procedure.

Response: This shortcoming was clarified at lines 183-186: *The flood events taken under analysis in this paper were identified using the hydrological warnings issued by the National Institute of Hydrology, and Water Management during 2020-2021, which were corroborated with information from a national news platform. Multiple news reports were used for the validation of each extracted piece of information.*

R2: The methodology, as explained in Section 3 and illustrated in Figure 4, is very complex and difficult to understand and follow. More specifically, I do not understand the rationale behind presenting two distinct impact chains —the one from the PARATUS project and the one incorporating vulnerability dynamics, and to make a comparison among them (e.g., in Fig.7). In my view, this unnecessarily complicates the methodology and results presentation, potentially confusing the reader. Instead, it would be advantageous to emphasize the modifications made from the original Impact Chains approach to the one delineated in this paper. This should encompass alterations introduced to accommodate multiple hazards as well as those aimed at identifying patterns of dynamic vulnerability. I suggest restructuring the overall methodology to simplify it and also change the presentation of the results in Chapter 4 accordingly.

Response: We align with the reviewer's opinion on the convoluted structure of the initial Methodology section. We restructured it according to the new aim (focusing only on analysing the dynamics of vulnerability), removing the former Section 3.2. Exploring the Impact Chain. The new approach relies only on the enhanced version of the Impact Chain, with the modifications made from the original presented at lines 283-288, and 368-406. Please note that we also simplified the methodological workflow figure (new Figure 3). By contracting the aim and simplifying the steps associated with the new objective, we removed 64% of the steps in the initial Methodology and shortened this section by 27.78%. The Results section was also modified to match the changes in Methodology.

R2: *Line 224: The Impact Chains approach is a standardized and codified procedure, well-developed and documented in a substantial body of literature. Given that this work builds upon the "original" Impact Chains approach, it is essential to provide additional background references on this methodology and introduce its founding principles in more detail. Regarding the references, please consider citing the following:*

Menk, L., Terzi, S., Zebisch, M., Rome, E., Lückerath, D., Milde, K., & Kienberger, S. (2022). Climate change impact chains: a review of applications, challenges, and opportunities for climate risk and vulnerability assessments. Weather, Climate, and Society, 14(2), 619-636.

Zebisch, M., Schneiderbauer, S., Fritzsche, K., Bubeck, P., Kienberger, S., Kahlenborn, W., ... & Below, T. (2021). The vulnerability sourcebook and climate impact chains—a standardised framework for a climate vulnerability and risk assessment. International Journal of Climate Change Strategies and Management, 13(1), 35-59.

Schneiderbauer, S., Baunach, D., Pedoth, L., Renner, K., Fritzsche, K., Bollin, C., ... & Ruzima, S. (2020). Spatial-explicit climate change vulnerability assessments based on impact chains. Findings from a case study in Burundi. Sustainability, 12(16), 6354.

Response: We are very grateful to the reviewer for pointing out this issue and for providing us with the above-mentioned references. Details on previous applications of Impact Chains were included at lines 274-288, highlighting the differences between them and the current approach: *Impact Chains represent conceptual models designed to facilitate the investigation of climate and disaster risk under a structured analysis framework for the risks associated with climate-related impacts (UNDRR 2022). They have been used for elicitation, conceptualisation, analysis, and information sharing purposes, as tools that explore and analyse the impacts of single hazards or multi-hazards specific to past or potential hazardous events, following different operational frameworks (e.g., expert workshop, desktop analysis, machine-generated) and taking into consideration different spatial and temporal scopes (Pittore et al. 2023). There are numerous examples where Impact Chains were integrated into vulnerability or risk assessments specific to climatic aspects (Becker et al. 2014, Schneiderbauer et al. 2020, Zebisch et al. 2017, 2021, Menk et al. 2022).*

In this paper, Impact Chains were used as models of cause and effect (Menk et al. 2022) that were upgraded to capture the augmentation of vulnerability by hazard impacts or adaptation options, with a limited participation of stakeholders (i.e., only integrating the feedback of first responders involved in flood emergency interventions).

Unlike the scientific papers reviewed by Menk et al. (2022), this study does not integrate Impact Chains as tools for the assessment of vulnerability or risk pertaining to a climatic hazard, but broadens their scope to focus on vulnerability dynamics within a multi-hazard context that involves a hydrological hazard (i.e., flood) and an epidemiological one (i.e., the COVID-19 pandemic). This approach aligns with Zebisch et al. (2021) recommendation that the “relatively linear and sectorial approach of impact chains could be widened to impact webs, which would include feedback relations and cross-connections.”

R2: *The “enhanced” Impact Chains approach introduced in this manuscript is presented in several sentences along throughout the text as a predictive tool. However, it appears that Impact Chains are primarily utilized as an analytical tool to deepen the understanding of multi-hazard vulnerability dynamics. I encourage the authors to reconsider this aspect and revise this concept throughout the manuscript.*

Response: We thank the reviewer for this tuned suggestion that we accordantly applied throughout the manuscript. The Impact Chain was upgraded to focus on the analysis of vulnerability dynamics and in the future we plan to further improve it and turn into a diagnosis and prediction tool (in another paper). In the reviewed manuscript, we addressed these concerns at the beginning of Methodology, at lines 252-257: *The proposed methodological framework aims to identify and analyse the augmentation in vulnerability conditions within a multi-hazard context. This framework dwells on Impact Chains as instruments for documentation, visualisation, organisation, and scientific inquiry, ultimately broadening their application to fit the objective of studying the dynamics of vulnerability – particularly the augmentation of vulnerability and henceforth to turn them into diagnosis and prediction tools. With this addition, the documentary focus of the chain progresses to a more analytical stance, specifically geared towards identifying and tracking the transformation of specific vulnerabilities into drivers of vulnerability.*

and also at the end of the Introduction, at lines 127-130: *This can be achieved by expanding the scope of Impact Chains to give visibility to such shifts in vulnerability, and further on to diagnose past or present multi-hazard risk management, and to predict potential crises, shortcomings of management approaches, and the transformation of certain vulnerabilities into drivers of vulnerability.*

R2: *Section 3.2 – “Exploring multi-hazard impacts” presents several unclear points.*

How the “relevance” and “confidence” parameters are related to the identification of multi-hazard impacts?

Response: As we contracted the aim of the paper to focus on the analysis of vulnerability dynamics, the Exploring multi-hazard impacts parts in Methodology and Results were deleted. Please note that these changes were also required by the first reviewer.

We decided to pursue the deleted objective (of analysing the multi-hazard impacts) in a forthcoming paper. The following insights from the reviewer are much appreciated, as they underscore the improvements we have to implement in the new planned paper, helping us to avoid future misunderstandings.

However, we want to briefly clarify the issues raised by the reviewer. The relevance and confidence parameters were assigned values from 1 to 10, with the highest scores pertaining to multi-hazard aspects. Thus, a high relevance to the multi-hazard coupled with a high confidence score indicated the multi-hazard impacts we had to focus our analysis on.

R2: *The “relevance” and “confidence” parameters are determined by applying the logical data model provided in Figure 5. However, interpreting this scheme may prove challenging for the reader without a more detailed explanation in the main body of the text. Please, explain more in detail.*

Response: The entire former Section 3.2. was deleted, and implementing the suggested changes in the current manuscript was thus rendered unnecessary. We noted this recommendation and will implement it in our future paper.

R2: *Please consider explaining the significance of the two metrics presented in Table 2 for identifying multi-hazard impacts. This could also be achieved by incorporating a dedicated column directly into the table.*

Response: We will consider this observation for the future paper. In this manuscript, the change is unnecessary because it no longer aligns with the ideas presented in the former Section 3.2. regarding the analysis of multi-hazard impacts.

R2: *The presentation of the Results in Section 4 does not follow the same structure of the methodology, as it is presented in Section 3, and this is not facilitating the understanding of the overall work. I suggest the authors simplify the methodology illustrated in Section 3 and then present the results accordingly.*

Response: Both the Methodology and Results sections were restructured and partially rewritten to match the contracted aim of the paper. The Methodology section was simplified and reduced to 72.22% of its initial length. Now, it is structured around the enhanced version of the Impact Chain, with 2 sections: the first presenting the building of the Impact Chain initially developed within the Paratus Project, and the second presenting the enhancements implemented to the Impact Chain to capture the various types of vulnerability augmentation. The Results section was shortened to 62% of its initial length, deleting the former Section 4.1. that referred to the multi-hazard impacts. Now, the Results focus only on the augmentation of vulnerability and align well with the new Methodology section.

R2: *Lines 400-401: It is still not clear to me how the Kumu metrics and the relevance parameters are combined to practically identify multi-hazard impacts. This aspect lacks clarity in Section 3 and remains somewhat ambiguous even when transitioning from the methodology to the results. The authors should provide a clearer and replicable explanation of their methodology, particularly concerning the novel aspects they have introduced.*

Response: We recognise the value of this observation and have noted it to amend in the future paper. In this manuscript, we removed the goal of analysing the multi-hazard impacts based on the relevance and Kumu parameters, the corresponding Section 3.2. in Methodology, and Section 4.1. of the Results. The new methodological framework highlights the novel aspects in the new Section 3.2. Enhancing the Impact Chain (lines 367-436). In addition, the new Figure 3. Methodological workflow should illustrate in a clearer, simplified way the main steps of the methodology.

R2: *Following from the previous point, I strongly recommend that the authors incorporate into the Appendix an integration of the original Impact Chains guidelines by Pittore et al. (2023). This would require presenting the new elements they have introduced to the methodology in a standardized and replicable manner.*

Response: We thank the reviewer for this suggestion and have carefully discussed it. However, including the guidelines by Pittore et al. (2023) seems to bring little value to

the manuscript, as they are readily accessible through the provided reference. Including them would increase the length of the paper and introduce a didactic tone that we would like to avoid.

R2: *Section 5.2: I invite the authors to discuss also some methodological limitations or assumptions they made, which are currently not mentioned, e.g. the limited participation of stakeholders in the construction of the Impact Chains. Indeed, Impact Chains are well suited for use in a transdisciplinary perspective for the co-production of knowledge.*

Response: We profoundly reflected on this comment and agree with the reviewer. The participation of stakeholders is limited to the feedback offered by first responders who performed on-site interventions during the flood events of 2021. We noted this limitation in the new Section 5.3. Limitations and constraints, together with other 2 methodological limitations, at lines 134-142: *The implication of stakeholders in the construction of the multi-hazard Impact Chain is limited to the feedback provided by first responders who performed on-site emergency interventions during the floods of 2021 (Fekete et al. 2023). Future research directions focus on a broader involvement of different stakeholders in order to maximise the benefits of co-produced knowledge and refine the details specific to the multi-hazard context from a transdisciplinary perspective. A notable methodological limitation refers to the lack of testing against other case studies and external validation; which we plan to address in the future by applying the methodological framework to other Impact Chains focusing on different multi-hazard case studies. Finally, the paper provides a limited view on the dynamics of vulnerability, relying only on two temporal pictures captured by the initial Impact Chain and the enhanced version of it. Some of these methodological limitations are inherent to Impact Chain-based analyses, as highlighted in the literature review performed by Menk et al. (2022).*

R2: *The entire manuscript would benefit from a systematic review of the language, including enhancements to the vocabulary and terminology.*

Response: During the review process, we reread and rewrote large parts of the manuscript, amending all of the identified language errors and vocabulary/terminology-related shortcomings. With the help of reviewers, the new version of the manuscript is improved in this regard too.

Other medium to minor issues:

R2: *Lines 30-31: The authors affirm that the co-occurrence of COVID-19 and other natural hazards has “caused a paradigm shift” from multi-layer single hazard approaches to interacting hazards. Indeed, the shift has been started before the occurrence of COVID-19. The co-occurrence of COVID-19 and other natural hazards has instead increased the attention to potential synergies and asynergies between pandemics and other hazards from the Disaster Risk Management and Emergency Management perspectives (see Terzi et al, 2022). Please, consider rephrasing this sentence.*

Response: Yes, we acknowledge the nuance highlighted by the reviewer. We rephrased the idea (lines 33-38) as: *In the field of Disaster Risk Reduction (DRR), the co-occurrence of natural hazards of various types and magnitudes amid the COVID-19 pandemic has increased attention to potential synergies and asynergies between pandemics and other hazards (Terzi et al. 2022). Even before the pandemic, multi-*

hazard analysis switched its focus from analysing all the hazards that can affect an area in a given period of time, which is often called multilayer single hazard analysis (Gill and Malamud 2014) or “all-hazards-at-place approach” (Hewitt and Burton 1971), to analysing the interactions between the hazards that overlap in time and space (De Angeli et al. 2022).

R2: Lines 34-35: please add references for the Sendai Framework and the Paris Agreement.

Response: We provided the references for the Sendai Framework and the Paris Agreement at line 39.

R2: Lines 42-43: “a European country”. I think it would be more beneficial to indicate directly which country.

Response: Yes, we clarified that the European country in question was Romania (line 50).

R2: Lines 61-62: Here there is a sudden shift of topic. The authors previously discussed vulnerability dynamics up to line 61, but then abruptly shifted focus to operational hazard management procedures during the COVID-19 pandemic. It seems there's a gap here, lacking a sentence that introduces why and how COVID-19 has posed challenges from a multi-hazard perspective.

Response: We thank the reviewer for helping us improve the flow of the Introduction. Indeed, we identified the missing link between the two ideas. The shortcoming was amended by adding the following connecting phrases at lines 69-72: *The interactions between the COVID-19 pandemic and co-occurrent natural hazards add layers of complexity to analysing vulnerability dynamics and constructing DRM models that factor in this dynamics. The complications arise from the necessity to adjust traditional natural hazard management approaches to the new pandemic conditions, with implications for both the impacts and the adaptation options that can increase vulnerability.*

R2: Table 1. This table, as it is presented, is not very informative and useful. It would be more beneficial to add a column to specify which kind of management issue has been encountered in each of the presented real-world cases.

Response: We deleted Table 1 in order to shorten the Introduction (as requested by the first reviewer). The references from the table were included in the paragraph at lines 73-79, which also highlights the overall management issues depicted in the case studies referred to: *Scientific literature provides several examples (Andrews 2020, Majumdar and Dasgupta 2020, UNDRR 2020, Kassegn and Endris 2021, Mangubhai et al. 2021, Mishra et al. 2021, Patwary and Rodriguez-Morales 2021, Pramanik et al. 2021, Izumi and Shaw 2022) that point out failures of hazard management, which stem from the fact that standard operational procedures were not adapted to pandemic conditions, or from the fact that the efforts of tilting the SARS-CoV-2 infection curve were not adapted to fit hazard management practices. In recent years, this conundrum has become a hot topic in the field of DRM, being debated by numerous scientists (Frausto-Martínez et al. 2020, Quigley et al. 2020, Potutan and Arakida 2021, Albulescu et al. 2022, Hariri-Ardebili et al. 2022).*

R2: Section 4.1, lines 378-381: several hazards are mentioned, but only pandemics and floods are selected. The authors should support this choice by providing some evidence. Moreover, I suggest moving this discussion to the beginning of Section 2, when the case study of floods and COVID-19 is discussed for the first time.

Response: According to the new aim, we deleted Section 4.1. which detailed the multi-hazard impacts. We value the suggestions on how to improve Section 2 by motivating the choice of the flood and COVID-19 hazards. We addressed this by introducing the following phrase at lines 133-135 in the beginning of Section 2: *Floods, the COVID-19 pandemic, and heavy rainfall were considered primary hazards within the Impact Chain, but only the first two are analysed in this study due to their significant impacts. Other secondary hazards (e.g., strong wind, landslides) co-occurred with the other two, but their role was of lesser significance in the analysed multi-hazard context.*

The motivation for the selection is presented at lines 152-158: *Floods are among the most common and impactful natural hazards that affect Romania, causing significant damage throughout the country. The EM-DAT (2023) database includes 102 natural hazardous events that occurred in Romania in 1900-2023, of which flood events represent almost 52%. These floods resulted in more than 1700 deaths, more than 146600 homeless people, over 1.64 million affected people, and total estimated damages of about 8.69 billion dollars. This incomplete dataset, complemented by other European flood-related databases (e.g., HANZE v2.1 developed by Paprotny and Mengel 2023, Paprotny et al. 2023) points out the prominence of floods among the natural hazards that occur in the country of reference.*

and at lines 213-217: *Until the beginning of June 2023, more than 3.4 million cases of COVID-19 and over 68,000 deaths were registered in the country of interest, of which 53.07%, respectively 86.09% can be traced back to the first two pandemic years (WHO Dashboard 2023). The largest number of both COVID-19 cases (1,179,282) and COVID-19-induced deaths (43,118) occurred in 2021. This human toll unfolded in five pandemic waves (Figure 32), of which the fourth one, starting in 2022, was the most aggressive.*

R2: *Section 4.1: it would be beneficial to include a table summarizing the main multi-hazard impacts discussed in the text.*

Response: Given that Section 4.1. was completely deleted (as it no longer matched the contracted aim of the paper), the inclusion of a new table can be viewed as unnecessary. Nevertheless, we noted the useful recommendation and will include it in the future paper that will integrate the text of former Section 4.1.

R2: *Figure 8 does not seem to be so relevant to be included in the paper, since a specific analysis and discussion of spatial distribution of flood impacts is not performed in the study.*

Response: We acknowledged the validity of the comment and carefully considered the utility of the mentioned figure. The former Figure 8 was transformed into Figure 1, and placed at the end of Section 2.1. which presents the flood risk and hazardous events in Romania. At this point, we think that an illustrative presentation of the spatial distribution of the flood impacts is required, since Section 4.1. (which presented the multi-hazard impacts) was deleted. This substantial removal left the reader with little information on the severity of the flood hazards that affected Romania in 2020-2021, which can be partially addressed by the new Figure 1.

Respectfully yours,
The Authors