

RC2: AUTHORS' RESPONSE TO THE REVIEWERS COMMENTS

nness-2023-142: "Between global risk reduction goals, scientific-technical capabilities and local realities: a novel modular approach for multi-risk assessment" by Schoepfer et al.

- page 1-5: Authors' response to the Reviewer#1 comments
- page 6-12: Authors' response to the Reviewer#2 comments

Line numbers refer to the track change version (nness-2023-142-manuscript-version3_ATC.pdf).

Anonymous Referee #1, RC2: 'Comment on nness-2023-142'

I thank the authors for their efforts to address my previous comments. Their responses have raised a few further queries/comments from me, which I think should be addressed before the manuscript can be published:

1. Novelty: The authors have improved the framing of the novelty of the proposed framework in terms of its practical relevance and user-centered design. But I think this framing should also be captured in the title of the manuscript, which is currently lacking any reference to user-centeredness.

Thank you for your feedback and suggestion. We changed the title to "Between global risk reduction goals, scientific-technical capabilities and local realities: a modular approach for user-centric multi-risk assessment".

2. While I appreciate the efforts of the authors to re-structure the introduction to improve its readability, it is still not clear to me why Section 1.3 deserves to be standalone, when its main aim seems identical to that of Section 1.1, i.e., providing motivation for risk management. If the authors insist on keeping it separate, then I believe its title needs to be modified given that it no longer discusses local impacts.

We have considered your comment and changed the section title from "From global risk reduction goals to local impacts" to "From global risk reduction goals to local solutions". We aim not to merge Section 1.3 with Section 1.1 as we want to dedicate a specific section to the global strategies highlighting the importance of aiming for practical solutions.

3. Line 240 (approximately): Some of the re-defined stakeholder categories appear to overlap. I am not sure what the difference between an institution operating a DRM information system and one that works "in DRM contexts" would be. Perhaps providing some examples as well as a rationale for the categories defined would be beneficial. Table 2 is helpful for the former, but does not come until much later in the text (it is also not clear to me whether the stakeholders listed in this table were those from the Peru case study or external to that process).

Thank you very much for this comment. Based on your comment, we now moved Table 2 from its current position to Line 244 and add "Peruvian" to the heading of Table 2:

Line 205: "Table 2. Peruvian stakeholder groups and the stakeholders involved in the feedback process from the user perspective."

4. Line 274: If conditional probabilities of hazards are not considered, how do you ensure that the multi-risk "stories represent realistic multi-risk situations", as stated in line 265? (By the way, it does not seem at least entirely correct to state that conditional probabilities of hazards are not considered, given that the size of the tsunami in the case study is related to the magnitude of the considered earthquake).

The term “realistic multi-risk situation” refers to the fact that we consider a physically sound realization of a multi-hazard event. Both the estimates of earthquake and tsunami impact are based on identical fault parameters describing the earthquake which results in damages due to ground acceleration, but is also the source of the tsunami leading to coastal inundation, which is simulated at resolutions high enough for realistic estimates of the flooding extent. The actual amount of “realism” with respect to historic events depends on the correctness of fault parameters and representation of the bottom relief and roughness, as it is already stated in the text (see e.g. in line 235: *"The quantitative models in the individual scenarios do not necessarily represent the entire complexity of a story. To which degree a story agrees with realistic circumstances depends on the modelling capabilities as well as on the availability of (geo-)data."*). We clarified the description of the story-based concept.

Line 225: *"With these objectives in mind, we followed the concept of story and scenarios in order to understand and describe possible multi-risk situations (e.g., Jarke et al., 1998; Sutcliffe, 2003). With the term story we refer to a "narrative description of a situation, defining the specific involved hazards, cascading effects and impacts, looking at a specific area of interest". These stories represent realistic multi-risk situations with cascading effects. We ensure physically sound settings of the multi-hazard situation by performing all calculations with identical fault parameters for both earthquake and tsunami simulations. However, although a story is based on physical drivers – i.e., natural hazards, – it is not limited to their description alone."*

5. Line 482: “we account for uncertainties with regard to the historic earthquake from 1746 which serves as basis for the simulation, by covering a range of magnitudes with simulations”.. I am not sure I follow this statement. Does the word “magnitudes” used here refer to the earthquakes? If that is the case, I thought only one magnitude is considered (rather than multiple), given that the authors state in line 463 that the scenario is “a single event”.

Thank you for pointing this out, indeed, a scenario represents a single event, thus magnitude as well as all fault parameters are fixed. The mentioned sentence is somewhat misleading and refers to the coverage of several magnitudes by different scenarios in the database. Since the correct magnitude of the event in 1746 cannot be specified exactly, we covered a range from Mw 8.5 to Mw 9.0 by different scenarios and different extents as suggested by Jimenez et al. (2013) and other sources. These realizations and corresponding impacts may be investigated and compared as separate scenarios in the Demonstrator. We modified the corresponding statement to clarify the meaning. It reads now as follows:

Line 445: *"For those earthquakes which can potentially trigger a tsunami, another web service is introduced which provides access to pre-calculated numerical tsunami simulations. The simulations were generated using the physical generation and propagation model TsunAWI (Harig et al., 2008), which accounts for a triangular mesh with variable resolution as proposed by Harig et al. (2020). The size of the tsunami is related to the magnitude of the selected earthquake. Generally, larger earthquakes result in larger values of the wave amplitude at the coast and broader inundation area. However, the relation is rather complex, since we account for the vertical displacement of the coastal area due to the earthquake, which might affect the inundation, and additionally, the run-up process is highly nonlinear. Based on the earthquake catalogue, a database of tsunami scenarios with earthquake sources offshore Peru was calculated. In case of the historic earthquake from 1746, we account for uncertainties by incorporating several scenarios covering a range of fault parameters for the source area as suggested by Jimenez et al. (2013). The available outputs including the maximum tsunami amplitude, arrival times and tsunami inundation depth are displayed (Rakowsky et al., 2013; Androsov et al., 2024; Harig et al., 2024). Some of these scenario-based tsunami inundation maps are available in Harig and Rakowsky (2021), respectively."*

6. I think the results of the Ecuador application need to be elaborated more, explaining more specifically how the transferability to another region was tested. In particular, it would be relevant to explain how stakeholders were involved in that application and what challenges arose (e.g., around the design of the interface, any modifications that were suggested for the workflow). Furthermore, the authors state that “we can report that we could successfully adapt the approach for another case study in the coastal area of Greater Valparaiso, Chile” but provide no evidence to support this statement (it is not even clear what hazards are considered for this additional case study), which is not acceptable. The statement should either be removed or the case study described in sufficient detail to support the claims made about it.

Thank you for pointing this out. We included more information in Section 3.2 and Section 4 regarding the case studies in Ecuador and Chile (see discussion point “vii. Transferability and scalability”).

Line 409: *“For this defined story, multiple scenarios including historical, observed as well as stochastic earthquakes, were made available. Each earthquake scenario serves as a trigger for the defined multi-risk chain resulting in different cascading impacts. A flow chart (Fig. 5) was created conceptualizing the main logic, its components and information flows of the multi-risk story. A database of historical, observed and stochastically distributed earthquakes with different locations and magnitudes was developed and made available via a web service. As each of these individual earthquakes serves as a trigger for the defined multi-risk chain resulting in cascading impacts of different degrees, the user can analyse scenarios of varying severity by choosing a specific earthquake from the database. We applied a similar approach for a multi-risk story on volcanic activities with compound hazards, i.e. ashfall and lahars, with damage on buildings and impact on the power network in a case study for the volcano Cotopaxi in Ecuador (see Sect. 4, vii). Here, too, users were able to analyse a number of scenarios of varying severities based on different VEI values (cf. Gómez Zapata et al., 2021a).”*

Line 703: *“vii. Transferability and scalability: The approach was presented for an earthquake-tsunami multi-risk story for the Lima Metropolitan area in Peru. Regarding the transferability to another region, we report that we have applied the approach in two further case studies. In the coastal area of Greater Valparaíso, Chile (cf. Gómez Zapata et al., 2021d; Gómez Zapata et al., 2022a), the multi-risk story was like Lima Metropolitan area focusing on the earthquake and tsunami cascade affecting housing and the critical infrastructure power grid. In Ecuador the approach has also been adapted for compound hazards (two hazard events happening in parallel) analysing the impacts of ash fall and lahar around the volcano Cotopaxi in Ecuador (cf. Gómez Zapata et al., 2021a). Similar to the Peru study case, a feedback process with four iterations involving comparable stakeholder groups was implemented. The use of similar questionnaires in the three country studies helped to compare results from the feedback. The results showed that comments on the main features of the tool were consistent across the study cases. Of course, there were specific points to consider in the individual countries, for example, regarding the colours used to display the results or the damage classes, as participating countries use different damage categories and colour codes. To ensure the transferability and scalability of our approach, the tool was designed from the outset to be adaptable to all types of complex multi-risk stories (see point iii on ‘Complexity’) at different scales and to accommodate national or local preferences regarding damage categories or colour codes.”*

7. It is surprising that the risk metrics output from the tool are not designed in collaboration with stakeholders, given their importance to the decision-making processes that the tool strives to facilitate. Furthermore, the metrics used are rather narrow in scope; repair costs may not fairly capture the effects of hazards on low-income populations, for instance (e.g., see <https://www.nature.com/articles/s41893-020-0508-7>). I think the narrow range of metrics used and the lack of stakeholder involvement in their design might be considered a notable limitation of the

framework and an aspect that should be improved in future work. I therefore believe it warrants some discussion in the conclusions.

We have updated Section 4 “Discussion and Conclusions”, not only on the discussion regarding the used risk metrics, but also other topics. We covered your concerns regarding the used risk metrics in the discussion point iii on “Complexity”:

Line 656: „iii. Complexity: Multi-risk situations can become very complex. Obviously, models and scenarios are always incomplete as they only can approximate the complexity of real situations (see for example the risk framework introduced by Taubenböck et al. (2008) with the manifold and still incomplete indicators for operationalization). The analytical process of the interactions of elements in scenarios is furthermore confined to selected processes. For demonstration purposes, we limited ourselves to the physical elements of vulnerability (buildings, critical infrastructure). Table 3 lists the numerous and partly high-resolution input data for the relatively simple earthquake-tsunami story. This is already a minimal data set to model and approximate the situation realistically with considerable uncertainties. More high-resolution data sets can improve the modelling and reduce the uncertainties. An important factor in the evaluation of data inputs is certainly the available IT resources for processing and modelling. Economic, environmental, political, social and societal aspects of vulnerability were left out, which, however, is not implying any judgement on their relevance for assessing and understanding vulnerability. This, of course, resulted in a considerable limited representation of what would actually happen in a real disaster situation. This limitation was openly addressed and made transparent in the feedback process. Despite this limitation, the stakeholders still rated the potential of the tool as high, considering the results of the physical vulnerability assessment and it has stimulated them to develop new strategies for capacity building and resilience measures. Ultimately, the tool is designed in such a way that interested parties can integrate social factors of vulnerability at any time during adaptation and further development of the multi-risk story. To allow for this, we made the framework and its source code publicly available.”

Some minor technical comments:

1. Line 30: I think the phrase “tool through an iterative participative approach” was more a more appropriate description than the term “method”

Thank you for the suggestion. We updated the abstracted and corrected the sentence accordingly.

2. Line 405: There are two sentences here that both state the demonstrator light version provides three different modes. Also, there is a typo in the statement: “comparison of two different scenarios within one multi-risk story two..” (same typo exists in line 529)

We apologize the duplication and typos. We have checked and corrected the text accordingly.

3. Line 568: please specify what you mean by “users”

We changed the sentence as follows:

Line 544: “During the joint discussion with the various stakeholders involved, a compromise had to be found between the requirements of practical DRM and planning processes on the one hand, and the technical possibilities of modelling certain processes on the other.”

4. Line 628: “totally likelihood” does not make sense .. rephrase using something along the lines of “proportion who are totally likely to use the tool”

Line 606: *“Although there was a slight decrease in the proportion who are totally likely to use the tool (year 1: 18%, year 3: 14%), we believe it is fair to say that the overall percentage has increased, as 39% were very likely to use the tool in year 3, while this answer was not given at all in year 1 (Fig. 10d).”*

5. Line 656: this sentence does not read correctly. I think you should rephrase the start of it along the lines of: “In this paper, we presented one (of many possible) approach(es) to multi-risk analysis that can make a practical contribution to...”

Thank you – we have amended the sentence accordingly.

6. Figure 8: “right ride” is a typo in the caption

Thanks for spotting this – we have corrected the typo.

Anonymous Referee #2, RC2: 'Comment on nhess-2023-142'

Thank you very much to the authors for their detailed responses to my comments (Anonymous Referee 2) and those of Anonymous Referee 1.

Your replies were clear and you let us know what you changed as a result in the manuscript. Many replies though were slightly confusing as you used future tense ('we will do....' 'we will add...') rather than telling us what you in fact did. I think this was the result of taking the reply in the response to our comments online, rather than the current stage of submitting the revised manuscript. However, the intent was mostly clear (although at times confusing, and I had to keep going back to the track change manuscript).

Yes, after getting your reviewer comments, we answered them with future tense, as we only updated the manuscript after the editor allowed us to re-submit a revised version of the manuscript. We are sorry that this brought some confusion.

In terms of replies, I think that you have made definite improvements, but at times these were superficial changes of a few words here or there, other times more substantive (e.g., for formatting, or adding in paragraphs here or there); more could have been done to substantively change the results rather than a bit of wordsmithing. As a result, I recommend slightly more than 'minor' changes to bring this to an appropriate level for publication. Ultimately, the manuscript will be a good addition to the literature, but taking time now to make the manuscript a bit more robust and in-depth, will make it that much more useful to the community.

I glanced over the Referee 1 comments and replies and will let them reply to those, although did feel, that at times you were sidestepping some of the substance of what was being asked. You answered many of my concerns, but some (will be mentioned below) could have been more substantive changes made.

Thank you for taking again for the time to provide this comprehensive review. We tried to further improve the paper based on your comments, as well as the comments of reviewer #1.

Abstract. I repeat what I said before. Although you have changed the manuscript you did not understand what I said. "This is a bit high level and more a motivation rather than an actual (with metrics such as 'how many' and 'of what') summary of the paper. I suggest you rethink a bit the abstract and consider more how it is a summary of the paper."

An example of including summary numbers to better help the reader might be the following (I'm not saying to use it, but it is an example after running your paper through an AI and asking for a summary):

"In our increasingly interconnected society, urbanization and the vulnerability to natural hazards, including climate change, have created complex risk scenarios. This paper introduces a modular approach for multi-risk assessment aimed at enhancing the capabilities of disaster risk managers, urban planners, and critical infrastructure operators. We developed a simulation and visualization method for various scenarios based on a decentralized system architecture using distributed web services, accessible via a user-friendly interface. Our approach is demonstrated through a case study of earthquakes and tsunamis in the Lima Metropolitan area, a megacity exposed to cascading natural hazards. The development involved a structured feedback process with ## participants over ## years, including ## [? disaster risk managers] and [## ? urban planners], who evaluated the tool's potential as a complementary analysis and visualization aid. Users reported high satisfaction, particularly appreciating the ability to simulate and compare different scenarios. The demonstrator's practical relevance and user-oriented design suggest it as a promising method for improving the understanding and preparedness for complex multi-risk situations."

Thank you very much for giving us such a detailed suggestion to improve the abstract. We considered your comments and updated the abstract as follows:

Line 18: *“Abstract. We live in a rapidly changing and globalized society. The increasing interdependence and interconnection of our economic, social and technical systems, growing urbanization and increasing vulnerability to natural hazards (including climate change) are leading to ever more complex risk situations. This paper presents a modular approach for user-centred multi-risk assessment aimed to support disaster risk managers, urban planners or critical infrastructure operators. Based on the latest scientific and technical capabilities, we developed a method that enables the simulation and visualization of a range of scenarios with different intensities. It is based on a modular and decentralized system architecture using distributed web services that are published online, accessible via a user-friendly interface. The approach is demonstrated using the example of earthquakes and tsunamis for the Lima Metropolitan area (Peru), a megacity exposed to various cascading natural hazards. The development involved a wider group of Peruvian stakeholders from research and practice in a structured, iterative and participative feedback process over a period of 2.5-years to capture the needs and requirements from the user perspective. Results from the feedback process, including 94 responses to 5 questionnaires, confirmed the high potential of the demonstrator as a complementary analysis and exploration tool. Together with the visualisation of cascading processes, the ability to simulate and compare scenarios of varying severity was considered relevant and useful for improving understanding and preparedness for complex multi-risk situations in the practical application, especially at the local level.”*

Table 1. This is an excellent addition, but (a) please now discuss it in the text (even one sentence) such as “In Table 1 are shown four global strategies from YYYY to YYYY. Within these strategies, we see overall that....”

We are pleased to read that the additional table based on your original suggestion is well received. We have described the table in the text as follows:

Line 118: *“Table 1 shows four selected global strategies ranging from the 2030 Agenda for Sustainable Development (UNISDR, 2015) to the New Urban Agenda (United Nations, 2017). As part of these strategies, we see the need for a better understanding of disaster risk and the need to consider the requirements of different categories of users.”*

Vulnerability. Thank you for defining this as physical and systemic. Please add a reference(s) for where you first introduce these definitions at the end of Section 1.

Thank you for this this advice. We have included a reference at the end of Section 1, see:

Line 133: *“Following this introduction, Sect. 2 presents the conceptual approach to developing a scenario-based multi-risk assessment tool. With the aim of developing a demonstrator (and not a fully operational system), we focused on analysing the physical vulnerability (e.g., Fuchs et al., 2018) of buildings (i.e., the likelihood that assets will be damaged or destroyed when exposed to a hazard event), and the systemic vulnerability (e.g., Pascale et al., 2010; Hernandez-Fajardo and Dueñas-Osorio, 2013) of electrical power networks (i.e., probability of failure of interconnected systems given hazard intensities). Sect. 3 describes the results and steps taken, including findings from the user perspective. The discussions and conclusions are outlined in Sect. 4.”*

Fuchs S, Frazier T, Siebeneck L. Physical Vulnerability. In: Fuchs S, Thaler T, eds. *Vulnerability and Resilience to Natural Hazards*. Cambridge University Press; 2018:32-52.

Pascale, S., Sdao, F., and Sole, A.: A model for assessing the systemic vulnerability in landslide prone areas, *Nat. Hazards Earth Syst. Sci.*, 10, 1575–1590, <https://doi.org/10.5194/nhess-10-1575-2010>, 2010.

Hernandez-Fajardo, I. and Dueñas-Osorio, L.: Probabilistic study of cascading failures in complex interdependent lifeline systems, *Reliability Engineering & System Safety*, 111, 260–272, <https://doi.org/10.1016/j.ress.2012.10.012>, 2013.

Social vulnerability. In section 4, under complexity, you state that you do not introduce social vulnerability because of data restrictions and data protection issues. Yes, I agree that doing a full analysis of social vulnerability might be difficult, but one can even do partial analyses based on (in this case) census data, or data that is publically available or from other papers. Stating you could not do it is a bit of a cop-out. Just say you did not do it, and don't make justifications. As an example, when I go to "Changes in Spatial Inequality and Residential Segregation in Metropolitan Lima" there are nice maps of socio-economic and other variables by district level. I am familiar with Lima, and there are multiple (at least district-level) maps of various characteristics from the different censuses or papers. I get frustrated when people discuss 'risk' but then leave out social vulnerability—in this case, you did so, but it was a limitation and could have been added if you had wanted to (even at a course level). Acknowledge it was not part of your design, that there are metrics available to the public that could have been used (roughly) but were not, and that more detailed analysis might have data protection issues.

Thank you for bringing this to our attention. Based on your suggestions we have updated the paragraph on "iii. Complexity" in Section 4 accordingly.

Line 656: „iii. Complexity: Multi-risk situations can become very complex. Obviously, models and scenarios are always incomplete as they only can approximate the complexity of real situations (see for example the risk framework introduced by Taubenböck et al. (2008) with the manifold and still incomplete indicators for operationalization). The analytical process of the interactions of elements in scenarios is furthermore confined to selected processes. For demonstration purposes, we limited ourselves to the physical elements of vulnerability (buildings, critical infrastructure). Table 3 lists the numerous and partly high-resolution input data for the relatively simple earthquake-tsunami story. This is already a minimal data set to model and approximate the situation realistically with considerable uncertainties. More high-resolution data sets can improve the modelling and reduce the uncertainties. An important factor in the evaluation of data inputs is certainly the available IT resources for processing and modelling. Economic, environmental, political, social and societal aspects of vulnerability were left out, which, however, is not implying any judgement on their relevance for assessing and understanding vulnerability. This, of course, resulted in a considerable limited representation of what would actually happen in a real disaster situation. This limitation was openly addressed and made transparent in the feedback process. Despite this limitation, the stakeholders still rated the potential of the tool as high, considering the results of the physical vulnerability assessment and it has stimulated them to develop new strategies for capacity building and resilience measures. Ultimately, the tool is designed in such a way that interested parties can integrate social factors of vulnerability at any time during adaptation and further development of the multi-risk story. To allow for this, we made the framework and its source code publicly available.”

Conceptual Approach. Previously I suggested you look again at the conceptual approach, to make it a bit more user-friendly and less dense, by breaking out some of the large amounts of text into bullet points or numbers or making it easier to read. You said that "you are aware that there is a lot of information provide. Our target group is the scientific community and not practitioners." Having a lot of information is fine, and lots of details, but again I ask if you might be able to make it easier to read. I'm part of the scientific community this is aimed at, and had to read the section a couple of times to grasp what was being proposed.

To improve readability, we have further structured the text into bullet points. Accordingly, we have changed it as follows:

Line 145: “Considering the *above-mentioned* guidelines and strategies in the context of disaster risk reduction (DRR) and disaster risk management (DRM), as well as the outlined research needs, we present a *conceptual approach* developed within the research projects RIESGOS and its successor RIESGOS 2.0 (Schoepfer et al., 2018; Schoepfer et al., 2024). The projects focused on the development of innovative scientific methods for the assessment of multi-risk situations with the aim of designing an approach that meets the needs of users at the local level. In addition to the German team coming from various disciplines, the project collaborated with a variety of research institutions and public authorities in Chile, Peru and Ecuador. This collaboration, both with *potential* users and stakeholders across different levels, frames the novelty of the approach towards its practical applicability.

The starting point of our conceptual approach is the finding that local risk situations and the challenges for decision-makers to pursue global risk reduction goals in practice can vary across the globe. Thus, there is a gap between scientific and technical possibilities (i.e., the knowledge created by them and concrete fact-based decisions in the planning or political field). The conceptualization of this overall approach is visualized in Fig. 1.

- *First, we conducted a context and stakeholder analysis to understand the organizational environment and underlying structures of the disaster risk governance and to identify stakeholders to engage (Sect. 2.1).*
- *A concept for a scenario-based multi-risk information system was developed (Sect. 2.2). We selected a story-based scenario concept that allows the description of a specific multi-risk situation and its representation through multiple scenarios (Sect. 2.2.1).*
- *As input for the demonstrator tool, the elements of risk (hazard, exposure, and vulnerability) and their impacts on critical infrastructure were considered in terms of their potential implementation (Sect. 2.2.2). In the process, we devoted efforts to the study of interactions at the physical and systemic vulnerability levels of cascading hazards, addressing cumulative damage and loss.*
- *During the development of the demonstrator for a multi-risk information system, we involved potential users from the beginning to ensure that the designed tool meets their requirements and needs (Sect. 2.2.3). For the demonstrator we chose a decentralized system architecture approach built on distributed web services, with a graphical user interface as the frontend (Sect. 2.2.4).*

During the project individual results have already been published and are cited accordingly. In this paper, we aim to present the overall approach, with focus on the feedback process from the user perspective showing the practical relevance of the designed tool. We are convinced that such a user-oriented approach for exploring, describing and quantifying different What-if scenarios can constitute a valuable tool for understanding complex multi-risk situations and to prepare for such situations.”

We have also introduced some paragraphs to make the structure of the text and the line of argumentation clearer. We have done this systematically throughout section 2.

Users. Adding Table 2 was helpful. I’m still confused though how many came from which group and how many participants there were for each year. So in one place you state 46 participants in year 3 and in another place there were 37 participants in Year 3. I can’t find how many there were in Year 2 or 1, or their realistic makeup, and only twice do you mention for Year 3, and the numbers are different. I’m confused. And, this was a point I brought up before. You need to be much clearer throughout on the number of participants in every workshop, both putting this into the text and into figure captions where ‘percentages’ are mentioned. This is a ‘red flag’ for me, when an author is vague.

Thank you for noticing this error in participant counts. We have corrected the paragraph and added more information about the numbers of participants in Section 3.4, both in the text and figure captions, such as:

Line 551: *“For the case study in Peru, the first two workshops took place in Lima (mock-up V0.1: 4 December 2018, with 11 participants; version V1.0: 19 November 2019, with 46 participants) while the third workshop was held online due to the global pandemic travel restrictions (version V2.0: 9 February 2021, with 37 participants). Next to open feedback rounds, feedback was additionally collected via questionnaires. During this process, we experienced that complementary practical hands-on session (V1.0: 19 November 2019, with 16 participants; V2.0: 10 February 2021, with 12 participants) with the tool increased significantly the quality of feedback as one can document the user experience in action.”*

Line 612: *“Figure 10. Feedback from user perspective obtained during the three development stages (mock-up V0.1, versions V1.0 und V2.0) of the demonstrator for a multi-risk information system for years 1 (V0.1), 2 (V1.0) and 3 (V2.0). The diagrams represent four selected questions (out of a total of 45) on the information content (Fig. 10a-c) and applicability of the tool (Fig. 10d) asked to stakeholders in Lima (V0.1 was evaluated by 11 participants; V1.0 by 46 participants; V2.0 by 37 participants).”*

Line 620: *“Figure 11. Feedback from user perspective on the potential of practical applicability obtained in a hands-on workshop with stakeholders and potential users (12 participants) in Lima during the development process of the demonstrator for a multi-risk information system in year 3 (V2.0).”*

Table 3. This is an excellent addition, but please discuss it in a few sentences (or paragraph). What should the reader be taking away from it?

Thank you for this positive feedback on Table 3. More information on the web services is described in section 3.3.1 above Table 3. We have now added as you suggested two more sentences as follows:

Line 476: *“Table 3 provides detailed information on the system components (web services) with input and output information including corresponding references. This set of web services documents the multi-risk sequence as visualised in Fig. 5. Interaction with the web services is achieved using the Web Processing Service (WPS) interface standard guidelines published by the Open Geospatial Consortium (OGC; WPS, 2018).”*

Additional Figures. Thank you for adding these additional figures on the GUI, as they helped to better understand what was being done. Double check that these will be legible though (font size) for the publication.

Thank you for pointing this out. We have improved the font size in the figures of the GUI. We have tried to find a good compromise between font size and displayed information layers as the tool is primarily optimized for online usage and not for screen prints (please see track change version).

Discussion. This has been expanded upon (thank you, although could use a bit more depth and insight from lessons learned, particularly around the practical elements of applying this in another location, data, and scalability), but you still do not relate a lot of your ideas back to the existing literature, as I suggested in my original review. In your revision, you added two in-text citations to the one already there. I realise it is not a numbers game, but it is highly unusual to have a substantive discussion with so few revisions, particularly given the amount of work you have done (and as you say, this is for the scientific community). Examples of places where you might expand your discussion could be (these are examples):

- Expand on the user feedback, challenges they found, you summarised, relating it back to the wider literature, of what others have found. Are you finding similar results?

We have extended the discussion point „x. Co-creation with users” in Section 4 as follows:

Line 742: *“x. Co-creation with users: Our experience of collaboration between researchers, software developers and different potential users confirms that users' satisfaction with their involvement and*

the resulting system are interdependent, with the degree of user satisfaction evolving at different stages of the development process, as postulated by Bano (2017). It also confirms that involving users as a primary source of information is an effective means of capturing system requirements (Kujala, 2003). However, such collaboration requires a strong engagement from all sides. We agree that the role of users in such a process must be carefully considered (Kujala, 2003) and therefore applied a moderated process, which allows that user demands can be communicated to the researchers and developers without outweighing the scientific relevance. At the same time, the involved user must be aware and able to cope with trade-offs and compromises, as not all requirements may be addressed or they might not be able to benefit directly from the tool while it is still under development or in a demonstrator stage. To avoid false expectations and misunderstandings, we emphasize that transparency and clear statements are most crucial throughout the user involvement process. Additionally, users (often) do not have the scientific expertise to adequately describe the individual processes in a multi-risk chain. Since the approach is based on the description of a multi-risk story, this story must always be defined in a joint dialog between users, researchers and software developers. In our experience, much of the mutual learning took place during face-to-face interaction rather than digitally. With this in mind, the design of such collaboration must be critically balanced against the quite justified demand for more cost-efficient methods of capturing implicit user needs and requirements in real product development contexts (Kujala 2003)."

- Expand on what would be the minimum amount/types of data to apply this study elsewhere, commenting on limitations, and bringing this back to the wider literature.

We have expanded the discussion point "iii. Complexity" in Section 4 accordingly:

Line 656: „iii. Complexity: Multi-risk situations can become very complex. Obviously, models and scenarios are always incomplete as they only can approximate the complexity of real situations (see for example the risk framework introduced by Taubenböck et al. (2008) with the manifold and still incomplete indicators for operationalization). The analytical process of the interactions of elements in scenarios is furthermore confined to selected processes. For demonstration purposes, we limited ourselves to the physical elements of vulnerability (buildings, critical infrastructure). Table 3 lists the numerous and partly high-resolution input data for the relatively simple earthquake-tsunami story. This is already a minimal data set to model and approximate the situation realistically with considerable uncertainties. More high-resolution data sets can improve the modelling and reduce the uncertainties. An important factor in the evaluation of data inputs is certainly the available IT resources for processing and modelling. Economic, environmental, political, social and societal aspects of vulnerability were left out, which, however, is not implying any judgement on their relevance for assessing and understanding vulnerability. This, of course, resulted in a considerable limited representation of what would actually happen in a real disaster situation. This limitation was openly addressed and made transparent in the feedback process. Despite this limitation, the stakeholders still rated the potential of the tool as high, considering the results of the physical vulnerability assessment and it has stimulated them to develop new strategies for capacity building and resilience measures. Ultimately, the tool is designed in such a way that interested parties can integrate social factors of vulnerability at any time during adaptation and further development of the multi-risk story. To allow for this, we made the framework and its source code publicly available."

- How might your results be integrated into work being done by others. You mention it briefly in the 'operational system' but can you go further?

We further discussed point "viii. Operational system" in Section 4:

Line 721: "viii. Operational system: Users showed strong interest in the presented tool. However, the transfer from a demonstrator system to an operational service requires further efforts along with a

clear commitment and solid institutional embedding. As we have chosen a decentralized service-oriented architecture (SOA) with distributed web services for the demonstrator also the individual web services (see Tab. 3) can be integrated in already existing information systems. The interaction with the web services is achieved using Web Processing Service (WPS) interface standard guidelines published by the Open Geospatial Consortium (OGC; WPS, 2018) and are openly documented. Interoperability is achieved by a thorough harmonization of input and output formats and the use of on-the-fly converters. Dedicated WPS create simulations of intensity maps for specific hazards on the fly (e.g. for earthquake ground motion simulation) or by querying a list of pre-simulated events (e.g. for tsunami inundation maps). We recommend a partnership between research institutions, public authorities and service providers whereas one key authority should act as the hosting institution to integrate the tool or individual web services. The integration process itself requires profound knowledge both, in the models and IT programming (both backend services and frontend development), which needs the interaction of different specialized institutions and professional support from IT experts.”

- There are a number of decision support tools out there now, how does this compare with them? This is what you have designed, with two references that include ‘decision support tools’. Can you expand on these as decision-support tools?

The demonstrator tool developed in this project does not claim to be a decision support system. The aim was to develop a multi-risk assessment approach to help potential users such as disaster risk managers, urban planners or critical infrastructure operators to improve their ability to cope with the increasing complexity of risks. Based on the latest scientific and technical capabilities, we have developed a method that enables the simulation and visualization of a range of scenarios with different intensities. By using web services, the tool can be adapted very quickly and flexibly to changing input data (e.g. exposure data). The references to Komendantova (2014) and van Westen (2014b) listed in Section 1.2 were made in relation to user involvement and to the overall topic of multi-hazard frameworks, and not regarding decision support tools.

Minor:

- “It is worth noting” “It has to be noted” “We note” “It should be noted” “It is important to note” are used on over a dozen occasions. I generally avoid these in my own writing, and recommend you look at and remove some of these from the text (if not all of them). As a minimum, remove the ‘it is important’ or ‘It should be’, as these convey an urgency that is not needed.

Thank you for your recommendation. We have revised the manuscript accordingly and rephrased sentences where necessary.

- I suggest reconsidering the word ‘tested’ and definitely ‘successful tested’ as it often conveys a sense of ‘truth’ to practitioners, for whom this is intended. See “Verification, validation, and confirmation of numerical models in the earth sciences” by Naomi Oreskes et al. (1994). Perhaps instead consider replacing it with the words ‘evaluated’ or we ‘used the approach’? For successful testing, this is difficult to ascertain how successful you really were, so I suggest other words such as ‘applied’.

Thank you, we have corrected the wording in line with your advice.

- Paragraphs. You still have some very long paragraphs.

We have made another revision of the current version.

- First line, Section 4, should ‘novel’ be removed?

We have deleted the word ‘novel’.