October 29, 2022

Editor
Natural Hazards and Earth System Sciences (NHESS)

Subject: Resubmission of revised article “Equivalent Hazard Magnitude Scale” with manuscript number nhess-2021-87.

Dear editor,

We thank you and the referees for careful review of our manuscript (nhess-2021-87) entitled “Equivalent Hazard Magnitude Scale”. To address the comments from the review team, we have made minor revisions to the manuscript.

A detailed account of how we addressed the comments from the referees is attached below this response letter in a point-by-point style. The major changes to the manuscript are summarized as follows:

1) We have modified the Discussion section to address the referees’ comments.

2) We have corrected the typos.

3) We have updated the references.

The revised manuscript is now 9 828 words long and contains seventy-one references, eight figures, two tables in the main text, two tables in the appendix, six supplementary data files, and one supplementary video.

We look forward to hearing back from you regarding our revisions.

Sincerely,

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Anonymous Referee #3

We thank you very much for your comments and suggestions. In the following, we copy your comments in *italics* and follow with our response. The major changes to the manuscript are summarized as follows:

1) We have modified the Discussion section to address the referees' comments.

2) We have corrected the typos.

3) We have updated the references.

Comment: *The revised version of the manuscript accepted some of my comments. However I have still some observations about the authors' replies to a couple of the issues I raised.*

Response: Thank you very much for your time and consideration to help us improve the quality of this manuscript.

Comment: *With regard to the possible misnaming in the EM-DAT catalogue of moment magnitude MW as "Richter magnitude" ML, the authors replied that "for any earthquake event, its ML and MW is usually similar" and "once rounded to integers, most of the earthquakes have the same ML and MW". In my opinion, this is not correct: some comparative studies pointed out possible underestimate by up to 2 units for ML in comparison to MW for earthquakes of magnitude 8 (cf. Chen & Chen 1989, https://doi.org/10.1016/0040-1951(89)90205-9), which, given the logarithmic nature of these parameters, is a rather large difference. The authors could resolve this question specifying that the EM-DAT catalogue reports generically as "Richter magnitude" estimates which likely include moment magnitude as well.*

Response: Thank you very much for your suggestion. We have modified the Discussion section to emphasize in the revised manuscript that "the EM-DAT database reported generally as "Richter magnitude" estimates for earthquake events" (L371-372).

The corresponding sentences of the Discussion section now read: "Selection of hazard magnitude indicators in this study was also limited by the adopted datasets. As an example, the earthquake Richter magnitude (Richter, 1935) was the only recorded hazard magnitude indicator in the datasets of this study. However, the EM-DAT database reported generically as "Richter magnitude" estimates for earthquake events, even though such estimates may include moment magnitude as well. In addition, regarding tsunami, the mere inclusion of earthquake magnitude of a tsunami-triggering earthquake as the magnitude indicator ignores the fact that tsunami can also be caused by non-seismic events, such as volcanic island collapses and large coastal landslides." (L370-376)

Comment: *With regard to the inclusion in the dataset of an earthquake of magnitude 3.2, which the EM-DAT catalogue reports to have caused significant damages, and which I suggested to remove from the regression dataset, the authors replied that, even though "M3-M3.9 earthquakes rarely causes any damage … being rare is not being never" and that "Rarely causing damage means that there is at least a possibility of damage". However, since the main target of the proposed methodology is to compare hazard strength of different hazard types from their impact*

for average exposure and vulnerability, I believe that the introduction of cases of abnormally high effect of small events could introduce a bias in the regression results.

Response: Thank you very much for your comment. We have added a new paragraph at the end of the Discussion section to address both this issue and the one raised in your next comment. We admit that inclusion or exclusion of data points such as this M3.2 earthquake may affect the modelling result, which deserve more attention in future work.

The new last paragraph of the Discussion section reads: "Beside these abovementioned issues, the inclusion and exclusion of certain data points based on values of variables may also affect the results of derivation of equivalency of hazard strength. First, in this study, a set of thresholds were adopted to filter out records of events with extremely small and large measures of magnitude indicators. However, some events with magnitude indicator measures barely inside the thresholds, such as the magnitude 3 earthquake in Southern Russia in 1999, were still included in the data for modelling. On the other hand, because the EM-DAT database only included events with loss records beyond a set of criteria, numerous events with lesser impacts were not recorded for model calibration in the study. Such exclusion of events with lesser impacts caused the empirical marginal distributions of the logarithmically transformed and standardized impact variables and the impact metric appear to be approximately Gaussian. Future work should explore to what extent the computation of equivalent hazard magnitude is sensitive to the inclusion and exclusion of data points of events of an either small or large size in terms of both the magnitude indicators and adverse impacts." (L400-409)

Comment: *At this regard I noticed that, commenting Fig.2, the authors reported that "the empirical marginal distributions of the logarithmically transformed and standardized impact variables and the impact metric are approximately Gaussian". I find this observation rather suspect: there is no plausible reason why the occurrence of impact values should show a Gaussian distribution. On the contrary, one could expect that lower energy events causing lower effects should be more frequent, so that the distribution of the occurrence of impact values should show a decreasing trend as event energy and impact increase. This is well known in the case of earthquakes through the Gutenberg-Richter law, so that the deflection of the number of recorded events from a log-linear descending trend is used to identify the completeness threshold of datasets. However, similar relations were proposed for other types of hazardous events as well. Thus, the decrease of occurrences below the modal value is likely an artifact due to data collection incompleteness and to the adoption of a minimum cut-off threshold for impact variables (number of fatalities, number of people affected, etc.). Such incompleteness could introduce a bias in the regression results, since it is likely that, in the datasets, small events that caused effects larger than the average for similarly energetic events be over-represented. This, for instance, could be the case of the mentioned earthquake of magnitude 3. This problem should be at least discussed and possible checks of the effects of such bias could be attempted or at least proposed (e.g. comparing the regression results obtained with the entire dataset with those obtained for a subset where data below the modal value are removed).*

Response: Thank you very much for your observation, comment, and suggestion. Indeed, it would make sense to assume that there is a lack of data points with small impact, which would make the distributions of impact variables look lognormal such that the transformed and standardized version of these variables would appear to be approximately Gaussian. To clarify this Gaussian

appearance of the empirical data, we have modified the first sentence of Section 4.1. To further address this issue, we have added sentences to the new last paragraph of the Discussion section as well.

The modified first sentence of Section 4.1 now reads: "Visualization of the distribution of data points with respect to the impact variables and impact metric (Figs. 2a, 2d, 2h, and 2m) shows that the empirical marginal distributions of the logarithmically transformed and standardized impact variables and the impact metric appear to be approximately Gaussian." (L185-187)

The new last paragraph of the Discussion section reads: "Beside these abovementioned issues, the inclusion and exclusion of certain data points based on values of variables may also affect the results of derivation of equivalency of hazard magnitude. First, in this study, a set of thresholds were adopted to filter out records of events with extremely small and large measures of magnitude indicators. However, some events with magnitude indicator measures barely inside the thresholds, such as the magnitude 3 earthquake in Southern Russia in 1999, were still included in the data for modelling. On the other hand, because the EM-DAT database only included events with loss records beyond a set of criteria, numerous events with lesser impacts were not recorded for model calibration in the study. Such exclusion of events with lesser impacts caused the empirical marginal distributions of the logarithmically transformed and standardized impact variables and the impact metric appear to be approximately Gaussian. Future work should explore to what extent the computation of equivalent hazard magnitude is sensitive to the inclusion and exclusion of data points of events of an either small or large size in terms of both the magnitude indicators and adverse impacts." (L400-409)

Comment: *Once clarified these points, my opinion is that the manuscript could be accepted for publication.*

Response: Thank you very much for your encouraging comment. We look forward to the editor's positive decision.

Anonymous Referee #4

We thank you very much for your constructive comments, questions, and suggestions. In the following, we copy your comments in *italics* and follow with our response. The major changes to the manuscript are summarized as follows:

1) We have modified the Discussion section to address the referees' comments.

2) We have corrected the typos.

3) We have updated the references.

Comment: *Authors propose in this manuscript an equivalent hazard magnitude scale to measure the strength of natural force involved in the entirety of a natural hazard event for comparative analysis across different hazard types. The study is interesting but there are some issues which need to be clarified.*

Response: Thank you very much for your summary and encouragement. We have made minor revisions to the manuscript, and we address your concerns as follows.

Comment: *Lines 103-105: 12 hazard types have been taken into account, and namely: cold wave, convective storm, drought, earthquake, extra-tropical storm, flash flood, forest fire, heat wave, riverine flood, tornado, tropical cyclone, 105 and tsunami. How were the types of hazards selected? What are the criteria at the base of this choice? For what reasons other types (for instance, landslides, sinkholes, etc.) have been excluded? This part needs to be better clarified.*

Response: Thank you very much for your comment. In the first paragraph of the Methodology section, we briefly introduced how the section was laid out. Regarding the selection of 12 hazard types, we provided the details of the rationale in the first paragraph of Section 3.1 Data Collection. Originally, we downloaded all available data from the EM-DAT database. However, many of the hazard types did not have magnitude indicator measures. Therefore, we could only include 12 hazard types with sufficient amount of data points with magnitude indicator values for modelling.

To explain this issue, the corresponding sentences in Section 3.1 read: "For this study, we downloaded the entire EM-DAT datasets on all types of natural hazards. However, since some records of hazard magnitude indicators of events for some hazard types (e.g., the volcanic activities and landslides) were missing, we only included 12 hazard types." (L116-119)

Comment: *Lines 367-369: Authors state that "To demonstrate the implementation of the proposed methodology for deriving equivalent hazard magnitudes of events, we only considered one hazard magnitude indicator for each hazard type. For many hazard types, one indicator cannot represent the true hazard magnitude of an event which may arise due to multiple forcings". This latter sentence is very true, and is a strong assumption, which would deserve some more comments from the Authors: how much does this assumption influence the outcomes? Did they make attempts in evaluating the effects on the outcomes of such a choice?*

Response: Thank you very much for your comment. We are glad that the referee also thinks that the consideration of multiple magnitude indicators is an important issue. If sufficient data on

multiple hazard magnitude indicators becomes available for modelling equivalent hazard magnitude on the Gardoni Scale, we would definitely be excited to conduct research to answer the questions raised by the referee. At the current stage, however, we only have one magnitude indicator for each hazard type because of the adoption of the datasets from the EM-DAT database. That is also mainly why we emphasized that this lack of data on other magnitude indicators was a limitation in the Discussion section.

Comment: *I also agree with the comment from the other reviewer about the Gaussian distribution invoked by Authors when commenting figure 2. This, too, needs further explanation.*

Response: Thank you very much for your comment and suggestion. As mentioned in our response to the other referee, we agree that the empirical distribution of the logarithmically transformed and standardized impact variables and impact metric appeared to be Gaussian. Correspondingly, the original impact variables would appear to have a lognormal distribution due to lack of data on small impact measures. To highlight this Gaussian appearance of the empirical data, not the actual theoretical distribution of the impact variables and impact metric, we have modified the first sentence of Section 4.1. To further address this issue, we have added sentences to the new last paragraph of the Discussion section as well.

The modified first sentence of Section 4.1 now reads: "Visualization of the distribution of data points with respect to the impact variables and impact metric (Figs. 2a, 2d, 2h, and 2m) shows that the empirical marginal distributions of the logarithmically transformed and standardized impact variables and the impact metric appear to be approximately Gaussian." (L185-187)

The new last paragraph of the Discussion section reads: "Beside these abovementioned issues, the inclusion and exclusion of certain data points based on values of variables may also affect the results of derivation of equivalency of hazard magnitude. First, in this study, a set of thresholds were adopted to filter out records of events with extremely small and large measures of magnitude indicators. However, some events with magnitude indicator measures barely inside the thresholds, such as the magnitude 3 earthquake in Southern Russia in 1999, were still included in the data for modelling. On the other hand, because the EM-DAT database only included events with loss records beyond a set of criteria, numerous events with lesser impacts were not recorded for model calibration in the study. Such exclusion of events with lesser impacts caused the empirical marginal distributions of the logarithmically transformed and standardized impact variables and the impact metric appear to be approximately Gaussian. Future work should explore to what extent the computation of equivalent hazard magnitude is sensitive to the inclusion and exclusion of data points of events of an either small or large size in terms of both the magnitude indicators and adverse impacts." (L400-409)

Comment: *For all the above, I ask for minor revisions.*

Response: Thank you very much for your comment and suggestion. We look forward to the editor's decision.