This article presents seismic risk results from 18 earthquake scenarios in the Sabana Centro province, an intermediate hazard zone in Colombia. The 18 scenario events were chosen based on hazard disaggregation results on a site within the region of interest, for a 475 years return period hazard level. The epicenters of the scenario events were located within the region. The exposure model was gathered from previous studies, complemented with census data and remote surveys. Finally, the set of fragility curves for the considered typologies was gathered from previous studies. Results show that, on average, the occurrence of one of the scenario earthquakes might result in about $800 million USD of economic losses (about $1000 million USD when adjusted by social vulnerability) and about 20% of all the buildings collapsing.

The study is well performed and written. In terms of scientific merit, although the article does not provide new methods for seismic risk assessment, it provides novel results on the seismic risk faced by the Sabana Centro province. I have some comments that may help to improve the quality of the article (I have marked the most important issues that I comment).

In particular, compared to the damage produced by previous earthquakes around the World, the numbers presented in this article seem to be too high, especially considering that: (1) these are mean values, not low-probability values (thus they are not even the "worst-case scenario"); and (2) the authors state that the risk results should be considered as a lower bound. Therefore, I strongly suggest a careful revision and discussion of the results.

Dear Dr. Heresi

You kindly spent time delving into our manuscript, and we are grateful. Thank you for your appreciation of the study's performance and writing style, and acknowledging the novelty of the results on the seismic risk assessment in the Sabana Centro province since the study performed by the Japan International Cooperation Agency (JICA) in 2001 has been neither discussed nor updated. Thank you for your comments. We will do our best to provide a complete answer to all of them.

Specific Comments (Individual scientific questions/issues)

1. Line 130: The authors state that the Bucaramanga's seismic nest earthquakes occur at depths between 140 and 200km. However, in Figure 3 it is possible to observe several events at depths between 70 and 150km. I suggest the authors comment something about this inconsistency.

R/: Thank you for your comment. The statement on line 130 corresponds to the general definition of the Bucaramanga seismic nest. In Figure 3 the authors show the complete catalog without source distribution. That is, the events that are the origin of the Bucaramanga seismic nest are considered as those cortical events, which can occur over the seismic nest. To avoid this misunderstanding, the following sentence will be included in the revised version of the article to clarify the information presented in the figure:

"Figure 3 shows the events of the complete catalog, considering those of seismic nest origin as well as those events of cortical environment."

2. Line 144: The description of Figure 3 does not match what is observed in the figure. The authors state that Figure 3 shows: (1) close (distance < 75km) and shallow (depth < 70km) events; and (2) far (150km < distance < 200km) and deep (depth > 70km) events with magnitudes greater than 6.5. However, the figure presents many other events. For example, there are shallow events at distances larger than 75km with magnitudes lower than 6.5, deep events with magnitudes lower than 6.5, etc. The description and the figure should be consistent.

R/: Thank you for your suggestion. To be consistent between the figure and the description we have improved the discussion of the figure by describing the events according to the distance from the disaggregation, as well as other information like the magnitude and depth.

3. Line 155: The authors state that the population centroid is located within Tenjo. Moreover, they use this municipality throughout the article as a reference (e.g., Figures 2 and 3). However, given the map provided in Figure 6c and the population of each municipality provided in Table 1, it seems like the centroid should be located somewhere between Zipaquirá and Chía (probably within Cajica), which are the two municipalities with the largest populations.

R/: We agree with you. The interpretation of the sentence is that the disaggregation was done for the population center of the entire study region; however, what was meant is that this procedure was done for the population center of Tenjo. This municipality was taken as a reference point at the authors' discretion. We rewrote the sentence so that it is clearer.

4. Figure 4: What is the distance type of the disaggregation? Rupture distance? Epicentral distance? Joyner-Boore distance? Given the depth of the deep sources, the difference between the distance types might be important.

R/: Thank you for your comment. For disaggregation, the authors used a distance to the projection of the rupture surface corresponding to the Joyner-Boore distance. To clarify both comments, we will include the following sentence in the revised manuscript:

The disaggregation was developed for a point within the region of analysis, which corresponds to the population centroid of the municipality of Tenjo (longitude: -74.144, latitude: 4.872), considering the Joyner-Boore distance to the projection of the rupture surface.

5. Table 2: The authors provide a list of the selected scenarios. A map showing these events might be useful for visualizing the epicenters with respect to the municipalities.

R/: We appreciate your recommendation. We will add a new figure with this information in the manuscript.

6. Table 3 and its description: Although the logic tree was proposed by Arcila et al. (2020), I suggest the authors provide a justification for the different weights to the Cauzzi et al. (2014) and Abrahamson et al. (2014) ground-motion models.

R/: The logic tree proposed by Arcila et al. (2020) for shallow crustal regions has three GMPEs: Cauzzi et al. (2014), Abrahamson et al. (2014) and Idriss. (2014). The corresponding weights are 0.39, 0.211 and 0.399, respectively. The Sabana Centro region has a significant number of soft soils for which the Vs30 is lower than 450m/s. The Idriss (2014) GMPE is not defined for these types of soils. Consequently, for this study we decided to exclude this GMPE and use a logic tree that included the Cauzzi et al. (2014) and the Abrahamson et al. (2014) GMPEs, which do account for soft soils.

To update the weights of the Abrahamson and Cauzzi et al. (2014) GMPE in the new logic tree, we adjusted them distributing the weight of the Idriss (2014) GMPE (0.399) proportionally to their weights in the initial logic tree. We did so because this allowed us to keep the same level of relative weights between the two GMPEs used for our study. This led to the following calculations:

$$Cauzzi_{updated} = \mathbf{0.39} + \frac{0.399}{0.39 + 0.211} = \mathbf{0.65}$$

$$Abrahamson_{updated} = \mathbf{0.211} + \frac{0.399}{0.39 + 0.211} = \mathbf{0.35}$$

7. ***Important comment*** In Line 105, the authors state that “The majority of the building stock of the region is comprised of one- and two-story houses.” However, as shown in Table 4, the considered building typologies include buildings with either 1 or 4 stories. The question is then, how are two-story houses classified into this system? This question is especially important because it has been previously demonstrated that one- and two-story houses present a significantly different seismic behavior and therefore levels of damage and losses (see, for instance, Heresi and Miranda 2022). In particular, classifying two-story houses as one-story structures may result in a significant underestimation of the seismic risk of these two-story structures.

Heresi, P., & Miranda, E. (2022). Evaluation of relative seismic performance between one- and two-story houses. Journal of Earthquake Engineering, 26(2), 857-886.

R/: Thank you for this important comment. Other reviewers also raised their attention to the need of updating the exposure model, further discretizing between building heights. We agree specially that the difference between one- and two-story houses is significant. Based on this comment and the other reviewers’ suggestions, we decided to update the exposure model using information of the 2018 national census, with further differentiation between building heights. To discretize the building height, we used information collected using remote and field surveys of 9000 houses in the Sabana Centro region, conducted by students of Universidad de La Sabana. We found that for houses between 1 and 3 stories, 34% are one-story houses, 48% are two-story houses and 18% are three-story houses. Accordingly, we updated our exposure model.

In addition, we decided to use the fragility functions calculated by Martins and Silva. (2021), which all use the same modeling approach, and they account for the differences in height.

Furthermore, we also updated the discussion section, including the suggested reference and the above-mentioned facts.

8. Table 5 presents the main parameters of the considered fragility curves. As stated by the authors, these fragility curves were selected from different studies after a thorough literature review. Although this is perfectly fine, it has an important drawback that should be commented on: the final set of fragility curves comprise curves developed with very different methods (e.g., analytical vs empirical) which have very different reliabilities (e.g., generally speaking, empirical fragility curves developed after earthquakes have higher uncertainties both in the probability of damage and in the ground-shaking intensity). The authors are encouraged to discuss about the limitations and reliability of the considered fragility curves, taking into account the methods, the data, and the assumptions used to develop them. They address some of these issues in the Caveats and Limitations section, specifically the issue of fragility curves not being developed directly for Colombian structures and not having a uniform description of the damage states, but there are other issues that are missing in this section, as those previously stated in my comment.

R/: Thank you for this comment. Other reviewers also raised their attention to this fact. For consistency in the revised version of the manuscript, we decided to use only analytical fragility functions. Most of them were those calculated by Martins and Silva (2021) and Villar-Vega et al. (2017). These functions are analytical and all of them use the same modelling approach. We used these functions for several buildings, with some exceptions such as the thin reinforced concrete buildings, for which we kept the fragility functions developed by Arroyo et al. (2021), because these are also analytical and use a more accurate model for these types of structures. We kept the comments about the issue that the fragility functions by Martins and Silva. (2021) were not developed accounting for the particularities of Colombian construction.

9. ***Important comment*** Results show that a Mw5.95 event at Chía is expected to cause the collapse of more than 17% of the buildings in the region, and some level of damage in about half of the building portfolio. In particular, 6722 out of 14959 (about 45%) of houses made out of non-ductile unreinforced masonry with adobe block walls (1-story) are expected to collapse, according to the authors. Moreover, in Chía, more than 44% of the buildings are expected to collapse due to this Mw5.95 scenario. These numbers seem incredibly high for a Mw5.95 event at a first glance (even more when the authors state, in Line 441, that these estimates should be considered as a lower bound). Note that these are mean (i.e., expected) values, not low-probability values that might represent a somewhat “worst-case scenario” (or, in other words, somehow answer the question “how big may be the consequence if this earthquake occurs tomorrow?”). To put these numbers in perspective, we can compare them with the damage produced by the 2010 Haiti earthquake, Mw7.0:

- According to DesRoches et al. (2011), the 2010 Haiti earthquake damaged nearly half of the structures in the epicentral region.
- Eberhard et al. (2013) performed two field surveys of: (1) 107 structures in Port-au-Prince, where 30 (28%) of them collapsed and other 35 (33%) had enough damage to require repairs; and (2) 52 structures in Léogâne (closest population center to the

epicenter), where 32 (62%) of them collapsed and other 16 (31%) had enough damage to require repairs.

- Rathje et al. (2011) performed a field survey of over 400 structures in Port-au-Prince. Of the 414 surveyed structures, 157 (38%) had significant damage (i.e., collapse or very heavy damage, EMS Grade 4).

Considering that the Haiti earthquake was not only 32 times larger in terms of magnitude, but also affected a more socially vulnerable country, it is expected that a Mw 5.95 event in the region of interest would result in considerably less damage and losses, especially if we talk about mean values.

In terms of losses, in Figure 12 we can observe that some of the earthquake scenarios have a 20% probability of producing more than 50% of the total replacement cost as economic losses (about 40% of the GDP of the region!). Considering that these curves were computed neglecting the spatial correlation of ground motion intensities (comment about this below), this probability for such a high loss is extremely large. For perspective, the 2010 Chile earthquake, Mw8.8, produced an economic loss of about 14% of the GDP of the country at the moment of the event.

The previous remarks highlight the importance of comparing risk results from scenario events with previous events to put the numbers in perspective. I suggest the authors include comparisons like the ones proposed above, but also include other events, such as, for example, the 2020 Puerto Rico earthquake, Mw6.4. Moreover, in the Introduction, the authors mention two historical earthquakes that affected the region of interest, which may also be used to evaluate the reliability of the resulting damage produced by the considered scenario earthquakes. These comparisons would further support the risk results of the article.

DesRoches, R., Comerio, M., Eberhard, M., Mooney, W., & Rix, G. J. (2011). Overview of the 2010 Haiti earthquake. *Earthquake Spectra*, *27*(S1), S1-S21.

Eberhard, M. O., Baldridge, S., Marshall, J., Mooney, W., & Rix, G. J. (2010). The Mw 7.0 Haiti earthquake of January 12, 2010: USGS/EERI advance reconnaissance team report. *US Geological Survey Open-File Report*, *1048*(2013), 64.

Rathje, E. M., Bachhuber, J., Dulberg, R., Cox, B. R., Kottke, A., Wood, C., ... & Rix, G. (2011). Damage patterns in Port-au-Prince during the 2010 Haiti earthquake. *Earthquake Spectra*, *27*(S1), S117-S136.

R/: We highly appreciate this comment and acknowledge the importance of comparing with previous events to put the results in a broader perspective. In this regard, we would like to frame the discussion in terms of the 1999 Armenia Earthquake in Colombia. This event had a Mw 6.1 magnitude at 15 km depth. Most of the building stock was comprised of URM buildings, built prior to the 1998 seismic design code of Colombia and like the buildings in Sabana Centro. This earthquake costed 1.6% of the national GDP (roughly five times higher than the earthquake considered in this paper). In terms of damage, the records indicate that 17551 were destroyed, 18421 had severe damage and 43474 had moderate damage. Another earthquake in Colombia was the Mw 5.5 in Popayán in 1983, which occurred at an estimated depth of 12 to 15 km. According to Colombian records, in this earthquake, 12% of buildings suffered complete damage and 34% experienced severe damage.

These two events put the numbers in perspective and support that the results of this paper are reasonable. In the discussion in the revised manuscript, we will include these facts and compare our results with those of these earthquakes.

Regarding the reviewer comment about the lower bound, the authors has this concern because the field surveys have shown that a significant number of buildings in Sabana Centro are informally constructed, rising the possibility that none of the existing fragility functions can represent this type of construction properly.

10. Table 10 presents the resulting SVI for the 11 municipalities of the region. Although the authors previously explain the variables involved in this index (Table 6), I have two comments about this:

I suggest the authors provide more detailed information about how the index of each category is obtained. This explanation would improve the reproducibility of the reported results.

R/: Thank you very much for this suggestion; the selection of the indicators that are part of the composite indicators: population, economy, infrastructure, education, health, and the variables considered for the indicator COVID-19 was already explained in section 3.4. The composite indicators, single indicators and variables considered initially to estimate the SV were listed in Table 6, in the submitted version. However, to provide more detailed information about how the SV index is constructed, we elaborate more on the explanation of the methodology. We did this in several ways: first, we explain in further detail each composite indicator, second, we checked the multicollinearity of the indicators based on the variance inflation factor (VIF) (see Table 6), and we excluded those that were potentially correlated with others and those that did not add significant information.

11. There are many variables used for the SVI that are strongly correlated. For example, in the "Population" category, there are 7 variables, where, for instance, "Female population" and "Total population" are expected to be strongly correlated, unless the percentage of women varies significantly from one municipality to another for some reason. As the authors did not provide too much detail on how the index is computed, I'm not sure if they tested for collinearity between these variables, for example. We can even expect some correlation between different categories. For instance, municipalities with a high index in Economy will probably have also a high index in Infrastructure. These correlations might result in biased SVI's when all the variables are considered.

R/: Thank you very much for this comment. The reviewer is right indicators such as female population and total population are strongly correlated (1.000**). Then, to avoid problems interpreting the model and overfitting, we checked the multicollinearity by looking at the variance inflation factor (VIF) of each variable and indicator. The VIF was identified in a linear regression that included collinearity diagnostics produced in SPSS (Field, 2005).

12. ***Important comment*** As one of the limitations, the authors state that they did not consider the spatial cross-correlation when modelling the ground motion fields. However, they do not justify this arbitrary exclusion. For example, the OQ-Engine has models of spatial correlation already implemented, and therefore I do not see a good reason for neglecting it. As the authors correctly state, the inclusion of a spatial correlation model would increase the dispersion of the curves presented in Figure 12, making them more "realistic". Thus, I suggest either including a spatial correlation model, or giving a strong justification for its arbitrary exclusion.

R/: We appreciate the reviewer comment, and we will update the discussion section based on the following arguments:

The reviewer expresses some concerns about having disregarded a spatial correlation model to model the ground motion fields. It is worth noting that we always consider the ground motion variability through uncorrelated random fields (that allowed us to create Figure 12). It is also worth noting that the sentence in line 451 did not refer to simple spatial correlation models, but rather to spatial inter-period cross-correlation models (IPCCM), i.e. when several intensity measures (IM) are simultaneously required by their set of fragility functions to calculate the physical vulnerability of building stocks to earthquakes. Related to this, it is important to note that the current OpenQuake engine only provides the option to simulate spatially correlated ground motion fields (e.g. Jayaram and Baker, 2009), but it does not provide spatially cross-correlated random fields.

Moreover, it is important to highlight the relation between the spatial extent and density of the building stocks with respect to the decision of including or not IPCCM. For instance, the study by Michel et al. (2017) found that for building portfolios that are spaced a few kilometers apart, the influence of cross-correlation in risk assessment is very small compared to the one imposed by ground motion variability itself. This feature is similar to the one we encounter in the Sabana Centro region where the main urban areas (cascos urbanos) between neighboring municipalities are separated by several kilometers. Conversely, other studies have found that the role of including either simpler spatial correlation models (e.g. Bazzurro and Luco, 2005) or IPCCM (Gomez Zapata et al, 2022a,b) for a dense and spatially aggregated building portfolio is comparatively more relevant, which is not to be the case of our study area. In fact, the aforementioned cited study remarks on this issue by stating that, since the spatial correlation of ground motion IMs decreases rapidly with distance (e.g. Schiappapietra and Douglas, 2020), its effect on loss-estimations is maximized when it is applied to a dense exposure model (i.e. with aggregation areas (~1 x 1km grid) significantly smaller than the correlation distance of the ground motions (~20 km) because buildings within a grid cell are treated as if the inter-station distance was zero. Since our exposure model in Sabana Centro is composed of only 11 geocells where the buildings are therein spatially aggregated and with centroid-to centroid distances of the same order as the ground motion correlation lengths, we can expect that the relevance of including a spatial correlation model would not be high. Of course, this feature is inherent to the decision of the aggregation areas (11 municipalities).

Aligned with the former, and as described by Stafford. (2012) and by Gomez Zapata. (2021), one can suspect that when the dimension of the geo-cells in the exposure model is larger than a typical seismic ground motion correlation length, an artificial bias in the ground motion correlation has to be expected which may be the case in our study. Therefore, more meaningful future studies with higher resolution exposure models are anyway required but are without our scope. These possible future improvements along with local fragility models (perhaps with more IM) will certainly require the incorporation of spatially correlated or cross-correlated models for which we can then confirm the important relationship and similarity between the correlation of ground motions and the damage correlation of exposed structures as comprehensively presented by Heresi and Miranda. (2022).

Technical corrections

13. Line 43: Change "7248 injured" for "7248 injured people" or "7248 injuries".

14. There is an inconsistency in the use of thousand separators. For example, in Line 45 the authors state "… and 35000 buildings that collapsed…", but then in Line 86, they write "resulted in 200,000 deaths". In Table 1, the authors use thousand separators again.

15. Line 118: Review the word "gro".

16. Line 158: The authors use the Quetame earthquake for defining the rupture geometry of the scenario events. I suggest adding an annotation in Figure 3, showing which one is the Quetame earthquake, for those of us who are not familiar with the historic seismicity of Colombia.

17. Line 249: There is an incomplete phrase.

R/: Thank you for taking the time to make technical corrections, we have addressed all of them in the manuscript.

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