REVIEWERS' COMMENTS TO THE AUTHOR:

Reviewer 1:

1. **General comment. Mesta et al. construct current and near-future urban development states (in total four exposure scenarios) for the Kathmandu Valley and assess the flood risk using flood inundation maps of the 100-year and 1000-year return level (pluvial and fluvial combined). In my opinion, the study has the potential to become a valuable contribution to risk research in the area. However, there are several points that need clarification and improvement before it can be considered for publication.**

Many thanks for your overall positive assessment of our manuscript and your insightful comments, which are addressed in detail below.

Major comments.

2. **Comment 1: Unspecific key result. The goal of the study (as far as I understood) is to provide decision makers with an adequate understanding of the risk consequences of particular actions. However, to me it was not clear what actually your key findings are. What is the new information that your study provides? What can decision-makers learn from your study? What is your key message to them? I image something like 5 bullet points summarizing the key findings of work.**

Thank you for pointing this out. Indeed, the study's primary goal (and our key message to readers, including decision-makers) is to demonstrate how risk-mitigation measures can substantially limit/reduce flood-induced losses in the future, compared to equivalent current levels. Please note that this and other key findings of our work were already presented in the second paragraph of the Conclusions (L533-L555), but we have slightly modified this paragraph to better emphasize our message. The paragraph now reads as follows, with modifications marked in bold:

*"**The key findings of this study are as follows. First,** results reveal that a significant proportion of the current building stock is located within the 100-year and 1000-year floodplains (14% and 15%, respectively), which may lead to substantial losses. However, an appropriate combination of DRR measures (i.e., building elevation and flood-hazard-informed land-use planning) can substantially limit mean absolute financial losses and reduce relative versions of these losses (i.e., expressed as a proportion of associated replacement costs) in the future, compared to equivalent current levels. **Second,** this study reveals that high-income populations are exposed to the highest mean loss ratios across both flooding-occurrence cases due to having the largest proportions of buildings in the floodplain. The trend in income versus flood-related losses contrasts with the trend in income versus earthquake-related losses identified for the same region in previous work (Mesta et al., 2022a), where low-income populations exhibited the highest seismic risk. This discrepancy illustrates that risk-mitigation measures can have varying effects for different hazards; therefore, DRR plans should be appropriately tailored for a specific region or sub-region and holistically account for multiple hazards. Kathmandu Valley's building stock is highly vulnerable to earthquakes due to the prevalence of URM buildings (particularly in low-income municipalities), such as adobe and brick/stone masonry. However, this feature of the building stock does not make it particularly susceptible to flood damage (except in the case of adobe houses, which are made of mud). This underlines why a multi-hazard approach to DRR that also considers earthquake vulnerability strengthening measures has little effect on the mean loss ratios (and even results in increased mean absolute financial losses) in this study. Instead, the flood risk is primarily controlled by the extent to which populations are located in the floodplain. Considering that hazard intensities vary spatially and that flooding and earthquake-induced ground shaking can affect different proportions of buildings in a given municipality, combinations of individual DRR measures should be investigated to find the optimal DRR solution for a given municipality. **Third,** this study*

demonstrates that DRR initiatives uniformly targeting flood risk across different income levels produce the largest benefits for low-income populations. These findings are relevant because the benefits of mitigation measures are currently not well understood/quantified by various stakeholders in Nepal. ***In summary, this work provides important insights for decision-makers on how effective risk-informed policymaking can limit future flood risk compared to current levels, particularly for low-income populations.***

3. **Comment 2: Lack of discussion. I general, I miss a bit a critical discussion of the data and methods used. Some aspects need to be discussed in more detail. Justify better why usage of global and low resolution data sets for regional risk assessment (Line 115). Discuss limitations of flood maps. You state yourself that resolutions of 10 m or finer are recommended. Also you state that 'urbanization effects on flood hazard' are neglected (Line124). Please discuss influence on your results.**

Thank you for your this comment. As we state in section "2.2 Hazard Modelling" (L137-L139), "the primary purpose of this study is to test different exposure/vulnerability scenarios using a common flood hazard input that is open and easily accessible; developing a bespoke fine-resolution hazard model for the study area is not within the scope of this work". Thus, the need for a detailed justification of the hazard model used is not warranted in this context, in our opinion.

However, based on this suggestion (and that of another reviewer), we have added a new section "4. Discussion" (between the "Results" and "Conclusions" sections), where we comment on the main limitations of this study (including all of those mentioned by the reviewer in this comment). Section "4. Discussion" (L483-L527) reads as follows:

*"**4 Discussion***

The main results of this study provide a clear description of the current and potential near-future flood risk in Kathmandu Valley, suggesting that decision-makers of today have a unique opportunity to positively influence the risk of tomorrow, through their choices on implementing policies that control future risk drivers (e.g., Cremen et al., 2022b). However, we acknowledge that different sources of uncertainty and limitations of the data and methods used can influence the accuracy of the results obtained, which is now discussed.

In this study, we characterize the flood hazard using global maps with a coarse resolution (i.e., 90 m), which may not capture the highly localized nature of flood hazard (e.g., associated with small streams). While finer-resolution hazard maps (e.g., 10 m or lower) are generally preferred for conducting urban flood risk assessments, the spatial resolution of the hazard model must also be consistent with the resolution of the exposure model used. We characterize exposure in the valley using urban maps with a spatial resolution of 30 m; therefore, our analyses would not benefit from hazard maps of a finer resolution. In addition, some authors (e.g., Fatdillah et al., 2022; Zhang, 2020) report that using finer-resolution digital elevation models (DEM), which would be needed to produce finer-resolution flood hazard maps, can result in larger simulated flooded areas and losses compared to coarser-resolution DEM; however, other authors (e.g., McClean et al., 2020) suggest the opposite, indicating that flood risk may be exaggerated using flood maps based on global coarse DEM. These ambivalent findings suggest that the advantages of using finer-resolution flood maps for regional flood risk assessments, in fact, require careful evaluation for each specific context. Another limitation of the flood maps employed in this study is that they do not capture the effects of urbanization on flood hazard (i.e., the replacement of natural ground with impermeable surfaces, changes to drainage or irrigation systems, and deforestation can increase runoff during precipitation events). The use of physics-based flood simulations that include future urban footprints would address this issue (e.g., Jenkins et al., 2022) but may entail a high computational cost.

Uncertainties and limitations associated with the exposure and vulnerability models also affect the loss outputs. Due to the absence of a reliable database for Kathmandu Valley containing exact building footprints (and relevant attributes such as building typology and height), we construct our exposure model by downscaling data collected from census and surveys (mainly at the municipality level) into the built-up areas of the valley (i.e., dasymetric mapping). While exposure disaggregation techniques are widely used in regional risk assessments (e.g., Geiß et al., 2022; Dabbeek et al., 2020), it is recommended to use original exposure models that are refined from the outset, since the accuracy of damage and loss estimates are highly sensitive to that of the exposure data. The accuracy of the exposure model may be of particular importance for flood loss assessments, given the potentially significant localized variability of flood hazard (i.e., flood depths can abruptly change even between closely-spaced locations). Moreover, the loss accuracy strongly depends on the quality of the vulnerability curves. In this study, we modify existing continental-based vulnerability curves to include relevant characteristics of the local building stock in Kathmandu Valley (e.g., building typology and height). However, it is difficult to ascertain how much (if any) uncertainty and/or accuracy is effectively improved with these modifications.

The design and implementation of risk-mitigation strategies also face several challenges. For instance, policies that restrict future urbanization within floodplains rely on the accuracy of spatial designations made within flood maps. While flood maps provide a good basis for floodplain management, regulation, and mitigation- e.g., in the USA, 100-year flood maps are used to identify Special Flood Hazard Areas where the National Flood Insurance Program's floodplain management regulations must be enforced (Ludy and Kondolf, 2012; Federal Emergency Management Agency (FEMA), 2010)- it is essential to acknowledge that different sources of uncertainty (e.g., climate change impacts, uncertainty in the hydrological/hydraulic models, etc.) can affect the resulting floodplain delineation (Zahmatkesh et al., 2021). Consequently, populations outside the designated floodplains may still be at risk of flooding and should be made aware of this.

A comprehensive sensitivity analysis could be conducted to investigate the impact of the aforementioned limitations on the results (e.g., Bernhofen et al., 2022). However, since the main focus of this study is to investigate relative risk changes across different sets of DRR-related actions, the exact values of absolute losses are not of particular interest or relevance."

References:

1. *Bernhofen, M.; Cooper, S.; Trigg, M.; Mdee, A.; Carr, A.; Bhave, A.; Solano-Correa, Y.; Pencue-Fierro, E.; Teferi, E.; Haile, A.; Yusop, Z.; Alias, N.; Sa'adi, Z.; Bin Ramzan, M.; Dhanya, C.; Shukla, P. The Role of Global Data Sets for Riverine Flood Risk Management at National Scales. Water Resources Research, 2022.*
2. *Cremen, G., Galasso, C., and McCloskey, J.: Modelling and Quantifying Tomorrow's Risks from Natural Hazards, Sci. Total Environ., 2022b.*
3. *Dabbeek, J., Silva, V., Galasso, C., and Smith, A.: Probabilistic earthquake and flood loss assessment in the Middle East, Int. J. Disaster Risk Reduct., 49, 101662, 2020.*
4. *Fatdillah, E., Rehan, B., Rameshwaran, P., Bell, V., Zulkafli, Z., Yusuf, B., Sayers, P. Estimates of Flood Damage and Risk Are Influenced by the Underpinning DEM Resolution: A Case Study in Kuala Lumpur, Malaysia. Water, 14, 2208, 2022.*
5. *Federal Emergency Management Agency (FEMA): Special Flood Hazard Area (SFHA). Available at https://www.fema.gov/glossary/special-flood-hazard-area-sfha, last access: 27 November 2022.*
6. *Geiß, C., Priesmeier, P., Aravena Pelizari, P., Soto Calderon, A. R., Schoepfer, E., Riedlinger, T., Villar Vega, M., Santa María, H., Gómez Zapata, J. C., Pittore, M., So, E., Fekete, A., and Taubenböck, H.: Benefits of global earth observation missions for disaggregation of exposure data and earthquake loss modeling: evidence from Santiago de Chile, Nat. Hazards, 2022.*
7. *Jenkins, L; Creed, M., Tarbali, K., Muthusamy, M.; Šakić, R.; Phillips, J.; Watson, S.; Sinclair, H.; Galasso, C.; McCloskey, J. Physics-based simulations of multiple natural hazards for risk-sensitive planning and decision making in expanding urban regions. International Journal of Disaster Risk Reduction, 103338, 2022.*
8. *Ludy, K, Kondolf, G.M.: Flood risk perception in lands "protected" by 100-year levees. Nat. Hazards 61, 829–842, 2012.*

9. *McClean, F., Dawson, R., & Kilsby, C. Implications of using global digital elevation models for flood risk analysis in cities. Water Resources Research, 56, e2020WR028241, 2020.*
10. *Zahmatkesh Z., Han, S., Coulibaly, P.: Understanding Uncertainty in Probabilistic Floodplain Mapping in the Time of Climate Change. Water 13, 1248, 2021.*
11. *Zhang, Y. Using LiDAR-DEM based rapid flood inundation modelling framework to map floodplain inundation extent and depth. Journal of Geographical Sciences, 30, 1649-1663, 2021.*

4. **Comment 2: Lack of discussion. Futhermore, I miss a discussion on the merging of fluvial and pluvial floods maps. Can you just do that and assume that the only thing that matters is the water level? What about velocity? I would find it very interesting to learn more about the importance of those two types that you merged. How much of the flooded area is from pluvial floods? Are there a lot of areas that are exposed to both?**

*Thank you for this comment. We have added some lines (**in bold**) (L146-L164) to the second paragraph of section "2.2 Hazard Modelling", which clarify that the merging of fluvial and pluvial flood maps into aggregated hazard maps is based on a previous study (Tate et al., 2021). Note that we aggregate two independent events (fluvial, pluvial), which is acceptable from a statistical standpoint. In addition, we have provided a brief description of the aggregated hazard maps and noted that the effect of pluvial flooding largely dominates the aggregated flood maps. Also, we have added some references there that justify our use of flood depth as the sole intensity measure; flood depth is the most widely used intensity measure in flood loss estimation, for instance.*

*"(…) We combine individual flood maps into aggregated hazard maps that represent fluvial-pluvial flooding for each mean return period by taking their maximum depths in line with the method of Tate et al. (2021), **who mosaiced fluvial and pluvial flood grids to generate an aggregated flood hazard map for the United States.** The fluvial-pluvial hazard maps for each considered mean return period are presented in Figure 2. Hereafter, we describe the flooding-occurrence cases using only the terms "100-year" and "1000-year", omitting the description "mean return period" for brevity. **Overall, the aggregated flood maps are largely dominated by the effects of pluvial flooding: in both 100-year and 1000-year aggregated flood maps, around 15% of the flooded areas are exposed to both types of flooding, 84% are only exposed to pluvial flooding, and less than 1% are only exposed to fluvial flooding. It should be noted that fluvial flooding generally results in low-velocity flows dominated by hydrostatic pressure, while pluvial flooding often features higher flow velocities (Gentile et al., 2022); these differences in velocity characteristics could be important for estimating flood damage in areas with steep terrain (Nofal and van de Lindt, 2022). However, we use only flood depth as the intensity measure in this study, since it is widely used for flood loss estimation (e.g., Federal Emergency Management Agency (FEMA), 2022; Nofal and van de Lindt, 2020) and flood velocities are more difficult to record than flood depths, requiring hydraulic simulations (e.g., Kreibich et al., 2009).***

References:

1. *Federal Emergency Management Agency (FEMA). Hazus 5.1 Flood Model Technical Manual, Federal Emergency Management Agency, Washington. D.C., 2022.*
2. *Kreibich, H., Piroth, K., Seifert, I., Maiwald, H., Kunert, U., Schwarz, J., Merz, B., and Thieken, A. H.: Is flow velocity a significant parameter in flood damage modelling?, Nat. Hazards Earth Syst. Sci., 9, 1679–1692, 2009.*
3. *Nofal O., van de Lindt, J. Understanding flood risk in the context of community resilience modeling for the built environment: research needs and trends. Sustainable and Resilient Infrastructure, 7(3), 171-187, 2022.*
4. *Tate, E., Rahman, M. A., Emrich, C. T., and Sampson, C. C. Flood exposure and social vulnerability in the United States, Nat. Hazards, 106, 435–457, 2021.*

5. **Comment 2: Lack of discussion. Please also discuss the usage of the flood vulnerability functions from JRC. E.g.: How is it possible that a one story building inundated by 6 m only suffers a loss of 60%.**

As mentioned in section "2.4 Modelling flood vulnerability", the JRC vulnerability functions represent the best choice for this study since no specific functions have been developed for Kathmandu Valley due to a lack of available data. Note that Gentile et al. (2022) also employed the JRC vulnerability functions to assess flood risk in Kathmandu Valley. 60% is the maximum loss that occurs to brick and concrete buildings since it is assumed that the flood cannot significantly impact the structural components of the building, which represent a substantial proportion of the construction costs. This assumption is in line with that of other authors (e.g., CAPRA, 2012; FEMA, 2022) and complies with the assumptions used to develop the JRC vulnerability functions (e.g., Huizinga et al., 2017).

*To clarify these points, we have added some lines (in **bold**) (L263-L267) to the second paragraph of section "2.4.Modeling flood vulnerability", as follows:*

*"(…) Firstly, we set maximum damage to be 100% for A and W, and 60% for all brick (BSM/BSC, RM) and concrete (i.e., RC-CCP, RC-WDS) typologies, following JRC recommendations. **The 60% maximum damage threshold used for some typologies reflects the assumption that a flood cannot damage major water-resistant structural components, which represent a substantial portion of building construction costs (Huizinga et al., 2017). This assumption is in line with other studies such as the Central American Probabilistic Risk Assessment (CAPRA) initiative (2012), which assigns 60% maximum flood losses to masonry and concrete buildings, and FEMA (2022), which indicates that major structural components are expected to withstand flood events.** (…)"*

References:

1. *Central American Probabilistic Risk Assessment (CAPRA). Integrating Disaster Risk Information Into Development Policies and Programs in Latin America and the Caribbean, 2012.*
2. *Federal Emergency Management Agency (FEMA). Hazus 5.1 Flood Model Technical Manual, Federal Emergency Management Agency, Washington. D.C., 2022.*
3. *Gentile, R., Galasso, C., Jenkins, L., Manandhar, V., Menteşe, E., Guragain, R., and McCloskey, J.: Scoring, selecting, and developing physical impact models for multi-hazard risk assessment, Int. J. Disaster Risk Reduct., 2022.*
4. *Huizinga, J., De Moel, H., and Szewczyk, W.: Global flood depth-damage functions: Methodology and the database with guidelines, 2017.*

6. **Comment 2: Lack of discussion. Please provide more information on how you distinguish groups of low, middle and high income (Line 249-250), as this is important for one of your main findings. Subsequently discuss this result better. Why do people with high income live in the same types of houses than middle and low income groups? Why do high income people live in flood-prone areas? Wouldn't they chosse to live in 'better' buildings outside dangerous areas? What is the reason for this? Or is that higher income people more live in urbanized areas prone to pluvial flooding? Please discuss better.**

Thank you for this comment. To address it, we have added a description of the procedure used to classify populations as low, middle, or high-income. Briefly, we classify populations at the municipality level based on three census variables (i.e., access to mobile/telephone services, mass media communication, and means of transportation) that are treated as proxies for economic wealth.

In addition, as you pointed out, people from different municipalities can live in buildings of the same typologies; however, the proportions of each building typology vary per municipality. For instance, as we state in the Conclusions (L542-L544), the prevalence of unreinforced masonry buildings, which are highly vulnerable to earthquakes but not to floods (except in the case of adobe houses), is larger in low-income municipalities. Moreover, as we have now emphasized in section "2.2 Hazard modeling" (L152-L154), pluvial flooding primarily contributes to the aggregated flood hazard of the region, and our income classification results in some high-income populations living in urbanized areas more prone to pluvial *flooding than those that house low- and middle-income populations. A discussion of the exact reasons for the geographical and socioeconomic trends observed is not within the scope of this study.*

*This description (provided **in bold** below) has been added to the fourth paragraph of section "2.4 Modelling flood vulnerability" (L209-L308):*

*"(…) Furthermore, we use the procedure detailed in Mesta et al. (2022b) to classify populations per municipality as low, middle, or high income for facilitating socioeconomic disaggregation of financial losses. **The classification is based on three variables (i.e., access to mobile/telephone services, mass media communication, and means of transportation) recorded in the 2011 Census, which are treated as proxies for economic wealth. The Census data are aggregated at the municipality level; therefore, any variability in the population's income level within each municipality is not (and cannot be) assessed. The classification is quantile, such that the three income categories contain an equal number of municipalities. We assume that the population's income level did not vary between 2011 and 2021 and would remain unchanged in 2031, given the lack of available data to make confident projections. This assumption is at least partially supported by previous work from Cutter and Finch (2008), who suggested that the social vulnerability of a community, which is influenced by its underlying socioeconomic and demographic characteristics (e.g., income level, gender, age), is not expected to vary significantly over timeframes similar to those considered in this study.**"*

References:

1. *Cutter, S. L., Finch, C.: Temporal and spatial changes in social vulnerability to natural hazards., Proc. Natl. Acad. Sci., 105, 2031-2306, 2008.*
2. *Mesta, C., Cremen, G., and Galasso, C.: Urban growth modelling and social vulnerability assessment for a hazardous Kathmandu Valley, Sci. Rep., 12, 6152, 2022b.*

7. **Comment 2: Lack of discussion. One strategy you assess is to restrict future urban growth within the floodplain. This floodplain is defined by your maps (100/1000-year return level). Please discuss the uncertainty and flaws of this simple approach.**

Thank you for pointing this out. These comments are addressed in the fourth paragraph (L516-L523) of the new section "Discussion":

"The design and implementation of risk-mitigation strategies also face several challenges. For instance, policies that restrict future urbanization within floodplains rely on the accuracy of spatial designations made within flood maps. While flood maps provide a good basis for floodplain management, regulation, and mitigation- e.g., in the USA, 100-year flood maps are used to identify Special Flood Hazard Areas where the National Flood Insurance Program's floodplain management regulations must be enforced (Ludy and Kondolf, 2012; Federal Emergency Management Agency (FEMA), 2010)- it is essential to acknowledge that different sources of uncertainty (e.g., climate change impacts, uncertainty in the hydrological/hydraulic models, etc.) can affect floodplain delineation (Zahmatkesh et al., 2021). Consequently, populations outside the designated floodplains may still be at risk of flooding and should be made aware of this."

References:

1. *Federal Emergency Management Agency (FEMA): Special Flood Hazard Area (SFHA). Available at https://www.fema.gov/glossary/special-flood-hazard-area-sfha, last access: 27 November 2022.*
2. *Ludy, K, Kondolf, G.M.: Flood risk perception in lands "protected" by 100-year levees. Nat. Hazards 61, 829–842, 2012.*
3. *Zahmatkesh Z., Han, S., Coulibaly, P.: Understanding Uncertainty in Probabilistic Floodplain Mapping in the Time of Climate Change. Water 13, 1248, 2021.*

8. **Comment 3: Abbreviations, acronyms and numbers. In my opinion, there is a very large amount of abbreviations, acronyms and numbers in the text that make it unnecessary difficult for the reader. For example, in section 2.2 there are new acronyms in almost every sentence. Particularly the acronyms for the building typologies are very hard to follow (e.g., Table 1) and also hard to find in the text. Please go through your text and think whether all those acronyms a required and maybe try to find more intuitive categories. If it is not possible to remove some acronyms, please provide at least an overview. Also, an overview table with details in the supplementary might be a good idea.**

Thank you for pointing this out. Indeed, in section "2.3 Modeling present and future exposure", we define seven acronyms that refer to different building typologies used in the analysis. However, as these acronyms were proposed by other authors in previous risk studies for Kathmandu Valley, we have decided not to modify them. In addition, we have removed the acronyms "GoN" (we directly use "Government of Nepal" in L77, L172) and "VDC" (which is replaced by "municipality") from the main text, but have kept the acronym "DRR" (that stands for disaster risk reduction) as this is a term widely used in risk analysis.

Based on your suggestions, we have added a full explanation of the building typology acronyms in Table 1 (in the table footer) and Figure 3 (please see our next response), to enhance readability. We have also added Table S1 to the Supplementary Material, containing a list of all acronyms used in the study.

Table 1. Summary of considered exposure scenarios for Kathmandu Valley

Exposure scenario	Scenario A	Scenario B	Scenario C	Scenario D
Year	2021	2031	2031	2031
Population	3,151,741	3,792,232	3,792,232	3,792,232
Number of buildings	789,898	943,606	943,606	943,606
Aggregated replacement value (€)	17,141,921,300	20,309,544,200	20,380,261,200* 20,409,943,100**	26,442,366,000* 26,470,663,000**
Building typologies featured	A, W, BSM/BSC, RC-CCP/WDS	A, W, BSM/BSC, RC-CCP/WDS	A, W, BSM/BSC, RC-CCP/WDS	RC-WDS, RM
DRR actions	-	-	Elevating buildings, flood-hazard-informed land-use planning	Elevating buildings, flood-hazard-informed land-use planning, structural retrofitting, building code enforcement

A: adobe; W: wood-frame; BSM: brick stone masonry with mud mortar; BSC: brick stone masonry with cement mortar; RM: reinforced masonry; RC-CCP: current-construction-practice reinforced concrete; RC.WDS: well-designed reinforced concrete.

Note: Scenarios C and D have two different aggregated replacement values, as the cost of elevating buildings in the 100-year (*) or the 1000-year floodplains (**) differ.

Table S1. List of acronyms used in this work

Acronym	Description
DRR	disaster risk reduction
A	adobe
BSM	brick/stone masonry with mud mortar
BSC	brick/stone masonry with cement mortar
W	wood-frame
RC-CCP	current-construction-practice reinforced concrete
RC-WDS	well-designed reinforced concrete
RM	reinforced masonry

9. **Comment 3: Abbreviations, acronyms and numbers. Please also update the legend in Fig. 3. It takes the reader a lot of effort and search in the text to find out what the different colors actually mean.**

We have updated Figure 5, by adding a full explanation of the building typology acronyms below the main plot.

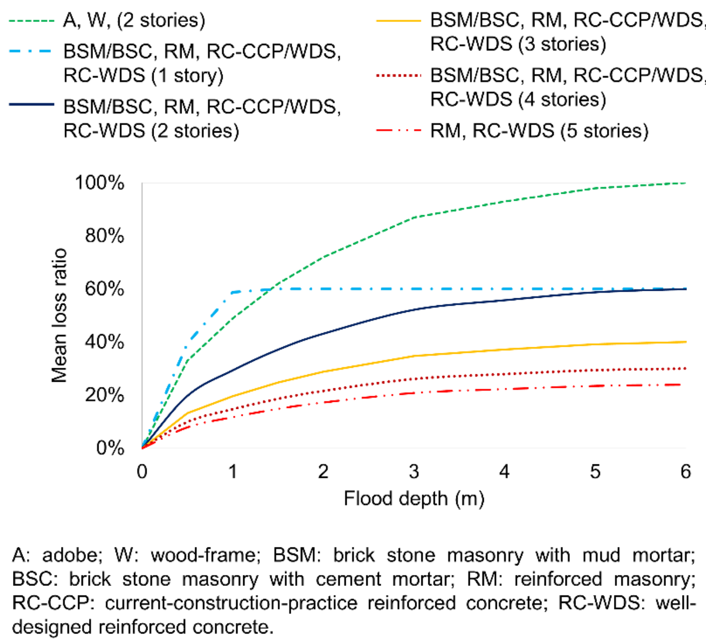

Figure 5. Flood vulnerability functions for the different considered building typologies and their associated range of heights

10. **Comment 3: Abbreviations, acronyms and numbers. Please consider to plot the numbers in table 2. Maybe you can try simple bar or pie charts. Please also explain why scenario C and D are together in this case.**

Thank you for your suggestions, which we have incorporated. We have added Figure 6 (bar chart) to plot the expected number of buildings in the floodplain for different flood depths (i.e., the absolute numbers previously reported in Table 2). As suggested by another reviewer, we have kept the information about the expected proportions of buildings within various depth ranges of the floodplains in Table 2.

Scenarios A, C, and D yield identical numbers in Figure 6 since the adoption hazard-informed land-use planning limits the expected number of buildings within the floodplain in 2031 (Scenarios C, D) to 2021 levels (Scenario A). In addition, as Scenarios C and D are associated with the same total building stock, both scenarios are grouped in Table 2 (i.e., they also have identical results in terms of the proportion of flood-exposed buildings).

We have modified some lines (L320-L323) (provided ***in bold*** *below) in the first paragraph of section "3.1 Distribution of buildings in the floodplain" to better clarify this:*

"Scenarios A, C, and D yield identical results in Figure 6, since the flood-hazard-informed land-use planning imposed as part of Scenarios C and D means that the expected number of buildings within the floodplain in 2031 (Scenarios C, D) remains limited to 2021 levels (Scenario A). *This measure decreases the proportion of flood-exposed buildings* ***in both Scenarios C and D (grouped in Table 2)*** *by 2.2%."*

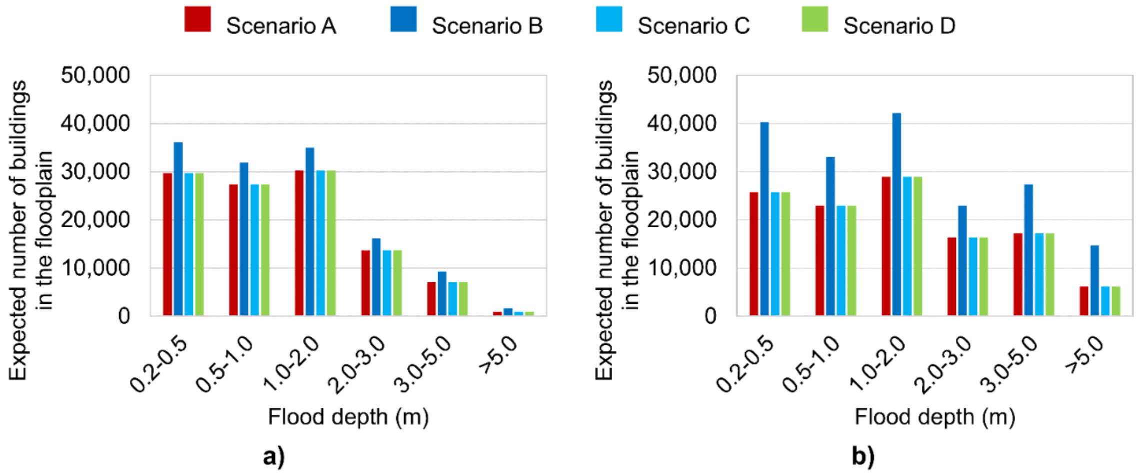

Figure 6. Exposure to flooding: the expected number of buildings within a given range of flood depth per flooding occurrence and exposure scenario

Table 2. Exposure to flooding: proportions of the total building stock within a given range of flood depth per flooding occurrence and exposure scenario.

Flooding occurrence	Scenario	0.2-0.5 m	0.5-1.0 m	1.0-2.0 m	2.0-3.0 m	3.0-5.0 m	>5-0 m
100-year	A	3.8%	3.5%	3.8%	1.7%	0.9%	0.1%
	B	3.8%	3.4%	3.7%	1.7%	1.0%	0.2%
	C, D	3.1%	2.9%	3.2%	1.5%	0.8%	0.1%
1000-year	A	3.3%	2.9%	3.7%	2.1%	2.2%	0.8%
	B	4.3%	3.5%	4.5%	2.4%	2.9%	1.6%
	C, D	2.7%	2.4%	3.1%	1.7%	1.8%	0.7%

11. **Comment 3: Abbreviations, acronyms and numbers. Also revise the paragraph between line 389-397. In general, you use a lot of numbers in the text. Please do not just list all the numbers, but select the numbers that you include into the text. These numbers need to underline your key findings and arguments. All the rest can go into the tables and figures, I think**

We have made some modifications to improve the paragraph in question. In particular, we have added the numbers about the changes in mean loss ratios for Scenario B, we have reduced the text that reports the changes in mean loss ratios for Scenario C (we group municipalities in three categories instead of four), and we have removed the numbers about the changes in mean loss ratios for Scenario D. as these numbers are quite similar to those from Scenario C.

Also, as you suggest in another comment (please, see our response #23), we have added new maps (Figures 12 and 13) to plot the differences in loss ratios between scenarios; these maps are now mentioned in this paragraph (L452-L465):

*"Figure 12 illustrates the absolute changes to the municipality-level mean loss ratios for the 100-year flooding occurrence, considering Scenario A as a baseline**. In Scenario B, the mean loss ratios show small absolute variations (between -1.0% and +1.2%) compared to Scenario A** since future urbanization continues occurring in both flooded and non-flooded areas. The relative effects of the building elevation strategy and the flood-hazard-informed land-use planning proposed in Scenario C are noticeable: **absolute reductions in mean loss ratio for Scenario C relative to Scenario A range between 2.0-2.9% in five municipalities, between 1.0-2.0% in 18 municipalities, and are less than 1.0% in the remaining 81 municipalities. The benefits of implementing additional multi-hazard DRR measures in Scenario D are almost equivalent to those in Scenario C because the seismic upgrading of the building stock does not contribute much to reducing flood risk.** Figure 13*

presents the absolute changes to the municipality-level mean loss ratios for the 1000-year flooding occurrence, considering Scenario A as a baseline. ***In Scenario B, the mean loss ratios exhibit some absolute variations (between -1.0% and +2.3%) relative to Scenario A, which are larger than in the 100-year flood case; in other words, the consequences of not controlling future urbanization in flood-prone areas can increase with the severity of the considered flooding occurrence.*** *The effects of the flood-specific DRR measures implemented in Scenario C are as follows:* ***absolute reductions in mean loss ratio for Scenario C relative to Scenario A range between 2.0-5.6% in 9 municipalities, between 1.0-2.0% in 32 municipalities, and are less than 1.0% in the remaining 63 municipalities. The benefits of the combined DRR measures in Scenario D are comparable to those in Scenario C.****"*

Specific comments

12. Abstract: Make the abstract more clear. Focus on the key results, numbers and message. For me it was very difficult to get the key message of your work first time reading the abstract. Only after reading the entire article, I also understood the abstract. Clearly state the different exposure inventories and mitigation strategies you investigate. For me, your key message in very simple words is: 'Measures can reduce the risk/damage a lot. That is why we need to do it.' And you give the numbers for it. I like your first sentence in the conclusion Line 408-411. This sentence is clear to me and maybe you can use it also for the abstract.

Thank you for this comment. We have addressed it by including the first sentence of the Conclusions in the Abstract. We also make it clear that Scenario A corresponds to the current urban system in Kathmandu Valley, while Scenarios B, C, and D correspond to the near-future development trajectories that the valley could experience. Moreover, please note that the risk-mitigation strategies we investigate and the key results of each scenario were already clearly stated in the abstract (L15-L27); therefore, we have not made additional changes.

The updated Abstract (with changes marked in ***bold****) reads as follows:*

"Flood risk is expected to increase in many regions worldwide due to rapid urbanization and climate change if adequate risk-mitigation (or climate-change-adaptation) measures are not implemented. However, the exact benefits of these measures remain unknown or inadequately quantified for potential future events in some ***flood-prone*** *areas such as Kathmandu Valley, Nepal, which this paper addresses.* ***This study examines the present (2021) and future (2031) flood risk in Kathmandu Valley, considering two flood-occurrence cases (with 100-year and 1000-year mean return periods)*** *and using four residential exposure inventories representing the current urban system* ***(Scenario A)*** *or near-future development trajectories* ***(Scenarios B, C, D)*** *that Kathmandu Valley could experience. The* ***findings reveal*** *substantial mean absolute financial losses (€ 473 million and € 775 million in repair/reconstruction costs) and mean loss ratios (2.8% and 4.5%) for the respective flood-occurrence cases in current times if the building stock's quality is assumed to have remained the same as in 2011 (Scenario A). Under a "no change" pathway for 2031 (Scenario B), where the vulnerability of the expanding building stock remains the same as in 2011, mean absolute financial losses for the 100-year and 1000-year mean return period flooding occurrences would respectively increase by 16% and 14% over those of Scenario A. However, a minimum (0.20 m) elevation of existing residential buildings located in the floodplains and the implementation of flood-hazard-informed land-use planning for 2031 (Scenario C) could respectively decrease the mean absolute financial losses of the flooding occurrences by 13% and 9%, and the corresponding mean loss ratios by 27% and 23%, relative to those of Scenario A. Moreover, an additional improvement of the building stock's vulnerability that accounts for the multi-hazard-prone nature of the valley (by means of structural retrofitting and building code enforcement) for 2031 (Scenario D) would further decrease the mean loss ratios (respective reductions for the 100-year and 1000-year mean return period flooding occurrences would be 28% and 24% relative to those of Scenario A). The largest mean loss ratios computed in the four scenarios are consistently associated*

with populations of the highest incomes, largely located in the floodplains. In contrast, the most significant benefits of risk mitigation (i.e., largest reduction in mean absolute financial losses or mean loss ratios between scenarios) are experienced by populations of the lowest incomes. This paper's main findings can inform decision makers about the benefits of investing in forward-looking multi-hazard risk-mitigation efforts."

13. introduction: Needs to be more concise. There are a lot of general information. Please try to tailor it to the specific content of your article. There is lot about climate change, but in this study you do not assess climate change impacts. This is almost a bit misleading.

Thank you for this comment, which we have addressed by making the following modifications to the Introduction:

- *In the fourth paragraph (L63-L81), we have removed four lines that provided specific details of the climate change scenarios developed by the Government of Nepal. The fourth paragraph (with changes marked **in bold**) now reads as follows:*

  *"The 2017 Terai flood and earlier major events have emphasized the significant risk that flooding continuously imposes on the Nepalese population. While flood risk is already substantial, several ongoing trends in the country could further amplify this risk in the coming years. **Firstly,** Nepal is projected to be one of the fastest urbanizing countries in the world over the 2018-2050 period (United Nations, 2019b), which could lead to significantly larger amounts of flood exposure. While urban growth is gaining pace across different regions of Nepal, Kathmandu Valley represents the "hub" of urban development in the country (Timsina et al., 2020). A previous study by the authors (Mesta et al., 2022b) revealed that urban land in Kathmandu Valley could reach 352 km2 in 2050, almost doubling its current size and covering half the total valley extent. A significant share of this new urbanization is projected to occupy the valley's most hazardous (at least in terms of flooding and liquefaction) and socially-vulnerable regions (Mesta et al., 2022b). **Secondly,** other natural hazards such as earthquakes have unveiled the poor state of Nepal's building stock and physical infrastructure, which is caused by a combination of low-quality building materials, deficient construction practices, low compliance with building codes, as well as aging, and deterioration (Bothara et al., 2018; Varum et al., 2018). Traditional materials, such as bamboo/wood, stone, and mud, are still preferred in many regions of the country (especially in rural areas) due to their availability and low cost (Bothara et al., 2018). However, buildings made of bamboo/wood or mud suffer severely from flood damage (e.g., Becker Andrea B. et al., 2011; Fatemi et al., 2020) due to low durability and high permeability**. Thirdly, climate change scenarios developed by the Government of Nepal (Ministry of Forests and Environment, 2019) reveal a rising trend in precipitation (for all seasons, except the pre-monsoon season) in the medium term (2016-2045) and long-term (2036-2065).** Therefore, it is critical to determine the potential benefits of implementing disaster risk reduction (DRR) strategies in the country (particularly Kathmandu Valley) towards preventing devastating economic losses and casualties in future major natural hazard events. "*

- *In the fifth paragraph, we have added a sentence (in **bold**) (L97) to emphasize that the impact of climate change is not within the scope of this work:*

  *"(…) The methodology employs a scenario-based flood loss estimation approach, using 100-year and 1000-year mean return period flood occurrence maps and four potential present (2021) and future (2031) exposure and vulnerability scenarios, focusing only on residential buildings. **Note that the impact of climate change is not explicitly considered within this work.** (…)"*

14. Page 1 Line 11: 'multi-hazard-prone area': There are multiple important hazard in the area, but you do not assess multi-hazards, as far as I understood.

Yes, this study only focuses on assessing flood risk. We have replaced "multi-hazard-prone area" with "flood-prone area" (L11), to address this comment.

15. **Page 1 Line 14: Be careful with the word 'predict'. Maybe better use 'Our results hint/point at/suggest…'**

We have replaced "the results predict" with "the findings reveal" (L15).

16. **Page 2 Line 56-57: Many readers are not familiar with these locations. Please explain where and what 'Terai regions'.**

*We have added some lines (in **bold**) (L59-L60) to the paragraph in question, to provide more information about the Terai regions:*

*"(…) **Terai is one of Nepal's three ecological belts (together with Mountain, and Hill), and covers the alluvial and fertile plains along the southern part of the country (Government of Nepal, 2017).** (…)"*

References:

1. *Government of Nepal, N. P. C.: Nepal Flood 2017: Post Flood Recovery Needs Assessment, Kathmandu, Nepal, 2017.*

17. **Line 110: Consider to include sub-section 'Study area'.**

*We have added the requested subsection to the manuscript. The subsection "Study area" (L108-L116) reads as follows (with changes marked in **bold**):*

*"This study focuses on Kathmandu Valley, Nepal, which is surrounded by the Himalayan mountains and lies within the Bagmati river basin. Kathmandu Valley occupies a total area of 721 km^{2,} consisting of three districts (Bhaktapur, Kathmandu, and Lalitpur), which comprise five municipal areas and several municipalities and rural municipalities (formerly named village development committees, or VDCs). **The built-up areas in Kathmandu Valley are estimated to be 202 km^2 for 2021 and are expected to increase to 307 km^2 by 2031 (Mesta et al., 2022b). Figure 2 provides a physical map of Kathmandu Valley, showing elevation (available at https://earthexplorer.usgs.gov/, last accessed December 2022) and the river network (available at https://openstreetmap.org/, last accessed December 2022). Figure 3 displays the administrative division of Kathmandu Valley and its built-up areas in 2021 and 2031 (Mesta et al., 2022b).**"*

References:

1. *Mesta, C., Cremen, G., and Galasso, C.: Urban growth modelling and social vulnerability assessment for a hazardous Kathmandu Valley, Sci. Rep., 12, 6152, 2022b.*

18. **Line 105: Not necessary to put coordinates in the text here, in my opinion.**

We have deleted these coordinates from the text.

19. **Figure 1: Include river network (and urban settlement layer?) into map. Also include larger overview map that at least shows location of Nepal within the Himalaya.**

We have updated Figure 2 by adding the river network and an inset overview map. We have also added a new figure (Figure 3) that displays the administrative division of Kathmandu Valley and its built-up areas in 2021 and 2031 (Mesta et al., 2022b).

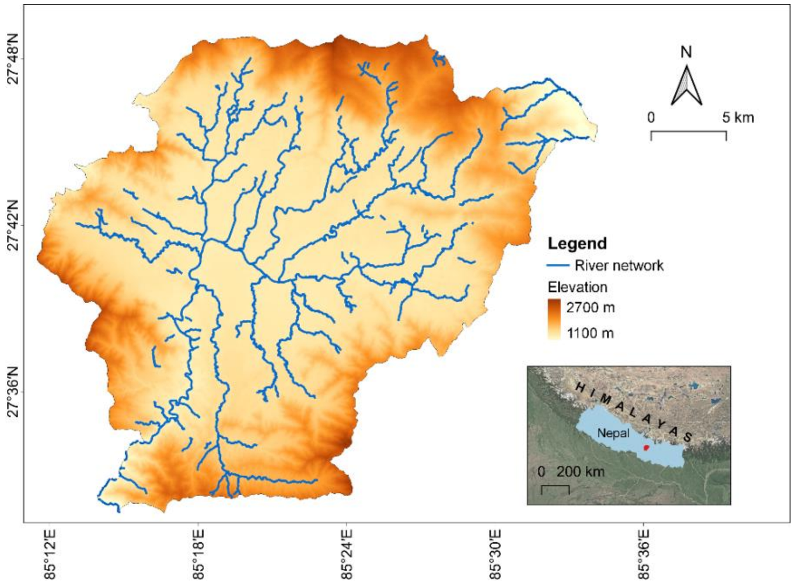

Figure 2. Physical map of Kathmandu Valley

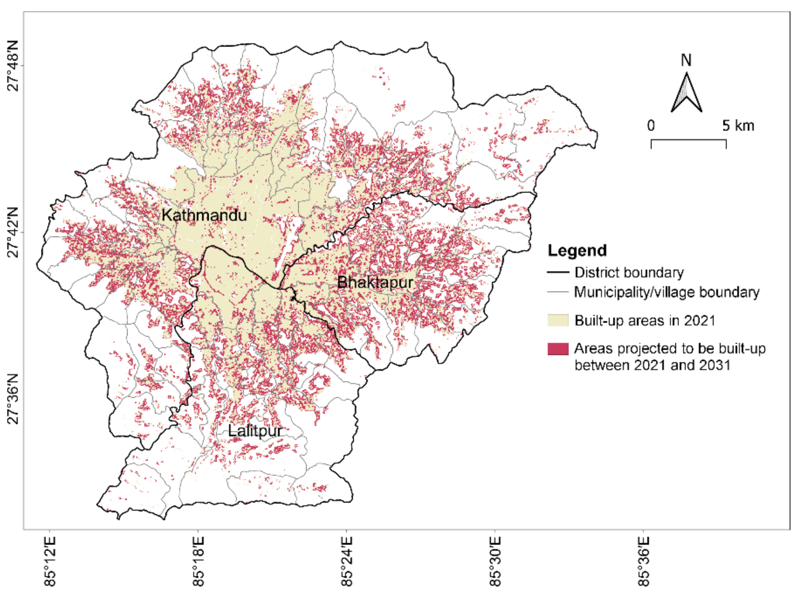

Figure 3. Administrative map of Kathmandu Valley and its built-up areas (Mesta et al., 2022b)

References:

1. *Mesta, C., Cremen, G., and Galasso, C.: Urban growth modelling and social vulnerability assessment for a hazardous Kathmandu Valley, Sci. Rep., 12, 6152, 2022b.*

20. **Line 130-133: I think you need to be careful here. You cannot say ‘approximately reflects a situation in which flooding is exacerbated due to climate change’ (Line 131). You compare 100-year and 1000-year flood. As you do not do any investigation and do not provide any information that could back this statement, you should not make it, I think. You do not do a climate change impact study.**

*Thank you for pointing this out. We have made modifications (L143-L145) to the sentence in question (marked in **bold**), removing the reference to climate change:*

*"The second flood-occurrence case reflects a situation **in which flooding is more severe** and is based on the Fathom-Global undefended flood map with a 1000-year mean return period."*

21. Table 1: Please consider to include a scheme that illustrated the set-up of your study. This table seems to form a good basis for this scheme. It should capture the main steps of your study (return levels, exposure scenarios, distinction of building types, imcome level,..)

Thank you for your suggestion. We have addressed it by adding a new figure (Figure 1), which provides an overview of this study's flood risk modeling approach.

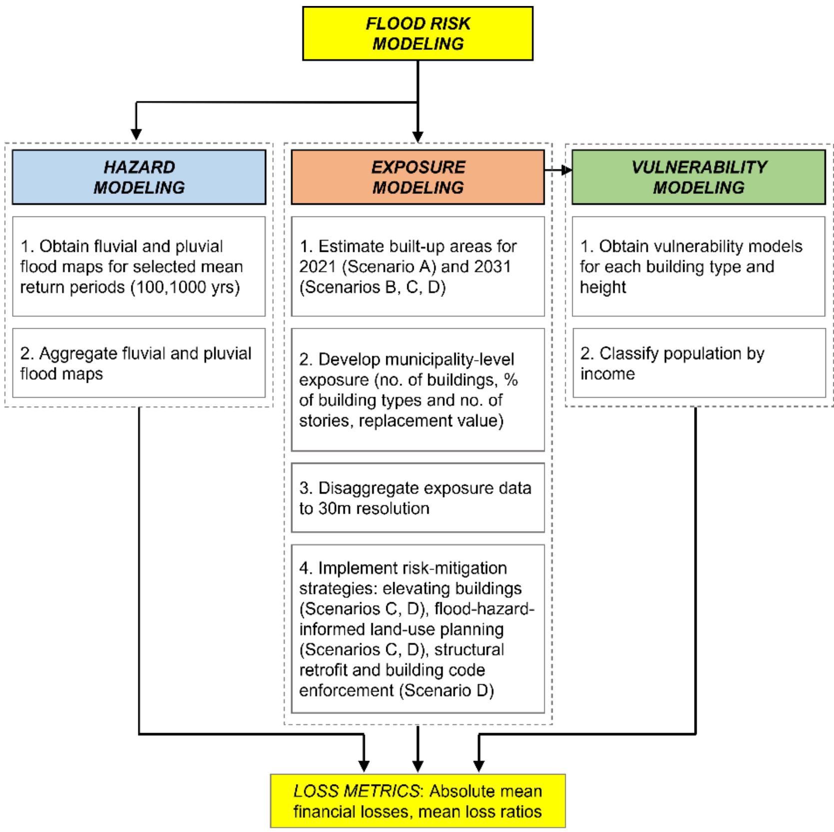

Figure 1. Overview of the flood risk modeling approach used in this study

22. Figure 4: Wouldn't it be better to (also) show the absolute numbers? In my opinion, showing the percentage without information of building density can be a bit missleading. Like this, it does not provide good information on the the spatial distribution of flooded buildings, I think. Can you maybe plot the buildings on the map directly?

Thank you for this comment. We have replaced the previous maps (Figures 4 and 5) with Figures 7 and 8. In these new maps, we plot both the expected number of buildings in the floodplain and the percentage of buildings in the floodplain.

Also, as suggested by another reviewer, we have rescaled the pie charts that show the distribution of the expected number of buildings within various depth ranges of the floodplains. Figures S1 and S2 (in the Supplementary Material) contain the updated pie charts.

*We clarify here that we have developed our exposure model by downscaling municipality-level exposure data to 30m resolution urban maps of built-up areas in the valley (see Figure 3), which are too coarse to contain exact building footprints; this is a typical feature of regional risk exposure models. Thus, we cannot directly plot the buildings on the map, as requested. To clarify this in the manuscript, we have added some lines (in **bold**) (L202-L203, L206-L207) to sections "2.3.1 Scenario A (population and buildings for 2021)" and "2.3.2 Scenarios B, C, D (population and buildings for 2031)":*

*L202-L203: "(…) **We disaggregate the exposure data to match the 30 m spatial resolution of the urban map containing the 2021 built-up areas (see Figure 3).**"*

*L206-L207: "(…) **We disaggregate the exposure data into the urban map containing the 2021 and 2031 built-up areas (see Figure 3).**"*

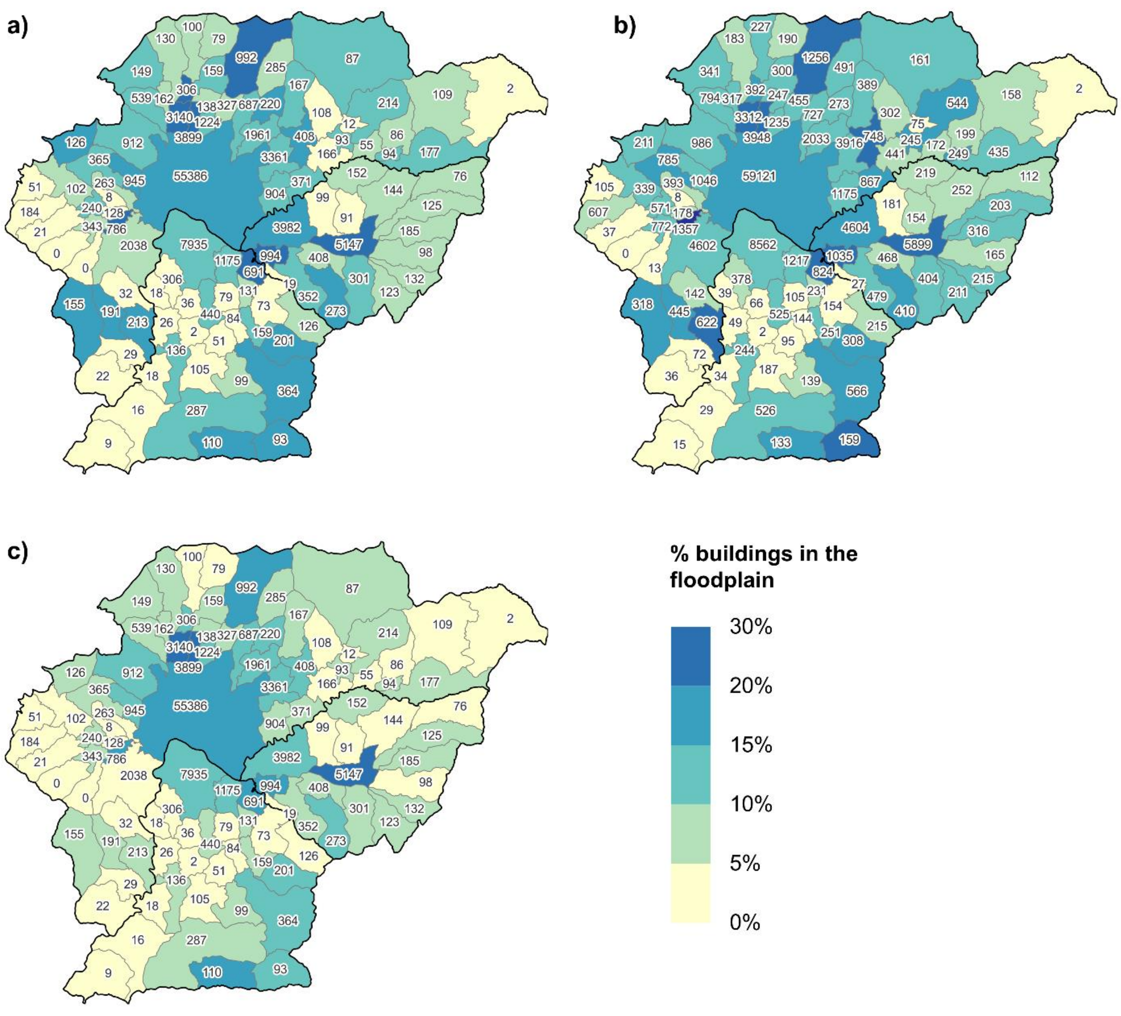

Figure 7. Spatial distribution of buildings in the 100-year floodplain for a) Scenario A, b) Scenario B, and c) Scenarios C and D. The numbers plotted inside each municipality correspond to the expected number of buildings in the floodplain.

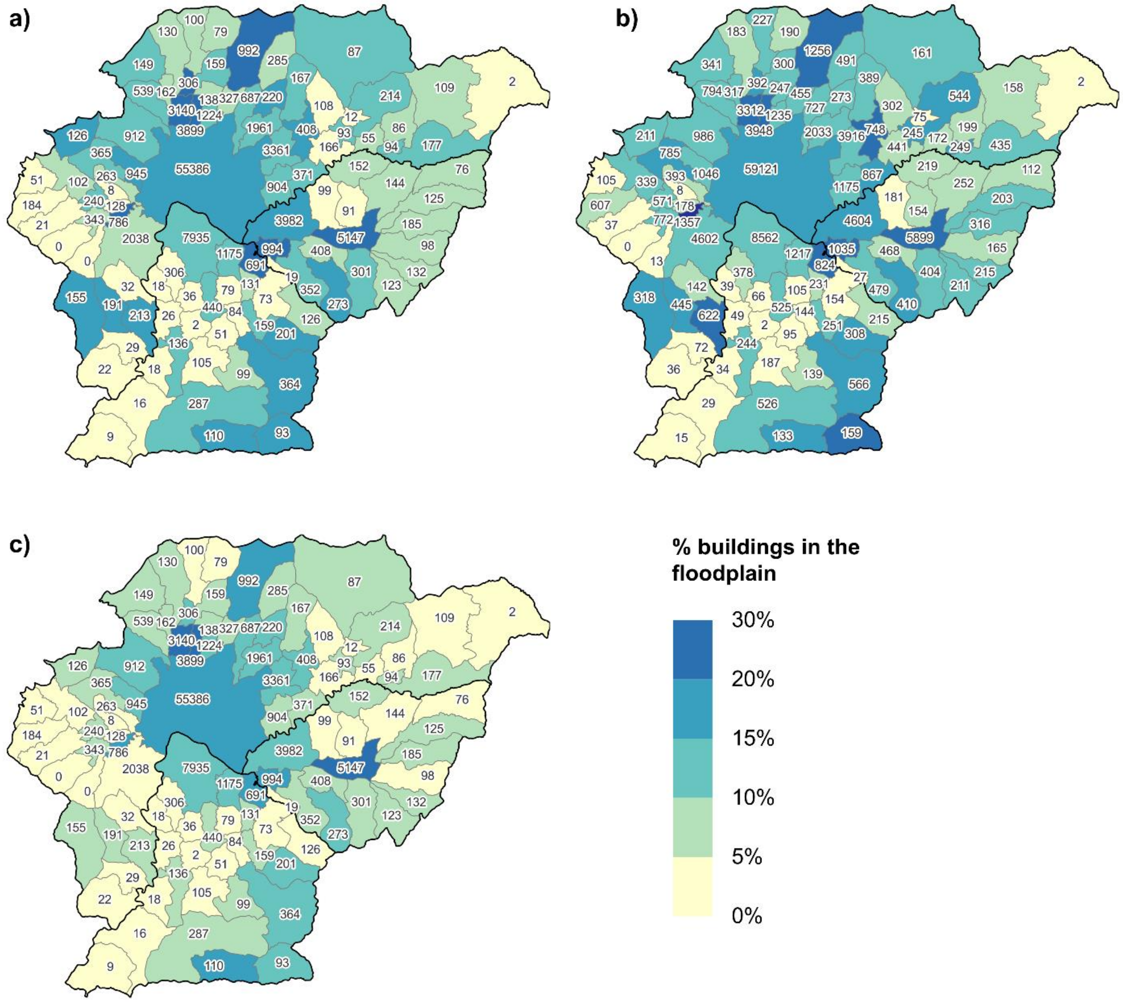

Figure 8. Spatial distribution of buildings in the 1000-year floodplain for a) Scenario A, b) Scenario B, and c) Scenarios C and D. The numbers plotted inside each municipality correspond to the expected number of buildings in the floodplain.

23. **Figure 5: I am not sure the mean loss ratio on a municipality level is a very interesting thing to plot here. As you have the exact flood maps, why not plot damage using the inundation maps. In this way, hotspots of damage are visible. Please also try to calculate difference maps, e.g. between A and C to show the benefit of certain measures.**

Thank you for pointing this out. We have decided to keep our municipality-level loss ratio maps in the manuscript, as we believe these maps provide a broad overview of flood risk hotspots.

As explained in the previous comment, we clarify that we have developed our exposure model by downscaling municipality-level exposure data to 30m resolution urban maps of built-up areas in the valley (see Figure 3), which are too coarse to contain exact building footprints. Thus, we cannot directly plot building-level damage on the map, as requested.

Based on your comment, we have added Figures 12 and 13 that show how mean loss ratios change in Scenarios B, C, and D relative to Scenario A. These maps are used in the discussion on the benefits of risk-mitigation measures, provided in the last paragraph (L452-L465) of section “3.2 Losses”:

“Figure 12 illustrates the absolute changes to the municipality-level mean loss ratios for the 100-year flooding occurrence, considering Scenario A as a baseline. In Scenario B, the mean loss ratios show

small absolute variations (between -1.0% and +1.2%) compared to Scenario A, since future urbanization continues occurring in both flooded and non-flooded areas. The relative effects of the building elevation strategy and the flood-hazard-informed land-use planning proposed in Scenario C are noticeable: absolute reduction in mean loss ratios range between 2.0-2.9% in five municipalities, between 1.0-2.0% in 18 municipalities, and is less than 1.0% in the remaining 81 municipalities, relative to Scenario A. The benefits of implementing additional multi-hazard DRR measures in Scenario D are quite similar to those in Scenario C because the seismic upgrading of the building stock does not contribute much to reducing flood risk. Figure 13 presents the absolute changes to the municipality-level mean loss ratios for the 1000-year flooding occurrence, considering Scenario A as a baseline. In Scenario B, the mean loss ratios exhibit some absolute variations (between -1.0% and +2.3%) relative to Scenario A, which are larger than in the 100-year flood case; in other words, the consequences of not controlling future urbanization in flood-prone areas are worse for a more severe flooding occurrence. The effects of the flood-specific DRR measures implemented in Scenario C are as follows: absolute reduction in mean loss ratios range between 2.0-5.6% in 9 municipalities, between 1.0-2.0% in 32 municipalities, and is less than 1.0% in the remaining 63 municipalities, relative to Scenario A. The benefits of the combined DRR measures in Scenario D are also comparable to those in Scenario C."

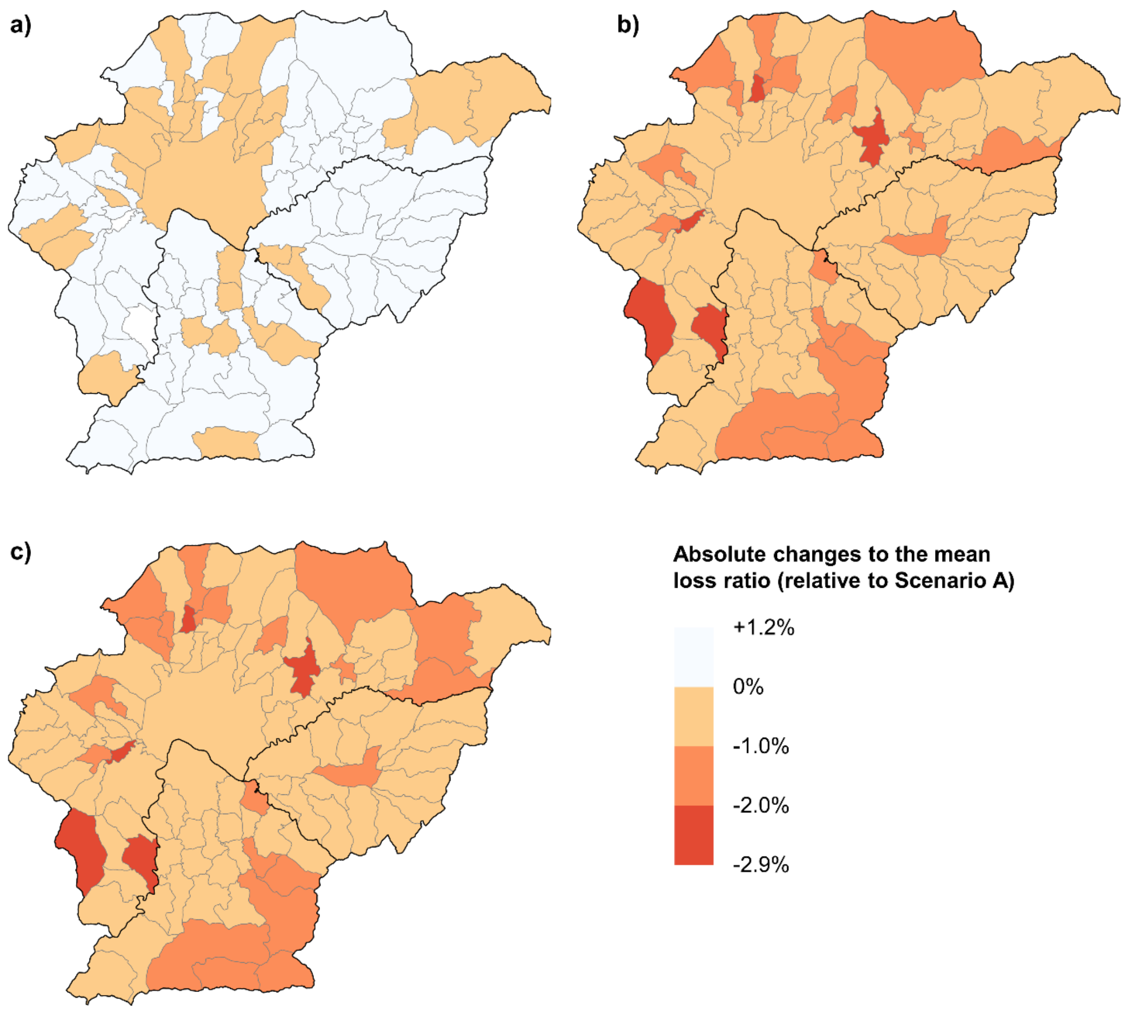

Figure 12. Absolute changes to the municipality-level mean loss ratios for a) Scenario B; b) Scenario C; c) Scenario D, relative to Scenario A, for the 100-year flooding occurrence,

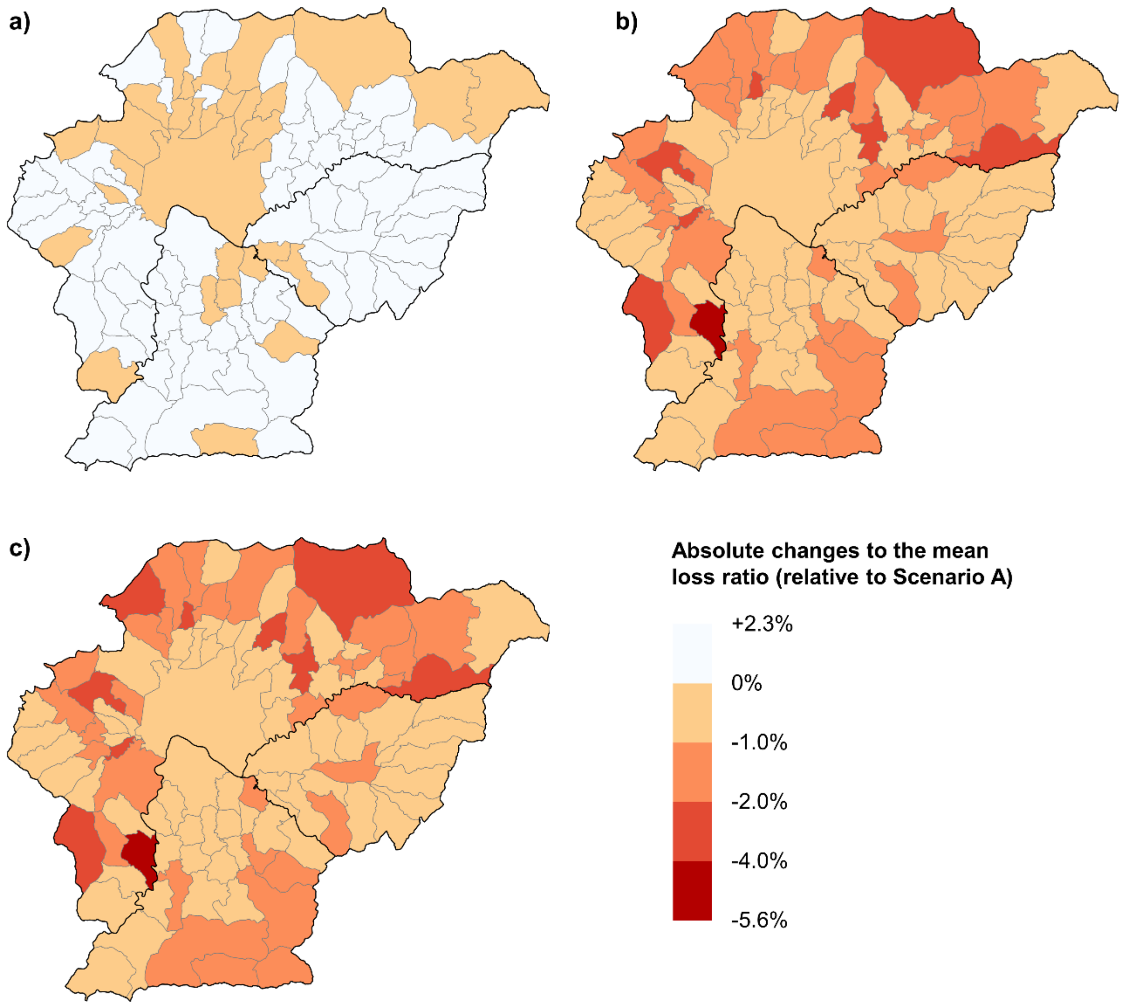

Figure 13. Absolute changes to the municipality-level mean loss ratios for a) Scenario B; b) Scenario C; c) Scenario D, relative to Scenario A, for the 1000-year flooding occurrence.

24. Line 450: Data availability: This is not sufficient, I think. Are there ownership issues and you cannot provide the data sets? Is it possible to put the data into a FAIR repository? At least the core data and an example data set?

Thank you for this comment. Indeed, it is important to point out that the hazard and urban map datasets are available online through public repositories. We have updated the section "Data availability" by providing links to access the datasets used in this study:

"Data availability. The flood hazard maps are available online from the METEOR project (available at https://maps.meteor-project.org/map/flood-npl/, last accessed December 2022). The urban maps for Kathmandu Valley are available online through a public repository (available at https://doi.org/10.5281/zenodo.7406981, last accessed December 2022). Other datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request."