First, we want to thank the reviewer for the insightful comments and recommendations. Following the suggestions, we will revise the manuscript. Detailed responses to the reviewers' comments are added below.

Note: Below is our response (italics) to each comment (regular font) from the reviewer

General comments

The study has merit in its outline, as a better understanding of flood impacts at this scale is definitely needed and I agree that doing this with a generally simple approach for a general kick start to the options of AI in this domain makes sense. However, I have a number of concerns on how the study is built and executed, which I believe are at this stage too big to recommend the manuscript for publication. I detail the concerns below and would encourage the authors to rethink their strategy before moving to an eventual submission. I fully understand that this is a submission from an ECR and I want to complement you on the aim and pulling this together – definitely work that should be pursued and there is a lot of demand for outcomes of such approaches! I would have hoped to see more scrutiny here before a submission from the more experienced co-author team.

1. My concerns range from (a) general sloppiness of manuscript writing (many simple editing mistakes that can always happen for drafts but should not occur for a submitted manuscript over

Response: *We will revise the manuscript thoroughly to correct these unnoticed mistakes.*

2. (b) the lack of appreciation of existing data and simply depicting the target region as 'data scarce' to avoid scrutiny from what is known already to

Response: *We thank the reviewer for this comment. Please note that our intent was not to avoid scrutiny of the data, but we understand that some of the statements were phrased in an ambiguous way, which we will rework to address accordingly.*

3. (c) a lack of proper documentation of data sources on the exposure side as well at times confusing jumping between topical (what types of floods) as well as spatial (national, watershed, HMA wise) domains.

Response: *We will provide a detailed description of the datasets considered in this study, and we will frame the work in a more structural manner. We discuss different flood disasters happening in the HMA region. Specifically, our study focuses on pluvial and fluvial flooding, which we will make clearer in the introduction and throughout the manuscript.*

4. I briefly summarize these concerns below and then present a list of line indexed responses for the complete manuscript.

    a) Sloppy mistakes
    In numerous instances references are reported as 'n.d.' where they actually have a date and some are completely missing from the reference list. There are many instances with missing spaces as well and figure captions are often incomplete. Please be careful on such matters before submitting

Response: *We will make sure to do a thorough check of the manuscript and correct these mistakes.*

5.

    b) General statement on 'no data'
    You make general unsupported statements on the region being data scarce on hydromet data. That is decidedly not the case. While data may often not be readily accessible, it is available and many studies have been published on this, especially for China and India and data is

generally reachable from China, India, Pakistan, Afghanistan as well as Central Asian states. The data that is available you do away with as 'not trustworthy' in a single sentence. This coming from an all-US based author team is problematic and I guess you could imagine how stunned a reviewer from the US (or Europe) would be if a Chinese author would make that claim before proceeding to apply ML on all of the US or Europe. You will need to make a clearer description (with references) on what is lacking and how your approach fills that gap.

Response: *We will revise this part of the manuscript and rephrase our statements to avoid confusion about data scarcity. It was not our intention to underrepresent available datasets. We will clarify that gathering data for the scale of the HMA region is a difficult task, as it requires collecting data from several countries and multiple sources, and this poses challenges due to the possible inhomogeneities of standards between different organizations. Especially in the context of the impact of floods using socioeconomic data, the analysis involves examining the number of fatalities, injured and people otherwise affected, as well as the financial damage that natural disasters cause, and this information is generally not always available, or it is collected at the local scale based on reported events. Major disasters are reported in global databases such as EMDAT, or, for Nepal, the DRR portal as we used in our paper, but these datasets are also not complete. For example, EMDAT only considers events with at least one of the following criteria:*

- *10 fatalities*
- *100 affected people*
- *a declaration of state of emergency*
- *a call for international assistance*

The main idea behind this paper was to provide a tool for a rapid estimate of potentially highly impacted areas, based on information accessible and updateable quickly, such as population number, rainfall intensities, and a geomorphologic index that can be derived from global DEMs (or high-resolution local ones when available).
We will rework our manuscript to be clearer with our statements.

6.

c) Poor documentation of socio-economic data
As I detail below there is very poor documentation on where the exposure data is taken from and there is no way to make this traceable (no stable links, and also no attempt so far to make your own produced data available, see comment on Availability statement).

Response: *We thank the reviewer for this comment. We will include a table with information on all the datasets used. Regarding the links being "not stable" – the data required for the index were accessed and we tested the links before submission. In the revised paper, we will clarify the date of the latest access so that the data is more clearly referenced.*

7. I also fail to see how you take census data to the watershed and how you align using Nepal government data with your approach to model at the watershed scale (which do not follow national borders).

Response: *We will clarify this in the manuscript. For Nepal, we considered **a weighted spatial join between the watersheds and the districts.** To each watershed, we attributed the statistics of the district intersecting it, weighted by the overlapping areas. In general, the districts we have for Nepal are of a smaller extent than those of the various watersheds.*

8.

d) General scope and methodology
At multiple points of the manuscript I was a bit confused on the scope. There is an introduction on all types of high flow events but the methods suggest you only look at fluvial floods with exceptionally high impacts. There is a relatively rapid investigation of the methods for

watersheds that do lie to some part in Nepal compared against data only from areas within Nepal and then an upscaling to all of HMA, which in turn is not clearly defined in its scope or climatologies. I would strongly suggest to maybe limit the study to areas where data is available before scaling it up, allowing you more space for methodological and data based issues.

Response: *We thank the reviewer for this suggestion. In general, this paper focuses on fluvial and pluvial flooding, and we will make this clearer in the introduction. Starting from this, for this work, we considered Nepal as our train site for two main reasons.*

1. *We had information at fine resolution regarding the flood events, in terms of the number of people, economic impact of the event, date of the event, and population data.*
2. *For Nepal, at the time of this paper we had access to the high-resolution 8m DEM from the previous NASA HIMAT effort. This DEM also covers other areas of the wider Himat region, but it presents some gaps. Nepal was completely covered, and we verified the homogeneity and quality of the data.*

It is true that the climatology in HMA is variable. In Nepal, as well, we have regional climate variations largely being a function of elevation. For this work, for the main rainfall driver of the model, we focused on climate concentration. This index was proven to be highly linked to pluvial/fluvial flooding impacts in other regions of the world, including for example Italy (both in mountainous landscapes and floodplains (Sofia et al. 2019), the US (Saki et al. 2023), or China (Du et al., 2023). *Climate concentration values are mostly related to the temporal variability of the rainfall, not to the total amount or to the average yearly and seasonal statistics, and its variability captures well various climates (Monjo et al. 2016). For Nepal, as we showed in the paper, we have a gradient of CI values, and as ML models learn from the data they ingest, we believe the system can work across various regions from the climatic point of view. We will add comments on this in the paper, highlighting the strengths and weaknesses of the approach.*

Specific comments:

1. There are multiple citations as ‘n.d.’ while actually they are published and have a year – please check your references carefully.

Response: *We will correct these carefully.*

2. L31: Be careful in your framing – population growth does not increasing likelihood of flooding, it increases flood risk!

Response: *We will rephrase this in the revised manuscript. The sentence was meant to refer to flood impacts.*

3. Also, in the abstract and your general analysis, you focus on precipitation as a flood driver but here then passingly mention glacial melt as well – those are very different flood drivers and would be crucial to be clear what kind of flooding you wish to tackle here.

Response: *We will be clearer on the fact that this work focuses on pluvial/fluvial flooding. We added background information on flood hazards in general in the region, as we believe some overview on this is needed to frame the work correctly in the context of the various possible flood hazards in the region.*

4. L54: ‘*HMA does not have enough hydrological stations for region-wide flood monitoring*’ is a huge statement to make without a citation – what is an appropriate number? Also most countries in HMA, especially China, India, Pakistan and Nepal have large and dense network of hydro(-met) monitoring, which they also use for forecasting. That is not as open as in the US, but the statement that there is ‘not enough’ needs to be qualified. You then claim ‘*Moreover, the available meteorological datasets may not be sufficiently trustworthy.*’, which again lacks any qualification. Imagine me making that statement for a European or North American country,

that would be thrown out. The region has a large amount of met data (see e.g. the overview figure in (Nepal et al. 2023)) and if you do not trust the data you need to justify why.

Response: *As mentioned before, we will revise this part of the manuscript and rephrase our statements. It was not our intention to underrepresent available datasets. Gathering data for the scale of HMA region would require collecting data from several countries. This is time-consuming and to some extent, it can be nearly impossible due to political constraints and limits on accessing the data for some regions. As a matter of fact, our goal for this study was to overcome the data and time constraints and provide a quick tool for disaster management. We will try to be clearer with our statements.*
Also, please refer to the response to comment no. 8 regarding the datasets available to us throughout the scope of the project.

5. L61: '*The use of remote sensing technology for disaster studies in HMA is comparatively new*' – I also do not quite agree. Remote sensing itself isn't very old and it has been used in HMA for many studies already (which maybe anyway would need some acknowledgement here).

Response: *We will rephrase this, adding references to wider literature.*

6. L87: You focus here a lot on monsoon changes with intense precipitation – but if you actually focus on HMA (rather than just the Hindukush Himalaya) there are a lot of other processes – Westerlies in Central Asia, Eastern Monsoons in the Upper Yangtze etc. Maybe it is required to reconsider the total spatial scope of the study here?

Response: *We wanted to draw the focus on the fluvial flooding caused by the precipitation, not the actual processes. We can add the processes mentioned by the reviewer as additional examples of flood drivers of the flooding in HMA region.*
It is true that the climatology in HMA is variable. In Nepal, as well, we have regional climate variations being a function of elevation. For this work, for the main rainfall driver of the model, we focused on climate concentration. This index was proven to be highly linked to pluvial/fluvial flooding impacts in other regions of the world, including for example, Italy (both in mountainous landscapes and floodplains (Sofia et al. 2019) and the US (Saki et al. 2023). Climate concentration values are mostly related to the intensity of the rainfall, not to the total amount or to the average yearly and seasonal statistics, and its variability captures well various climates (Monjo et al. 2016). For Nepal, as we showed in the paper, we have a gradient of CI values, and as ML models learn from the data they ingest, we believe the system can work across various regions. A recent work by (Khanal et al., 2023) *characterized overall the variability of precipitation over the same region from ERA5 data, also highlighting an overall homogeneity in trends (aside from a few hotspots) and regional statistics of precipitation.*

7. L92: You now finally get to actual numbers of potential affected, but leave it to the reader to get the data from EMDAT.

It would be prudent to explain here (or rather in the introduction) what the actual numbers are and for what types of hazards, to then narrow down and which ones you actually focus.
Response: *The EMDAT link was used as a reference to the statement. We can certainly add the numbers calculated. This was not provided to direct the reader to get the data from EMDAT.*

8. Figure 1: Up to this point there was no clear description how the watersheds are selected, i.e. what boundary you used for HMA. This needs to be provided to give context to why so many watersheds outside HMA are also included.

Response: *We have selected the watershed covering the area that was included in the Himat project.*

The HMA region is generally identified as the extent we considered in this paper.

9. L116: At this point you mention that you will predict impacts of 'floods', i.e. all of them? The way you describe your research you are narrowing this down on pluvial floods, as glacial lake outburst floods or debris flows etc need very different driver analysis. Can you be precise here? In L185 you then suddenly just focus on 'fluvial flooding', so is it just that you focus on?

Response: *Thank you for this comment. We will make sure to be consistent with the terminology. And we have used only fluvial flooding in the analysis.*

10. L120: This part is crucial as you present the socioeconomic data and how you treat it. However there are a few issues that would need to be addressed with respect to traceability and presentation of data used.

- You refer to data sources that are questionable, the knoema.com page is not stable and it is unclear from where their data is sourced or where it is known needs to be documented here.
- You refer to general government and Worldbank websites (like http://drrportal.gov.np/) that exist but what data you took from there at what point in time remains unclear. Copernicus Journals subscribe to FAIR practices, that includes the documentation of third party data used in a publication.
- You introduce a lot of data as well as parameters from literature (like T and e) without any questioning of their accuracy, uncertainty etc. This would propagate and need to be addressed, especially as you seem to upscale from this approach with a few numbers on Nepal government websites to all of HMA.
-

Response: *We will double-check the links. The parameters (like T and e) are used by (Noy et al., 2016) for the LYI, and in their work the LYI is calculated also for the countries included in our analysis. For consistency, we maintained the same standard values. We will clarify this in the paper. We will also add the following table to the manuscript where we clarify the data sources considered for the analysis.*

Variable	Description	References
M	Mortality (number of deaths due to disaster	http://drrportal.gov.np/
Aexp	Average life expectancy at birth (by year)	WHO (https://data.who.int/countries/524)
Amed	Median age (by year)	WHO (https://data.who.int/countries/524)
e	Welfare reduction weight associated with being exposed to a disaster	set to e = 0.054 according to Noy, 2016a, based on Mathers et al., 2013
T	Time taken by the affected person to get back to normal	Noy, (2016a)
N	Number of affected people	http://drrportal.gov.np/
c	Percent of time not used in work-related activities (.75)	Noy, (2016a)
Y	Y = Financial damage (value of destroyed/damaged infrastructure)	
PCGDP	Income per capita (by year)	http://drrportal.gov.np/

11. You calculate these values for Nepal as a whole but then work on the watershed scale – how is this compatible?

Response: *We did not calculate the values for Nepal as a whole. The LYI is calculated by event and summarized for each district as an overall number of LYI for all the events geolocated within that district. To scale it up to the watershed level, we did a weighted spatial join.*

It is true that there are a few parameters that go in the LYI equation that are standard, but this is consistent with the calculation of the index as it was defined by Noy et al. 2016. Most of the other *parameters, such as median age, or life expectancy at birth may vary from country to country. But as we 'train' the model considering a temporal variability of this parameter, for example, we believe that the overall combination of values can account for the potential variability by country. For example, Figure R1 shows the life expectancy over time for Nepal, to show that we do have a variability in time for the index. We will clarify this in the manuscript.*

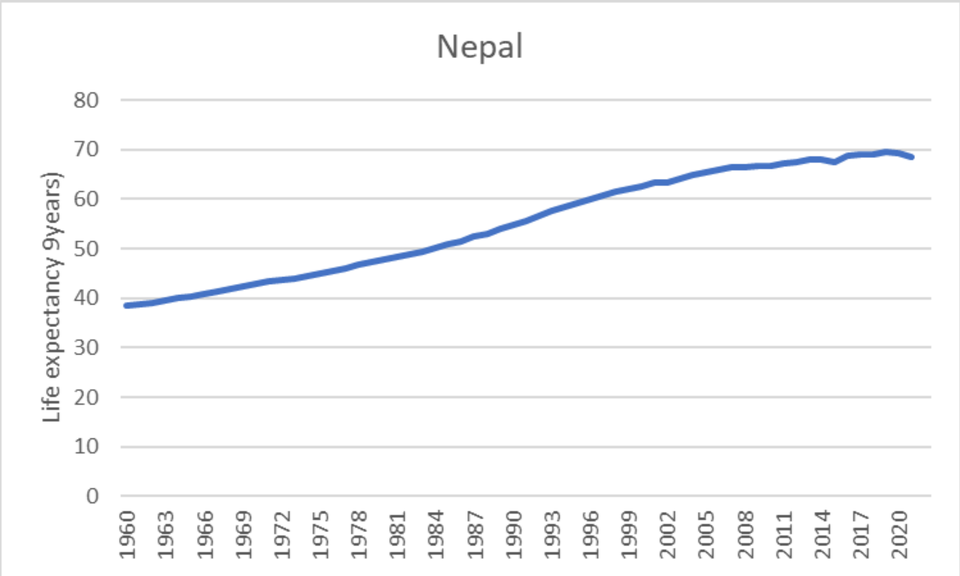

Figure R1: Life expectancy at birth for Nepal over time (Source: https://data.worldbank.org/indicator/SP.DYN.LE00.IN?end=2021&locations=NP&start=1960&view=chart&year=2021)

*For Nepal, we considered **a weighted spatial join between the watersheds and the districts.** To each watershed, we attributed the statistics of the district intersecting it, weighted by the overlapping areas. In general, the districts we have for Nepal are of a smaller extent than those of the various watersheds.*

12. Figure 3: I am not sure whether these are now LYl only due to floods or all disasters. Considering that there are no jumps for earthquake events like 2015, I assume this has been calculated for floods only? Then this needs to be made very clear in the caption rather than just calling it 'disasters'.

Response: *This is for fluvial and pluvial flood only. We will make sure to revise the manuscript to be clear and consistent.*

13. L176 + Figure 4: What is HAND in Figure 4. Is this from (Delalay et al. 2018)? The publication is not open access and only limited to Sindupalchowk, how does it go to all of Nepal? What does it actually map?

Response: *We thank the reviewer for this comment. We will clarify better the figure. The work of Delalay et al 2018 just provided information on some specific inundation depths pertaining to critical floodings with specific return periods. To highlight the importance of the FGP map, we showed an example of inundation produced from a terrain dataset using those critical depths, and the FGP maps for the same area. Please note that the FGP itself was not invented for this paper, but rather it has been published and applied in other contexts (Samela et al., 2017). For this work, we automated the computation so that it was possible to apply it widely by improving the definition of the hydrauliic scaling functions needed for the system integrating the methods also published and referenced in Sofia et al. 2015 and Sofia & Nikolopoulos 2020. Testing the quality of the FGP is not the scope of this work, as its feasibility for flood mapping has been proven already (Manfreda et al., 2011, 2014; Manfreda & Samela, 2019; Samela et al., 2016, 2018). These papers showed how these methodologies are extremely useful in ungauged conditions to preliminary identify flooded areas since they only require a DTM to* *perform the simulations.*

14. L194: While I understand that it would be well beyond the scope of this study to evaluate the suitability of ERA5 data for flood simulations (let alone in a mountain context where precipitation products are of poor quality) but it would be crucial to address this and dispel concerns from the get go by referring to discussions of this data in mountain regions as well as for flood mapping.

Response: *This study is a part of the HiMAT project. There are a number of research groups working on different aspects of HMA. At the time we conducted this study, a subgroup of our team was working with ERA5. We wanted to utilize the available dataset and complement the existing study. We will add few comments on this, with highlights on HMA from other related works from the HiMAT team, such as* (Maggioni & Massari, 2018; Maina et al., 2023)

15. L210: As for the other socioeconomic data above, the description of population data here remains lacking. For Nepal you only refer to the Census Bureau, which does not report distributed data or data by watershed (so how was that brought in line with inundation maps) and you also do not specify where on the general page you retrieved the data from. You then refer to the GHSL but do not provide a citation or link where this data was retrieved. Distributed data in Asia is generally of problematic and definitely not homeogenous quality, hence a discussion of how this was dealt with need a much more thorough description than the short paragraph here without any references.

Response: *We thank the reviewer for this comment. Indeed, obtaining population data at a detailed scale depends on local authorities, and for Nepal, we relied on the official source of the census bureau, which provides this information by the district. To extend it to the whole HMA, we considered the dataset by Center for International Earth Science Information Network - CIESIN - Columbia University. 2018. Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 11. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H49C6VHW. Accessed DAY MONTH YEAR. This dataset provides spatially explicit estimates of population density for the years 2000, 2005, 2010, 2015, and 2020, based on counts consistent with national censuses and population registers, as raster data to facilitate data integration. The dataset is provided in raster form and can be aggregated at any scale a user wants, provided that the user has the boundary of the area they want to investigate. We will clarify this in the revised manuscript.*

16. A detail but you also call it LYI (capital I) here while it should be LYl (lower case L)!

Response: *We have decided to call the life year index (LYI) as an abbreviation for Life years lost. We will check for any inconsistency in the manuscript and correct it.*

17. L227: You discuss your first results here on the F score and model performance discussion – this should come under Results and Discussion respectively, not Methods! Figure 6 as well as Table 1 also lacks a description of variables and results presented. Unclear how this should be interpreted.

Response: *Thank you for this comment. We will relocate this part to the results and discussion section. Also, we will add more explanations to make it clear for the reader.*

18. L248: Apart from the Brakenridge citation not having a date nor being present anywhere in the references, and agreeing that in principle such a dataset would be an interesting set for validation, the fact that the whole dataset only has 46 events from Nepal since 2021 and <10 with the 1000 deaths plus displaced criterium you introduce below makes its use questionable

considering this is the area you run your model in. Wouldn't data from Nepal (like https://bipadportal.gov.np/) be much more appropriate then?

Response: *We have done our study for both Nepal and HMA from 1980-2020. To our best understanding, the dataset from emdat and DFO have the longest and most detailed series of point datasets for different events for the time period we are interested in. We appreciate the separate data source that you shared with us. Please note that we trained our model considering information for NEPAL from http://www.drrportal.gov.np/ which includes flood/heavy rain/flash flood events for all districts in Nepal from different sources. This database includes more than 46 events reported in the DFO. At the scale of HMA, there is no other available dataset reporting flood impacts, aside from DFO and EMDAT, to our knowledge, hence we considered these two, with their limits, to highlight how our model could help target priority areas where indeed events have happened, of a large impact, as highlighted by actual floods reported in these two independent datasets.*

19. Also this database captures lowland floods, rather than mountain floods, making me wonder whether the aim to characterize 'High Mountain Asia' floods is really the right scope here. Also the DFO reports single coordinates, are you then simply assuming the watershed that matches the coordinate is the only one affected? Likely the reported numbers refer to much larger areas, as the size of the watershed you chose is rather small (guessing from the Figure, it's not actually described anywhere!)

Response: *The dataset is not only capturing lowland floods but also mountainous river floods that are characterized as fluvial floods. Also, the damage dataset can only be "point" data at a particular location. There may be one, many, or no point for the whole watershed. As we have described previously, we have used GIS techniques to distribute the damages for the watersheds. This is a common technique that is used widely.*
We will add information on the size of the watershed. (e.g., range of the watersheds' area)

20. L261: You include a crucial boundary condition of your model here, i.e. '1000 deaths plus displaced'. Does this mean your model will only be useful in this domain? It would be crucial to report how many such events have actually happened in your domain then. Also how is the adding up of 'dead and displaced' justified? These are quite 'different' responses to a flood.

Response: *In the LYI calculation, the formula refers to the number of affected people, without making differences between deaths or displaced. Hence we considered the number of people from the DFO as a proxy. If there were fine scale datasets with this complete information, we would have validated the model outside Nepal for those datasets, but unfortunately, this information is not available at a fine scale, but only for the events reported in the DFO/EMdat. Please note that the paper by Noy et al, where the life year is calculated globally country-wise, considers the EMDAT source for the analysis, so numerically it reports the life year lost based on the available numbers. Regarding the ML model we propose, the model itself is bounded by the data it ingested. The training set contains a variability of LY lost, that is in the order of magnitude of 10^0 up to 10^3 life year lost, consistent with the examples provided in Noy et al. 2016 globally.*

21. Figure 9: Panel a is elevation not rainfall as your legend suggests!

Response: *There was a mistake in the legend. The rainfall in the yellow contour lines overlayed on the elevation. The yellow line is not showing up in the legend. We will correct this.*

22. L265: To be honest I am not entirely sure how I should interpret Figure 7 – doesn't it just confirm that people live close to wide river channels? Then there is really no link to atmospheric

characteristics as you claim in L270. There is a lot of discussion already as well on convection patterns all stemming from other literature and not really relevant to what I read in the Figure.

Response: *In Figure 7, the main target was to analyze the variability of average CI and population over the time frame (1980-2020) of the study compared to the calculated static FGP. FGP is calculated using DEM dataset solely based on elevation. Higher FGP does not mean wider channels, rather it gives you the areas with higher potential to flood. In Figure 7, we tried to draw a correlation between the CI and FGP in areas with a higher potential to flood. We did the same with the population.*

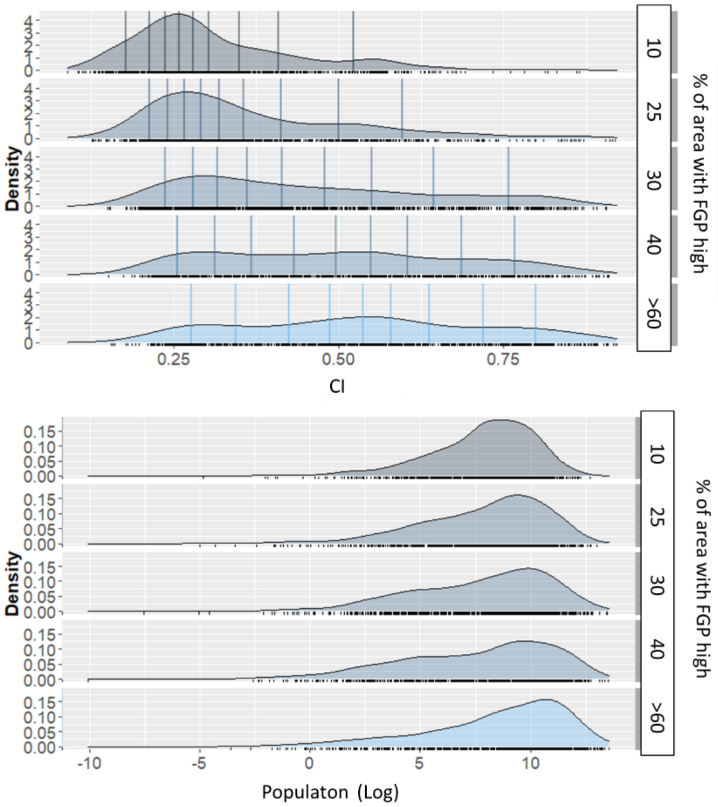

Figure 7: Average variability of the CI (top) and population (bottom) compared to FGP from 1980-2020

23. L295: A main concern I have here is that I am still not very clear on where the observed events come from you compare this to. I am also wondering if your Figure 8 simply only confirms one thing – that there are many people (an input to your model) where there are many people (a validation of your model). How does your model compare on actually coming up with an observed flood from the input 'ERA5 rain'? This concern then propagates into the result for the whole region, where you 'predict' the biggest impacts with the highest population densities. That isn't quite so surprising and it is unclear to me how I can see the power of ML in these results. To be provocative, would the results have been different if you would have just distributed rainfall across the watersheds without a model in between?

Response: *The observed/ actual values of LYI of the remaining 10% dataset for Nepal. We will be clearer in the manuscript about this.*
Figure 8 showcases the comparison of LYI, not people or flood. WE compare the LYl provided by our model, to the LYi calculated numerically from the data included in the drrportal for NEPAl.

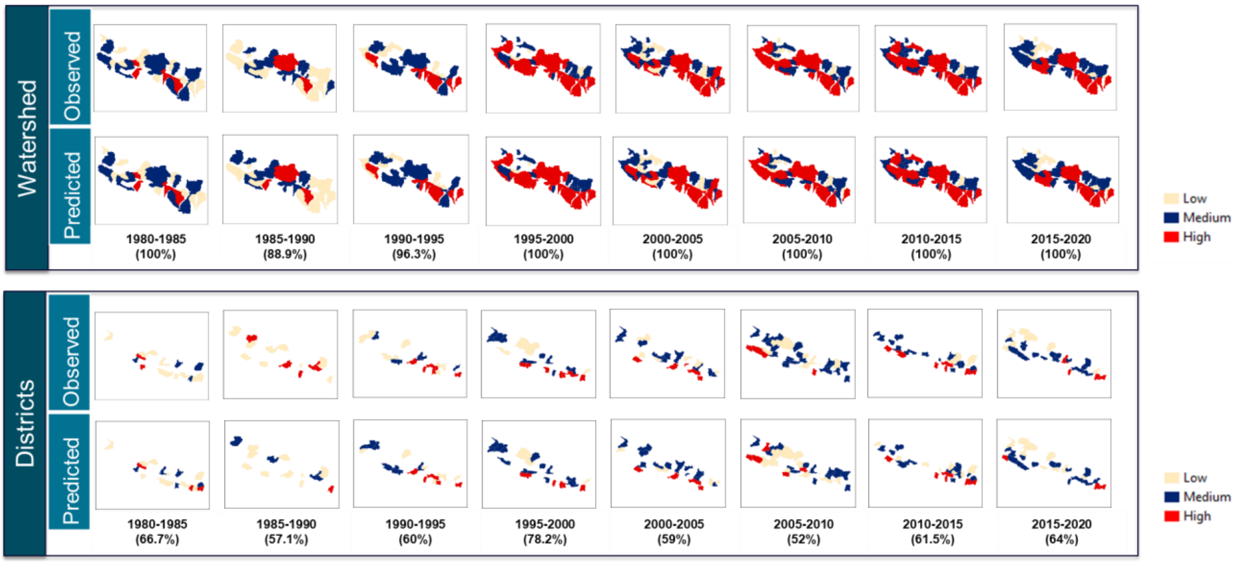

Figure 8: Comparison of prediction with actual socioeconomic impact for watershed on Nepal. Basin/districts are marked as "high" for LYI over 1000 years. Medium is between 100 and 1000, and low is less than 10. Numbers in parentheses represent accuracy.

24. L349: The figures you note here do not show what is described in the text.

Response: *We will correct this mistake.*

25. L356: I lack some context here - <10% of watersheds see an increase, are all other stable or see a decrease?

Response: *We will revise and clarify this part in the manuscript.*

26. How can you differentiate here between hazard (rain) and exposure (population) as a driver of change?

Response: *We do not attempt to differentiate between hazard and exposure. Rather we use them together to find out the impact. We simply tried to analyze the results and connect the dots by revisiting past occurrences (such as population boom, extreme events, or both).*

27. How do you explain that increase has slowed after 2010 significantly? And how is it possible that in the 1995-2010 jump the number of increasing watersheds is similar to the just 5 year jump between 1990 – 1995? Isn't that completely counterintuitive?

Response: *It may be counterintuitive, however, there may have been many events that have caused more damage in that 5-year window than the longer span.*

28. L406: While in general 'an intention to make data available' shouldn't be followed, for a journal like NHESS this is definitely not acceptable. Data availability needs to be clearly described (or arhued why this is not the case).

Response: *At the time of submission, we were working towards publishing the datasets on NSIDC. It must be published eventually as a requirement of the HiMAT project. This dataset will be publicly available. Before the data is published it goes through a quality check, hence why the link is not available yet. The input data themselves are available through the various portals we considered. In the revised paper we will better clarify the data source for each independent dataset considered, to avoid confusion on its accessibility.*

29. *Technical corrections (Minor issues):*

Response: *We will carefully go through all the minor comments and correct the mistakes.*

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