** Please find our point-by-point response highlighted in blue to the reviewer's comments.

Response to RC1- Adam Emmer

This study aims at modelling potential future GLOFs from 21 Nepalese glacial lakes identified as potentially dangerous in previous study by Bajracharya et al. (2020). This study uses regression model to estimate plausible ranges of mean lake depths and so lake volumes and peak discharges. Further, exposed elements within the limits of modelled inundation areas are mapped and potential damage is assessed. Undoubtedly, such results are of value for disaster risk management authorities and I appreciate holistic approach going beyond GLOF modelling itself. While I'm very much in favor of GLOF hazard / risk assessment studies that consider a range of scenarios and I really appreciate the amount of work done, I have some thoughts for further improvements in the hazard assessment part.

Response: Thank you very much for the reviewer's overall positive feedback.

Similar approach has been developed and employed by Veh et al. (2020) across the whole Himalaya. While thousands of lakes were considered in their study and the approach was suitable, I would expect bit more site-specific input data in case study of 21 lakes. For instance, moraine dam geometry (height and width) could be used to estimate max. breach depth and so max. flood volume that could differ substantially compared to the assumption of 100% lake volume release which is: (i) in general very unlikely for large lakes; and (ii) physically not even possible in many cases (when the height of a damming moraine is less than max. depth of the lake or the geometry of the dam is very flat).

Response: I believe the reviewer is referring to Veh & Walz (2020), Proceedings of the National Academy of Sciences, 117(2), 907-912. We have indeed adopted the same approach developed and employed by Veh & Walz (2020). However, in addition to hazard evaluation that Veh & Walz (2020) focused on, our focus extends to exposure and impact assessments of GLOFs. To achieve this, our study relies on several key components. These include remote sensing techniques for accurate glacial lake area delineation, Bayesian regression models for deriving relationships between lake water depth and peak discharge (Veh & Walz, 2020), state-of-the-art flood modelling technology supported by parallelised high-performance computing, and object-based GLOF exposure and impact evaluation using open-source data. Not covered in Veh & Walz (2020), our study conducts high-resolution inundation simulations for various GLOF scenarios using flood modelling technology. This facilitates subsequent object-based assessments of GLOF exposures and impacts. The results provide a comprehensive and detailed evaluation of potential exposures and impacts stemming from these PDGLs. While much of the prior work has focused on the initial step of GLOF risk evaluation, specifically hazard assessment for glacial lakes, like Veh & Walz (2020), our study advances the field by addressing the second stage, which involves exposure and impact evaluation. The insights gained from this study can empower authorities not only with knowledge of where threats exist but also with an understanding of the expected magnitude and location of impacts.

I agree that incorporating additional data, such as moraine dam geometry (height and width), would enhance the estimation of maximum breach depth and flow volume. However, it is challenging to obtain these data for all 21 lakes. Therefore, to encompass all potential glacial lake outburst scenarios, we have also considered less severe conditions. Specifically, scenarios where 25%, 50%, and 75% of the lake water volume is released have been examined. The outcomes of these less severe scenarios have been compared to the worst-case conditions, where 100% of the lake water is released, as discussed in Section 4.3.1.

Further, the procedure of random selection of 1000 scenarios and subsequent calculation of inundation frequencies and median of max. inundation depths for each lake is not appropriate because these scenarios are not equally probable. Reflecting on frequency-magnitude relationships of common GLOF triggers (various mass movements), low to moderate magnitude GLOFs are more frequent and more likely while extreme GLOFs are rare and less likely. Instead of selecting the scenarios randomly, my suggestion is to select them on purpose to cover the full range, with assigned weights (or ideally probabilities).

Response: Thank you so much for pointing out this question. When taking the median of the maximum values, we default to assuming each scenario is equally probable. However, as highlighted in the reviewer's comments, this assumption is not correct. Therefore, we assigned weights to each scenario based on probabilities. The weight of each scenario is determined by its occurrence probability, i.e., the proportion of times its peak discharge does not exceed that of other scenarios relative to the total number of scenarios. A smaller proportion indicates a lower likelihood of occurrence, while a larger proportion indicates a higher likelihood. The weight of each scenario is calculated by dividing the proportion by the total proportion of all possible scenarios. Subsequently, the final flood inundation probability and maximum water depth are derived by multiplying each scenario's results by their respective weight. Based on these derived flood inundation probability and maximum water depth values, exposure and impact evaluations have been conducted for these 21 lakes. Section 4.3, which covers flood inundation simulation, exposure, and damage assessment, has been reanalysed and rewritten.

Since the modelling part lacks any validation, this is where frequency-magnitude relationship can come into play. I wonder whether employing your approach over past GLOFs can yield “typical extremity” of GLOFs (if you standardize the extremity of your scenarios for each lake on the dimensionless scale from 0-1)? While it is mentioned in Discussion section that the incompleteness of data about past GLOFs prevents the authors from attempting validation, I wonder whether any single GLOF characteristic (e.g., breach depth, flood volume, peak discharge, inundation area, etc.) could be used to validate the flood modeling results and estimate “typical extremity” of GLOFs in Nepal? Such an analysis could guide the weighting of your scenarios.

Response: On one aspect, we did not consider the GLOF outburst frequency because the underlying database for frequency–magnitude relations typically is very poor. Here, we considered different scenarios, i.e., the release of lake water at different predetermined proportions. Under the predetermined proportion, we examined a plausible range of values for lake volumes and peak discharges for each glacial lake, ensuring comprehensive coverage of all potential glacial lake outburst scenarios.

For validation, we appreciate the reviewer's understanding regarding the lack of historical event records, which is a common issue with GLOF inundation simulations. Additionally, it is noteworthy that our proposed framework utilises the fully physically based hydrodynamic model HiPIMS, intricately designed to capture the highly transient and complex hydrodynamic processes induced by events such as dam breaks and flash floods. HiPIMS has been successfully validated for these extreme flow conditions (e.g., Smith and Liang, 2013; Liang et al., 2016). The adoption of this model enhances our confidence in simulating the spatial-temporal processes of GLOF inundation, ultimately contributing to improved hazard evaluation results. Regarding the "typical extremity" of GLOFs, the weight assigned to each scenario is determined by its occurrence probability (see above). We are uncertain whether this addresses the reviewer's comments, and we would greatly appreciate further guidance and clarification on the term "typical extremity".

Smith, L. S., & Liang, Q. (2013). Towards a generalised GPU/CPU shallow-flow modelling tool. *Computers & Fluids*, 88, 334-343.

Liang, Q., Chen, K. C., Jingming, H. O. U., Xiong, Y., Gang, W., & Qiang, J. (2016). Hydrodynamic modelling of flow impact on structures under extreme flow conditions. *Journal of Hydrodynamics*, Ser. B, 28(2), 267-274.

Overall, I'm in favor of recommending this study for further processing and subsequent publication after some modifications are considered. My suggestions to the authors are: (i) to consider dam geometry when estimating max. flood volume; (ii) to consider the validation of this approach with some of the past GLOFs in the country (and obtaining "typical extremity"); (iii) to consider avoiding the use of random selection of scenarios which may be misleading.

Response: Thank you very much for the valuable comments from the reviewer. If there are any additional considerations beyond our responses provided above, we hope the reviewer will let us know.

Response to RC2- Anonymous Referee #2

This paper established the method for quantitative assessment of GLOF risk by combining Random Forest model to extract lake surface area, well-established Bayesian regression models to estimate glacial lake volume and peak discharge of outburst flood, hydrodynamic flood modelling, and damage analysis. Then the framework was applied to assess 21 glacial lakes in the Nepal Himalaya. I enjoy reading the methodology and believe it will contribute greatly to the quantitative assessment of the glacier lakes in the Himalaya with data sparsity. However, several major issues still need to be addressed carefully before further consideration of publication for this manuscript.

Response: Thank you so much for the reviewer's overall positive feedback.

First, an isosceles triangle shape was assumed for the hydrograph of outburst floods (line 376, this information is better to be shown in the methods section by the way). I understand this assumption would simplify the calculation of hydrograph, which acts the key input for 2D hydrodynamic model. But this assumption needs to be justified before it can be used. If the hydrological monitoring data for the hydrograph of GLOF is too scarce, the authors can check the measured hydrographs of outburst floods for glacial lakes or barrier lakes in experimental research and see whether this assumption is close to the observations. The hydrograph shapes affect the interaction between morphology and hydraulics along the river significantly, so the assumption here needs to be made very carefully.

Response: Thank you for your understanding and valuable advice. The assumption of an isosceles triangle shape for the dam breach hydrograph has been validated through experimental observations and simulation results obtained from commonly used mechanisms and empirical models. This information has been relocated to the methodology section. The revised text is presented in the methodology section of the main text and references as follows:

Lines 206- 212: In these simulations, the dam breach hydrograph is assumed to have an isosceles triangle shape, simplifying its derivation from Q_p and V_0. The breach hydrograph then serves as the boundary conditions for the hydrodynamic modelling. Although there is some uncertainty, the assumption of an isosceles triangle shape for the dam breach hydrograph aligns with experimental observations (e.g., Morris et al., 2007; Walder et al., 2015; Yang et al.,

2015) and is supported by simulation results from commonly used mechanisms and empirical models (e.g., Yang et al., 2023).

Morris, M. W., Hassan, M. A. A. M., & Vaskinn, K. A. (2007). Breach formation: Field test and laboratory experiments. *Journal of Hydraulic Research*, 45(sup1), 9-17.

Walder, J. S., Iverson, R. M., Godt, J. W., Logan, M., & Solovitz, S. A. (2015). Controls on the breach geometry and flood hydrograph during overtopping of noncohesive earthen dams. *Water Resources Research*, 51(8), 6701-6724.

Yang, M., Cai, Q., Li, Z., & Yang, J. (2023). Uncertainty analysis on flood routing of embankment dam breach due to overtopping failure. *Scientific Reports*, 13(1), 20151.

Yang, Y., Cao, S. Y., Yang, K. J., & Li, W. P. (2015). Experimental study of breach process of landslide dams by overtopping and its initiation mechanisms. *Journal of Hydrodynamics*, 27(6), 872-883.

Second, I did not find the points in classifying the glacial lakes into three categories (lines 275-277). The classification standards were blurry and the glacier lakes were not analyzed by category (e.g., the volumes, peak discharges, or inundation areas of each class) in the results. I do not think it will make much difference to the clarity of the results if the classification is removed but will help reduce the length of the manuscript, which is already a bit too long.

Response: Great advice. The classification details have been removed from the main text.

Third, the manuscript is verbose in some sections and will benefit a lot if the irrelevant or repeating information is removed. For example, in lines 318 to 322, the lake areas from literature are listed, but these are not the results or findings of this study. So these lines can be shortened into one short sentence indicating the two glacier lakes are expending rapidly. Another example is the first paragraph in the discussion section. The paragraph adds very little information, mainly repeating what has been done in this work. It is fine to summarize the work in this study as the start of discussion but the summary needs to be concise. The second paragraph in the discussions has the same issue, with repeating information from the introduction and methodology section.

Response: We have shortened lines 318 to 322 into a short sentence as below. We have removed the first and second paragraphs of the discussion section to avoid redundant information with the introduction and methodology, and to shorten the length of the paper.

~~Remarkably, Lower Barun Lake has undergone significant area growth since its initial appearance, with an area of 0.04 km2 in 1987 (Sattar et al., 2021), 0.64 km2 in 1989 (Maskey et al., 2020), 1.79 km2 in 2017 (Haritashya et al., 2018), 2 km2 in 2018 (Maskey et al., 2020), and 2.09 km2 in 2019 (Sattar et al., 2021). Imja Tsho Lake, the second largest PDGL, also underwent rapid growth in both area and volume. It did not exist in 1960, but its area in 1963, 1992, 2002, and 2012 measured 0.03, 0.648, 0.868, and 1.257 km2, respectively (Budhathoki et al., 2010; Somos-Valenzuela et al., 2014).'~~ → Lines 321-322: Lower Barun Lake, along with the second largest PDGL, Imja Tsho Lake, has undergone significant area growth.

Apart from being verbose, the discussion section needs to be more focused. In lines 551 to 566, the authors introduced the backgrounds of hydropower projects in Nepal. This may help the readers to understand why the risk of hydropower stations was evaluated in this work, but too many details may become a deviation from discussing how the risk is distributed and varying in

Nepal. Such information is more proper to be put into the supplementary materials rather than the maintext.

Response: Agreeing with the reviewer's comments, we have removed lines 550-555 and only retained the most crucial information relevant to GLOF risk.

Although the discussions include some comparisons with other studies to show the advantage of the methodology, I suggest the authors work on improving the depth of the discussions. For example, the assessment of inundation, exposure and damage has been presented in the results section, but the spatial distribution pattern, key influencing factors and the reasons or mechanism for the most severely affected glacier lakes can be further discussed. The discussion on the performance of the method used in this study is already enough but the interpretations of the outcomes of the method have not been dealt with in depth. But the interpretations will provide crucial insight to risk management of the glacier lakes for the study area.

Response: We really appreciate the valuable comments on improving the depth of analysis. However, since our focus was on 21 potentially dangerous glacial lakes rather than examining all glacier lakes in Nepal, it is difficult to identify the spatial distribution pattern of GLOF risk. When considering the key influencing factors and underlying mechanisms, we directly investigated the identified potentially dangerous glacial lakes, whose hazard factors have been scrutinized in existing studies. This study expands upon prior research by examining the exposure and impact situation of GLOFs, primarily influenced by downstream topography, community, and building locations. Therefore, we opted not to specifically analyse some specific lakes, avoiding the repetition of existing hazard factors or a simple description of their downstream conditions.

Last, so many abbreviations were used in the manuscript but a list of abbreviations is missing. This creates extra difficulty for the readers to follow the manuscript.

Response: Abbreviations have been checked and all are defined at the first instance in the text, and a corresponding list of abbreviations has been included for reference.

Appendix A: List of abbreviations used in this study.

DEM	digital elevation model
EVI	Enhanced Vegetation Index
GIS	Geographic Information System
GLOFs	Glacial Lake Outburst Floods
GPU	Graphics processing unit
HiPIMS	High-Performance Integrated Hydrodynamic Modelling System
MNDWI	Modified Normalized Difference Water Index
NIR	Near Infrared
NDMI	Normalized Difference Moisture Index
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
OSM	OpenStreetMap
PDGL	potentially dangerous glacial lake
SRTM	Shuttle Radar Topography Mission
TOA	Top-Of-Atmosphere

Also, figures need to be refined. Figures 4, 6, 7 and 8 do not show any ticks on the axes while the flow directions should be marked in figure 5.

Response: Ticks have been added to the axes in Figures 4, 6, and 7, shown below. Figure 8 has been removed due to the new analysis of the GLOF simulation and impact results based on the comments from the other reviewer.

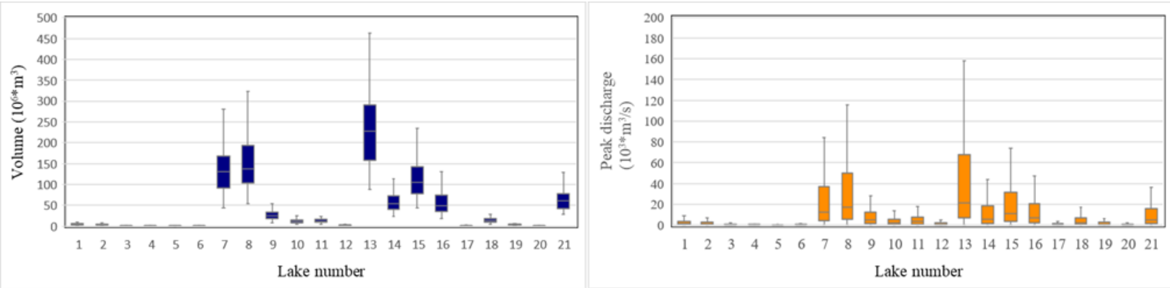


Fig 4 (a) Estimated lake volumes and (b) estimated peak discharges for each glacial lake

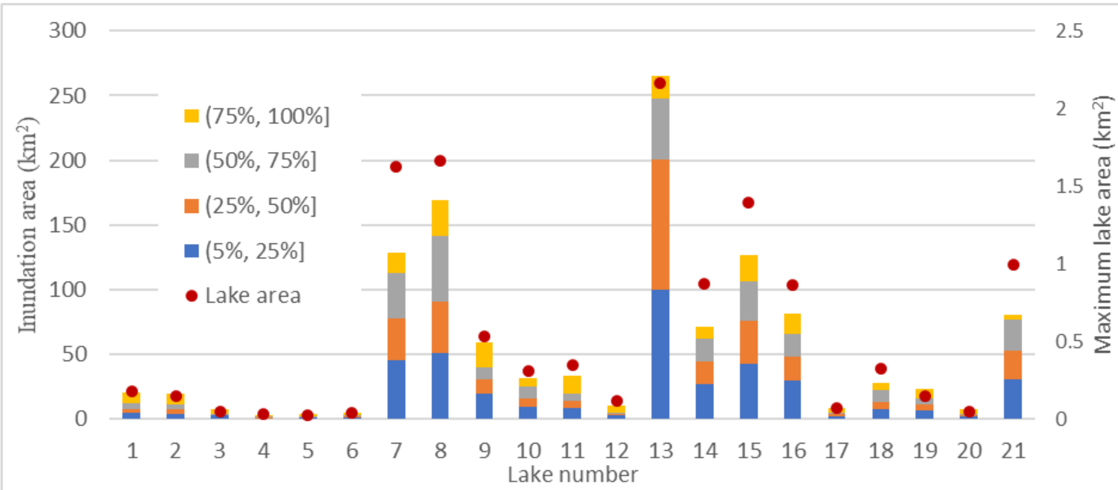


Fig 6 Inundation area (km^2) at different levels of inundation probabilities and maximum lake area (km^2)

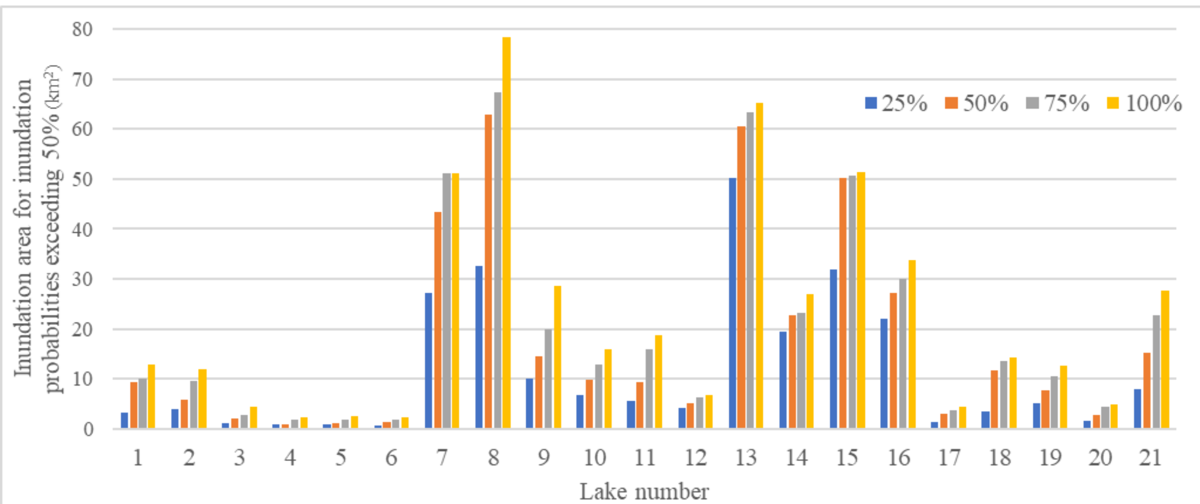


Fig 7 Inundation area (km^2) for inundation probabilities exceeding 50% under 25%, 50%, 75% and 100% of lake water volume released

Flow directions have been marked in Figure 5.

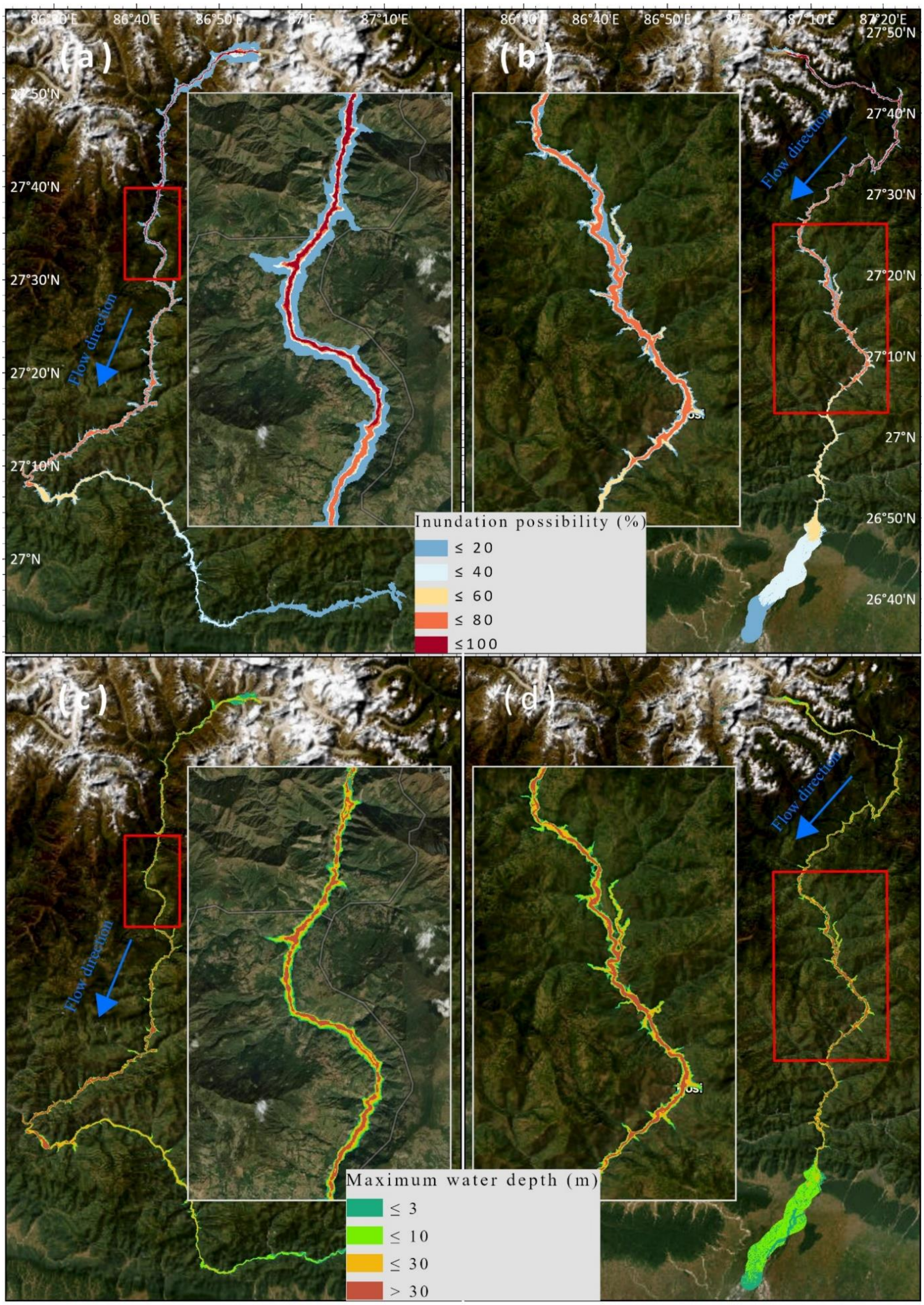


Fig 5 GLOF inundation probability for (a) Imja Tsho Lake and (b) Lower Barun Lake, and maximum water depth for (c) Imja Tsho Lake and (d) Lower Barun Lake under respective worst

situation i.e., all lake water will be released. (The basemaps used were accessed from ArcGIS Online Basemap provided by Esri.)

Specific comments

Line 38: revise "… has observed…" to "is experiencing".

Response: Revised according to the comment.

Line 42: change "an objective and reproducible assessment" to "the requirement for reproducible assessment".

Response: Revised according to the comment.

Line 45: remove "typically focus on individual glacial lakes, which".

Response: Revised according to the comment.

Lines 54-57: the sentence can be more concise. Please rewrite.

Response: Revised according to the comment, as below.

~~However, the complexity of GLOFs, characterized by complex hydraulic dynamics resulting from sudden releases of large water volumes and the rugged, steep terrain downstream, renders simple flood models insufficient for capturing the complex dynamics of GLOFs to support a detailed assessment of the potential impacts on downstream communities and their infrastructure.~~ → Lines 53-55: However, the complexity of GLOFs renders simple flood models inadequate for capturing their dynamics, thereby making them incapable of supporting detailed assessments of potential impacts on downstream communities and infrastructure.

Line 85: reference(s) are needed after "impact of GLOFs".

Response: Revised according to the comment, as below.

Lines 83-85: Previous studies have typically relied on census data at coarse spatial resolutions or aggregated land use data that encompass various objects like properties and infrastructure, to estimate the potential socio-economic impact of GLOFs (e.g., Shrestha & Nakagawa, 2014; Rounce et al., 2016).

Shrestha, B. B., & Nakagawa, H. (2014). Assessment of potential outburst floods from the Tsho Rolpa glacial lake in Nepal. *Natural Hazards*, 71(1), 913-936.

Rounce, D. R., McKinney, D. C., Lala, J. M., Byers, A. C., & Watson, C. S. (2016). A new remote hazard and risk assessment framework for glacial lakes in the Nepal Himalaya. *Hydrology and Earth System Sciences*, 20(9), 3455-3475.

Line 216: reference(s) are needed after "CPU-based counterpart".

Response: Revised according to the comment, as below.

Lines 229-230: It's worth noting that the GPU-accelerated model has demonstrated computational efficiency up to ten times greater than its CPU-based counterpart (Smith & Liang, 2013).

Smith, L. S., & Liang, Q. (2013). Towards a generalised GPU/CPU shallow-flow modelling tool. *Computers & Fluids*, 88, 334-343.

Line 231: the year seems to be 2022 from the reference list.

Response: The error has been rectified in the Line 245.

Line 239: are the values of Manning coefficients appropriate for Nepal? Please justify this setting.

Response: Lines 253-255: The Manning coefficients 0.016 to 0.15 were specified based on values provided in earlier hydraulic textbooks or reports (such as Chow, 1959; Barnes, 1967; Arcement and Schneider, 1984), aligning with previous studies, for example, 0.035 to 0.17 in Nepal (Sattar et al., 2021) and 0.035 to 0.120 in Bhutan (Rinzin et al., 2023).

Sattar, A., Haritashya, U. K., Kargel, J. S., Leonard, G. J., Shugar, D. H., & Chase, D. V. (2021). Modeling lake outburst and downstream hazard assessment of the Lower Barun Glacial Lake, Nepal Himalaya. *Journal of Hydrology*, 598, 126208.

Rinzin, S., Zhang, G., Sattar, A., Wangchuk, S., Allen, S. K., Dunning, S., & Peng, M. (2023). GLOF hazard, exposure, vulnerability, and risk assessment of potentially dangerous glacial lakes in the Bhutan Himalaya. *Journal of Hydrology*, 619, 129311.

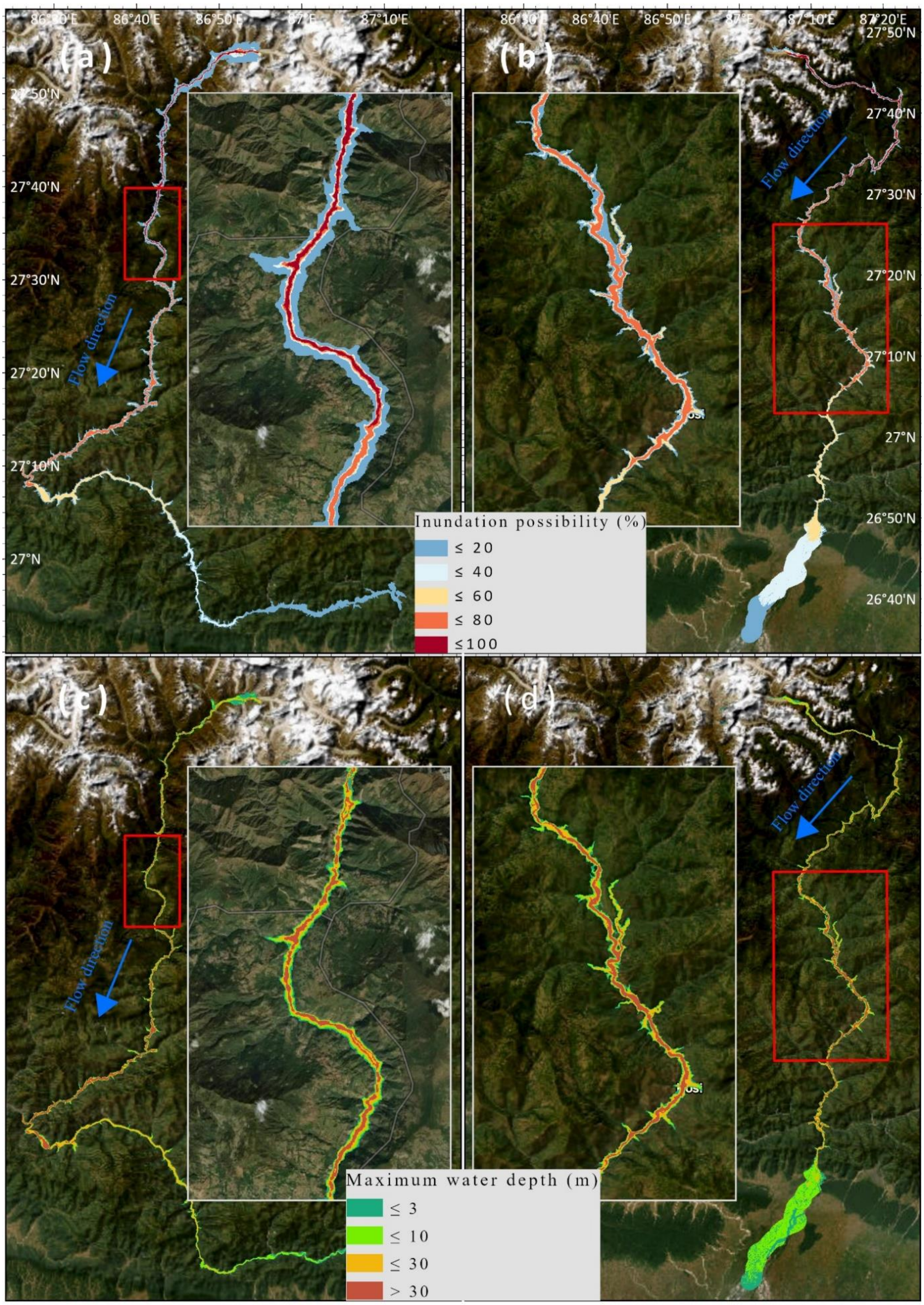
Lines 345-357: most of the paragraph should be moved to the methods part. Please consider.

Response: The paragraph has been moved to Section 2.2.1 within the methodology, as below.

Lines 195-357: To account for the most severe GLOFs, we assume that the entire total lake volume V_{tot} would be released to create GLOFs. For each lake, we predicted the peak discharge Q_p based on a given value of V_{tot} and η using the Bayesian piecewise linear regression model. We generated 100 estimates of the posterior predicted Q_p for each given value of V_{tot} and η. The values of η for individual lakes encompass the assumed flood volumes, and we also considered 100 physically plausible values of the breach rate k based on a log-normal fit to reported breach rates. By multiplying the 94 samples of V_{tot} with the 100 samples of k and 100 samples of Q_p, we ultimately obtained a total of 940,000 scenarios of Q_p per lake. Considering the substantial computational resources required for GLOF inundation simulations in section 2.2.2, 1,000 scenarios are randomly selected from the total of 940,000 Q_p scenarios per lake.

Figure 5: The locations of inset plots in the big map need to be marked.

Response: The locations of inset plots have been marked as below.



Lines 402-405: The sentence should be moved to discussions.

Response: Yes, this has been moved to discussions.

Lines 460-464: While there is a positive correlation between inundation extent and lake area (Fig 6), it's important to note that inundation propagation and extent also depend on dam breach processes as well as the underlying topography and land surface conditions of downstream areas (Worni et al., 2012; Ancey et al., 2019). Particularly, steep and narrow valley gorges can influence flood waves, causing them to rapidly spread over long distances, often accompanied by significant physical processes such as erosion and the transport of ice, sediment, and debris.

Figure 8: It may be clearer if the results for the scenario when 100% lake water is released are presented together with the less severe scenarios.

Response: We have addressed this comment by incorporating the less severe scenarios alongside the 100% lake water scenarios as shown below.

Lines 390-398: To account for all possible glacial lake outburst scenarios, less severe conditions are also considered, where 25%, 50% and 75% of the lake water volume is released. In each of these less severe scenarios, 100 cases are randomly selected from a total of 940,000 samples. The outcomes of these scenarios will be compared to the worst-case conditions. Fig 7 illustrates the inundation area for inundation probabilities exceeding 50% resulting from GLOFs. In the case of Lower Barun Lake, the release of 25% and 50% of the lake water leads to the inundation of 50.2 km^2 and 60.6 km^2 of downstream areas, respectively. When 100% of the lake water is released, the inundation areas are 1.29 and 1.08 times larger than those under the 25% and 50% lake water release scenarios, respectively. Following Lower Barun Lake, Tsho Rolpa Lake and Lumding Lake have the potential to cause significant inundation areas. Even with just 25% of the lake water being released, Tsho Rolpa Lake and Imja Tsho Lake can potentially submerge approximately 30 km^2 of areas for inundation probabilities exceeding 50%.

Response to CC1 - Taigang Zhang

Interesting paper. You might want to have a look at these papers recently published about GLOF risk assessment and lake bathymetry modeling. I hope it can be useful. https://doi.org/10.1038/s41467-023-44123-z; https://doi.org/10.5194/tc-17-5137-2023; https://doi.org/10.1016/j.scitotenv.2021.150442

Response: Thank you very much for sharing these excellent papers. They are very useful, especially the recent publications from 2023, which offer methods for estimating drainage volume and a framework for comprehensive GLOF risk evaluation. We have integrated these two recent publications into our introduction to enhance the discussion of current progress in the field of large-scale GLOF risk assessment.

Lines 58-59: Recently, researchers have explored the use of a hydrodynamic model to assess GLOF downstream impacts in the Third Pole (Zhang et al., 2023b).

Lines 70-72: Combining satellite imagery with existing lake bathymetry measurements offers the possibility of estimating water volumes and peak discharges from outbursts by establishing empirical relationships (e.g., Zhang et al., 2023a).

Zhang, T., Wang, W., & An, B. (2023a). A conceptual model for glacial lake bathymetric distribution. *The Cryosphere Discussions*, 2023, 1-35.

Zhang, T., Wang, W., An, B., & Wei, L. (2023b). Enhanced glacial lake activity threatens numerous communities and infrastructure in the Third Pole. *Nature Communications*, 14(1), 8250.