Editor Comments

Public justification (visible to the public if the article is accepted and published):

Dear Nazir Ahmed Bazai and Co-authors,

The reviewer who reassessed the manuscript has now submitted his feedback. The reviewer notes that most of the comments have been addressed; however, there are still some issues that need to be revised. For example, the focus of the paper is still not clearly outlined, a point raised by all three reviewers in the first review. Furthermore, the title suggests a focus on GLOF hazards, but this is not fully reflected in the article. I kindly ask you to consider the comments and suggestions (see attachment). A final review of the revisions will then be done by me. If all issues are addressed, the article will be recommended for publication.

Yours sincerely,

Tobias

Thank you for your comments. Our replies follow the specific comments of the reviewer below.

Referee Comments Addressed Point by Point

Dear authors,

In your contributions, you have endeavored to incorporate the minor and major revisions of the three reviewers into your article, and you were largely successful in doing so. The article now reads better than before, the reading flow of the individual chapters is much more structured and many ambiguities have been resolved.

However, one main problem remains: The focus of the paper and the objective are still not entirely clear. The title is too vaguely formulated and can be interpreted as pointing in the wrong direction. A real "GLOF hazard anticipation" for the Karakoram is not the focus of the paper, it is much more specific.

I have summarized the comments of the three reviewers (see pdf) and discuss how I think the authors have implemented the suggestions. If the remaining minor revisions are incorporated and the title and aim of the paper are coherent, I recommend publication, as the topics covered are quite interesting and of value, especially if the parameters for water pressure and critical depth are incorporated into a GLOF warning system in the future.

The pdf is attached.

Text below is that found in the reviewer's pdf

Review of the revision of the manuscript:
Anticipation the Hazard of Glacial Lake Outburst Floods in Karakoram by N.A. Bazai et al.
The authors of the manuscript "Anticipation the Hazard of Glacial Lake Outburst Floods in Karakoram" took great care to respond to the reviewers' comments. The article now reads better than before, the reading flow of the individual chapters is much more structured and many ambiguities have been re-solved. However, one main problem remains: The focus of the paper and the objective are still not entirely clear. The title is too vaguely formulated and can be interpreted as pointing in the

wrong di-rection. A “GLOF hazard anticipation” for the Karakoram is not the topic of the paper, it is much more focused on the relationship between surge speed / critical lake depth and GLOF events.

I have summarized the comments of the three reviewers and discuss how I think the authors have implemented the suggestions. If the remaining minor revisions are incorporated and the title and aim of the paper are coherent, I recommend publication, as the topics covered are quite interesting and of value, especially if the parameters for water pressure and critical depth are incorporated into a GLOF warning system.

Thank you for recommending publication subject to minor changes. The referee notes that “The focus of the paper and the objective are still not entirely clear.”. At the end of the Introduction (Section1) we provided our objectives as follows “Herein, the primary objective of this study is to enhance predictive capabilities regarding GLOF event timing by refining empirical lake volume estimation and identifying critical depths for future hazard and risk reduction.”. However, we have now edited this statement to ensure there is no confusion and that the role of glacier surging in controlling lake volume is also acknowledged as an objective, as follows: “Herein, the primary objective of this study is to enhance predictive capabilities regarding GLOF event timing by refining empirical lake volume estimation and identifying critical depths for future hazard and risk reduction. We seek to achieve the objective within a framework of adjustment of lake volume to glacier surge speed, which has implications for changes in the depth of lakes relative to the heights of the ice barriers that impound the lakes.”

General comments:
1) The title and the aim of the manuscript

The authors have replaced "predicting the risk" with "anticipating the hazard", but a true hazard analysis would need to consider more parameters than just lake volume and surge velocity (e.g., the stability of the ice or moraine dam, the likelihood of triggering events, or the potential paths of the flood). Therefore, the title is too broad and does not reflect the content of the manuscript. Also, mentioning the Karakoram region in the title suggests that the results are somehow specific to this region (apart from the location of the lakes, which is not relevant in the manuscript) – which, as the authors admit in their response, is not the case. I would therefore suggest that the title be changed to better reflect the scope and aim of the manuscript. A title along the lines of "Refining Lake Volume Estimation and Critical Depth Identification for Enhanced GLOF Event Anticipation" would better reflect the authors’ statements at the end of the introduction and in the conclusion.

Thank you for these considerations. We have accepted the reviewers suggested title and have made the change.

2) The topic of surge velocity

Following the reviewers’ comments on the relationship between surge velocity and GLOF event, the authors have made some changes. However, it is still not clear enough to the reader why this topic is part of this manuscript. The introduction states that the "primary objective of this study is to improve the predictive capability of GLOF event timing by refining empirical lake volume estimates and identifying critical depths for future hazard and risk reduction". Surge velocity is not mentioned – which is not a problem in itself, as other papers have investigated this at the same lakes (e.g., Bazai et al. 2022, Li et al. 2023). The authors themselves warn that this part of their results should be treated tentatively and with caution. In my opinion, the more valuable results are the surprisingly accurate geometric estimates of lake volumes and the investigation of critical lake depths. I would therefore agree with the other reviewers in suggesting that the part on surge velocity be omitted.

Thank you for these comments. We agree that the data relating surge velocity and GLOF volumes is sparse, which is why we present a cautious interpretation. However, as we noted in the last round of

reviews, we believe that it is important to report this relationship. This section is central to our arguments because, as we had already indicated in the text, there is a direct relationship between the negative function between surge velocity and the volume of the lake that maps on to geometric changes in lake volume including the dimension of lake depth. Going over the original reviews, only the second reviewer suggested we might omit this section and the current reviewer (in a comment below) makes suggestions as to how we can strengthen this section. We have provided additional explanation for retaining this section in reply to a comment below. Rather than delete the section we have provide an improved justification for this aspect of the study within the Introduction.

Specific comments:

1)Chapter 2, Study Area, is a welcome addition to the manuscript and serves its purpose well. However, it lacks a review of previous research for the selected glaciers and their lakes. There has been some research focused on these three glaciers and their lakes, some even focusing on the relationship between surge velocity and GLOF occurrence. For example, Round et al. (2017) state that surges are the main factor in lake formation at Kyagar Glacier, while Li et al. (2023) found that the volume of the lake there reaches its maximum three years after a surge period. Furthermore, Bazai et al. (2023) conclude that surge velocities have a significant impact on lake formation at Khurdopin. I would therefore encourage the authors to add some paragraphs detailing previous research in order to avoid duplication in later parts of the manuscript.

Citing of key references later in the text is always for a given context so there is no duplication. However, we take the point that a little more could be added to the Study Area section to provide context. To that end we have added text at line 120 as follows: "For example, Round et al. (2017) concluded that surges were the main factor controlling the formation of ice-dammed lakes associated with the Kyagar Glacier, and li et al. (2023) states that the volumes of the lakes reaching a maximum three years after the surge period. Similarly, Bazai et al. (2023) concluded that surge velocities have a significant effect of lake formation related to the Khurdopin Glacier."

Regarding Figure 1, I have some minor annotations, mainly for the overview panel in the top right: The fonts are too small to read – and not really necessary, as the other regions of HMA are not part of this study. Also, the long-lat grid is too small, and also not necessary for this kind of map. Thirdly, I understand that the map depicts a hillshade of the region, but the color map is unusual and would need to be explained. I suggest using a surface reflectance with low opacity and an underlying hillshade would be easier to understand, but that my only be my opinion.

2) In the three small panels, the authors indicate a "Dam site". Maybe I'm misunderstanding something, but isn't the location of the ice dam at the very other end of the lake where the lake connects to the glacier? The arrows seem to point to the inlet of the lake.
At last (and again, this is just personal preference): Please make the outline of the three glaciers stand out from the outlines of all other glaciers. If you choose to include the Indus, please use a shapefile with a higher resolution. And to be *very* nitpicky: Please adjust the scale bar lengths to 100 km (panel a) and 1000km (overview panel).

Thank you for your detailed feedback on Figure 1. We have carefully considered all of your suggestions and have made the following revisions in the updated figure:

Overview Panel: We have removed the font labels and the lat-long grid, as they were not necessary for this map and could detract from the clarity.

Hillshade and Color Map: We adjusted the map by using a surface reflectance layer with low opacity and an underlying hillshade, as per your suggestion. This should improve the visual clarity and ease of interpretation.

Dam Site Label: We reviewed the "Dam site" locations and corrected the placement to accurately indicate the position of the ice dam at the lake's connection with the glacier, as the previous arrows were mistakenly pointing toward the inlet.

Glacier Outlines: We have now highlighted the outlines of the three glaciers central to our study, distinguishing them from other glaciers for better emphasis.

Indus River Shapefile: We have replaced the previous shapefile with a higher resolution one to improve the depiction of the Indus River.

Scale Bar: We have adjusted the scale bar lengths to 100 km for panel (a) and 1000 km for the overview panel, as per your suggestion.

We appreciate your thoughtful suggestions, which have helped enhance the clarity and precision of the figure.

3) In Chapter 3.3 (L197f), the authors claim that the inlet of the subglacial conduit is always located at the deepest position in the ice dam. This may well be true for most cases, but the possibility of higher drainage channels in the ice should be mentioned, as this would have a large influence on the potential GLOF volume. I would also advise the authors to rephrase the start of this paragraph (L195) because, contrary to their statement, there are records of higher drainage channels at Kyagar Glacier (Li et al. 2023).

Thank you for making this point. We have added the following text at new line c. 203 "For the Kyager Glacier, Li et al. (2023) suspected that the drainage conduit may not have been at the deepest part of the lake basin and its configuration changed between GLOF events."

4) As mentioned in the general comments: Chapter 4.1 is very long, although the reviewers have criticized the presentation of the surge-GLOF relationship. Although the authors have partially addressed this, the chapter still adds little to the scientific discourse. The results presented are tentative at best, but there are other studies that clearly define the relationship between surge events and lake development as an increase in lake volume in the months/years after surges, i.e., a negative relationship between velocity and volume. The focus of this paper should be on estimating of lake volume and critical water pressure/lake depth, not on the relationship between surge velocity and lake formation. I agree with the other reviewers in suggesting that the paper be restructured and the surge aspect de-emphasized in order to properly focus on the more original content.

Thank you for your comments on Chapter 4.1. We appreciate your feedback and understand your concerns regarding the length of the section and its focus on the surge-GLOF relationship. However, we would like to clarify our reasoning for including this discussion and argue that the findings presented offer valuable contributions beyond what has been covered in previous studies.

It is true that studies, such as those by Round et al. (2017) and Li et al. (2023), have discussed the relationship between glacier surges and lake formation, specifically for the Kyagar Glacier. Both studies highlight that glacier surges are indeed responsible for the formation of lakes. For example, Round et al. (2017) suggests that historic lake outbursts could indicate surge activities at Kyagar Glacier, while Li et al. (2023) identifies surge events as a key factor in lake formation and further notes that the Kyagar Glacier lake volume reaches its maximum approximately three years after a surge.

However, what distinguishes our study is the more in-depth exploration of the relationship between glacier velocity and lake volume, along with the mechanisms leading to glacier lake outburst floods (GLOFs). Previous research has not fully explored how glacier velocity controls lake volume nor delved into the timing and triggers of GLOF events. Our study provides a more comprehensive

analysis that includes data not only from Kyagar Glacier but also from Khurdopin and Shishper Glaciers. By examining multiple glaciers, we aim to deepen the understanding of the surge-GLOF relationship, with a particular focus on estimating lake volume, critical water pressure, and lake depth—factors that are crucial for GLOF hazard anticipation.

While we acknowledge the suggestion to shift focus solely to estimating lake volume and critical water pressure/lake depth, we believe that the inclusion of the surge-velocity discussion offers a necessary foundation for understanding the dynamics of lake formation and the conditions that lead to GLOFs. Thus, we argue that this section of the paper is essential to support the original content and the broader context of GLOF hazards in the Karakoram region.

To address your concern about Chapter 4.1's length, we must say that it is not very long, totalling only 569 words! Much of the physical length in the manuscript from is taken up by Figs 4 and 5. Fig. 5 which you suggest (see other comment) could be moved to the Supplement was suggested as a necessary addition to the manuscript by another referee. We must agree with him/her that the whole text is easier to understand given the process controls that are shown now in Fig. 5.

5) The conclusion is indeed very short, as previously mentioned by the reviewers. Furthermore, the first five lines are not really part of the conclusion but more of a secondary introduction to the topic. To my mind, the conclusion should comprise the summary of the findings (a little bit more detailed than in its current state) and give indications on how to use them (which are currently absent). The ability to apparently determine the lake volume quite accurately based on the geometric estimate is an important point and should be the focus of the paper, together with the critical depth parameter. In the conclusion, the authors should describe in more detail how and when these values can be applied meaningfully.

Thank you for bringing this matter to our attention. We agree with you. We have deleted the first two sentences and added text to indicate how our findings might be used in a practical sense.

Technical corrections:
L 165: “Khurdophin” → “Khurdopin”

Corrected

L 206: The layout of Table 1 seems very crowded. If the need arises, the column “Type of drainage” could be omitted, because it mirrors the values in “Vol after”.

Agreed. Column has been deleted

L 261: The assumptions are not addressed in the Discussion, but in the Results.

Corrected to ‘Results’

L 264: “ice dam volume” → “ice-dammed lake volume”

Corrected

L 281: For the sake of completeness some comments on Figure 4, despite my concerns with the whole surge analysis in general and chapter 4.1 more specifically: My main point is that panel d does not correctly summarize the other three panels. The bars representing the surge periods do not correspond to the position of the GLOF events. One example: The first four GLOF events at Khurdopin appear during the surge period in panel a, but in panel d they all appear after it. The same applies for multiple other occasions. Also, the labeling of the X-Axes is still confusing, as the labels area sometimes five and sometimes six years apart – in the same panel. Why is the X-Axis in panel d formatted differently

when the style of the other panels could be used here as well? Why doesn't the X-Axis in Panel c start at 0 as well?

Thank you for your insightful comments regarding Figure 4. We have carefully reviewed the issues you raised, particularly concerning panel d.

Panel d: We have rearranged the data in panel d for all three glaciers. Initially, we presented the surge period only until the peak velocity. Thanks to your observation, we have now extended panel d to cover the entire surge period, which better aligns with the GLOF events and ensures consistency with the other panels.

X-Axes: The X-Axis labels were set at varying intervals due to data limitations, which is why they appear five to six years apart in some sections. After careful consideration, we have maintained this approach to preserve data integrity.

Panel c: We have updated the X-Axis of panel c to start at 0, as per your suggestion, to improve clarity.

We appreciate reviewer attention to these details, which has significantly improved the figure's accuracy and presentation.

L 301: This figure is a response to a reviewer's comment, but since it takes up a lot of space, I would suggest moving it to the supplementary material.

We appreciate that the figure takes-up space. However, we strongly disagree with moving it to the Supplement. The dynamics of damming and GLOF draining are complicated. This figure which, as the reviewer notes, was suggested as an addition by a previous reviewer, we think will help readers understand the time sequence of the processes we are reporting. Consequently, we have retained it.

L 318: In this chapter and the next, the authors assume the lake surface to be a triangle. This is only the case for the lake at Shishper Glacier. I would encourage the authors to address the question how their method can be applied to more unregular surfaces, like the lakes at Khurdopin and Kyagar.

This comment is perplexing. We assume the lake surface area is a triangle for all the three lakes. The degree of fit is reasonable in the case of Khurdopin as well as Kyager and Shishper, as is shown in Fig. 7. Clearly if a lake might conform to some other geometric shape, then the triangular approximation would not be appropriate. We provide an alternative volume calculation based on an irregular pentahedron as well as two references that consider other lake shapes.

L 335: In the corresponding figure, this coefficient is given as 0.93. Which is correct?

The reviewer is referring to the wrong panel (i.e. panel b). The correct coefficient in both panel a and in the main text is 0.88

L 347: "of the lakes was determined…" → "of the lakes determined…"

We have not made this correction as the text as written is grammatically correct and the suggested change is not grammatically correct.

L 349: The authors need to provide references for their statement that the lake depth is the main driver for tunnel drainage. According to other studies, low water pressure inside or under the glacier can also trigger a drainage.

We have added a reference here as the referee suggests. As was made clear from the sentence that follows this statement, the connectivity has to be made within the subglacial conduit. We have edited the text at this point and added three references to make it clear why the lake depth is regarded as a main driver.

L 355: The authors should choose their words more carefully when describing the applicability of their n'-value. It could play a valuable role in determining GLOF probability, but while they do not say so explicitly, readers could gain the impression that with a lake level of n'=0.6 there is the danger of a GLOF occurring imminently. It should be made clearer that a GLOF warning would be based on more components than lake depth.

In the original text we state "Thus, $n' = 0.60$ can be regarded as a warning level value with the potential for a GLOF occurring imminently increasing as n' approaches unity". Thus, we do believe that there is an imminent risk of a GLOF. We do not agree that a warning would only be made after other components are considered. We thought about inserting additional text at this point to indicate that consideration of other parameters would be wise, but that takes the text off into a direction whereby the alternative indicators would have to be spelt out and discussed. We rather keep the text as it is, so that authorities can considering issuing a warning when $n' = 0.60$.

L 363: Please be more specific here: Low values of n' do not necessarily indicate shallow lakes, as it is a relative value. A large lake with a maximum depth of 300m could still contain a significant amount of water with a value of n'=0.5.

We do not state that low values of n' necessarily indicate shallow lakes. We have edited the text to indicate that this statement only refers specially to the lakes we have studied.

L 363: As one reviewer mentioned before: The reasoning behind the 500kPa is not clear and may confuse the reader. You have three glaciers with three significantly different water pressures – why choose the Kyagar? Do you mean to suggest that lakes shallower than 50m (~500kPa) are not capable of producing significant GLOFs?

The reason for selecting 500kPA is that it is the minimum we recorded for the three glaciers, and this is stated in the text. Just above this sentence we have indicated that shallower lakes are of minimal risk. By modifying the text, we have also indicated that this pressure value applies to GLOFs in the region, which indicates to the reader that the value may not apply to other regions of the world.

L 364: I agree with the other reviewers: The regional aspect of the values for depth and water pressure is not clear. Why is the region mentioned here?

'region' is mentioned here as a caveat, so that readers do not necessarily think the value applies across the world. We have added a further qualifier here in the form of an additional sentence: "However, consideration should be given to local conditions when applying the findings of this study to other locations around the globe."

L 391: Again – why are your results specific to the Karakoram region? Even the three glaciers selected for this study are very different in terms of the shape, area, depth, and volume of their lakes – which of these characteristics are typical for this region?

From the revised text given above to answer the previous two queries it is evident that we are adding a caveat that the findings of this regional study do not necessarily apply around the globe. We do not argue that specific aspects of these lakes such as shape, area etc are typical of the region. We have just studied three glaciers within the Karakorum that are associated with GLOFs and extracted some commonality in behaviour.

L 419: The value of 0.6 appears solid in this context, but the second part of this sentence should be rephrased: the lake depth would be part of the hazard determination, and in itself not sufficient to issue a warning.

The text at this point states “From this result, we infer that a safe lake level can be defined as < 0.60, while the trigger level is ≥ 0.60.”. The reviewer states that the first clause is acceptable but not the second. However, the second clause follows automatically once the first clause is accepted as true. The reviewer does not indicate why using the critical depth alone as a GLOF warning is not sufficient. For reasons of safety, one might use the critical depth alone, rather than spend time considering other indicators as we have noted in response to a query above.

L 422-424: This should be mentioned before and not be part of the discussion, as it does not discuss results.

We added this text at this point to pull the discussion together to a concluding point. We have deleted it at this location and moved it to the Conclusions where it has more impact.

L 451: A small point: n’=0.6 does not automatically mean 510kPa, as n’ depends on the water depth, while 510kPa corresponds to a fixed depth of approximately 50m. If n’ is only valid from a water depth of 50m, this should be mentioned in the paper.

This is a good point. We have added the following caveat to the Conclusions. “In this respect, it should be noted that the water pressure recommended herein as potentially of concern (510kPA) pertains to lake depths of c. 50 m, whereas deeper lakes in other regions might drain at different values of pressure.”

References:

Bazai, N. A. et al. (2022) Glacier surging controls glacier lake formation and outburst floods: The exam-ple of the Khurdopin Glacier, Karakoram, Glob. Planet. Change, 208. 10.1016/j.gloplacha.2021.103710.

Li, G. et al. (2023) Characterizing the surge behaviour and associated ice-dammed lake evolution of the Kyagar Glacier in the Karakoram, The Cryosphere 17(7), 10.5194/tc-17-2891-2023.

Round, V. et al. (2017) Surge dynamics and lake outbursts of Kyagar Glacier, Karakoram, The Cryosphere 11(2), 10.5194/tc-11-723-2017.