The Cryosphere Discuss.,
https://doi.org/10.5194/tc-2020-327-RC2, 2021

Interactive comment on "Controls of outbursts of moraine-dammed lakes in the greater Himalayan region" *by* Melanie Fischer et al.

Holger Frey (Referee)

holger.frey@geo.uzh.ch

Received and published: 20 January 2021

GENERAL COMMENTS:

Based on an inventory of moraine-dammed glacial lakes and an inventory of 31 glacial lake outburst floods (GLOFs) from 1981-2018 in the Hindu-Kush Karakoram Himalaya Nyainqentanglha (HKKHN), the authors apply four Bayesian multi-level logistic regression models to estimate the susceptibility of these lakes for GLOFs. As predicting factors they combine lake elevation, lake area, lake area change rate, glacier-mass balance, and monsoonality, factors that are often used in regional-scale GLOF hazard assessments. They find that lake area is a useful predictor of GLOF susceptibility, as well as glacier mass balance. In contrast, lake area changes do not significantly

improve GLOF susceptibility estimates, which contradicts several existing lake hazard assessment schemes, where lake growth sometimes is an important hazard indicator.

As the authors point out, a large number of regional GLOF hazard assessments and assessment approaches is available for the HKKHN and other glaciated mountain ranges, many of them using a combination of weighted parameters, with a related number of different inventories and differing lists of potentially dangerous glacial lakes. This is a major challenge for decision makers and authorities responsible for hazard and risk management and planning. This study now presents for the first time a data driven, quantitative evidence on the ability of different parameters for posterior predictions of GLOF events, i.e. to estimate GLOF susceptibility.

Such quantitative assessments are highly needed and of major interest to the scientific community. The article is well written and structured and meets the requirements of a scientific publication (for instance regarding citing relevant works etc.), and the topic fits perfectly to the scope of The Cryosphere. However, there are a few aspects, detailed below, that need to be improved before publication.

SPECIFIC COMMENTS:

Hazard concept: The article is strictly focusing on GLOF susceptibility and using this term consistently throughout the manuscript. Nevertheless, I think regarding some aspects of the study, concepts and terminologies are mixed at some places. According to international standards from UNISDR, IPCC etc., hazard is a function of probability (of occurrence) and intensity (or magnitude). Susceptibility in turn 'is a relative measure of the likelihood (or probability) that a hazard will occur or initiate from a given site, based on intrinsic properties and dynamic characteristics of that site' and 'has an inverse relationship with stability' (GAPHAZ, 2017). I.e., susceptibility can be considered as probability of occurrence and is one factor of hazard. It is determined by conditioning factors (=inherent and more or less static factors) on the one hand, and triggering factors (=factors that directly initiate an outburst) on the other. The factors (predictors) analyzed in this paper, are limited (for good reasons!) to conditioning factors. In other words, the result of an analyses based on the parameters used in the present study, is mainly a lake stability assessment. In contrast to this, most of the mentioned regional glacial lake assessment approaches with more expert based, and probably subjective, parameter weightings, follow a hazard assessment approach, rather than a stability/susceptibility assessment. The reasons why these other studies consider factors like lake area or volume, or regional glacier mass balance, is not mainly because these factors directly influence lake stability, but because they have an impact on hazard potentials. Larger lake volumes (area is often used as a proxy for volume) and lake growth imply higher potential flood volumes, and therefore increase the hazard due to higher intensities, without affecting GLOF susceptibility. For similar reasons glacier masse balance is included in such models: Negative regional mass balances lead to glacier retreat and the formation of new and growth of existing lakes. Both processes increase the GLOF hazard potential in a region, but only have minor effects on GLOF susceptibility of individual lakes.

Further, unfavorable conditioning factors do not lead to a lake outburst immediately. It of course increases GLOF susceptibility, but requires still a triggering event to initiate an outburst. Clague and Evans (2000) and Emmer et al. (2020) present concepts about the timing of the causal chain of climate change, glacier retreat, glacial lake formation, and glacial lake outburst and conclude, based on empirical data from British Columbia and the Cordillera Blanca, that there is a lag between lake formation and outburst of up to several decades. The fact that a lake did not have an outburst event in the periods investigated in this study, does not automatically imply that the lake has a low GLOF susceptibility. It is indeed possible, that the lake is actually unstable (i.e. has a high susceptibility) but an outburst simply has not been triggered (yet).

Used data and parameters: Data availability for the entire study region is of course an important criterion for the selection of predicting parameters. But in addition to the parameters investigated in this study, there are candidates for other parameters which

are often and successfully applied in other regional assessment approaches cited in the study, such as the Steep Lakefront Area (SLA) developed by Fujita et al. (2013) and used by Rounce et al. (2016), or the topographic potential for rock or ice avalanches (cf. Allen et al., 2019), one of the most frequent GLOF triggers in High Mountain Asia. Considering this, I suggest to include more details about the selection of the predicting parameters.

Then, the influence of overlapping time periods of the different data sets used should be discussed in more detail, as also mentioned in the review of A. Emmer (Emmer, 2021). In particular the fact that the lake area change period overlaps the period which is investigated for GLOF occurrence, in my view disqualifies this parameter to be considered, as actually discussed in L340-344.

Statistical significance: Bayesian approaches are certainly most suitable for this type of research question where a large number of lakes (3,390) had relatively few (31) GLOF events. But still this is a very limited data basis, in particular since for the Forecasting, the Glacier-mass balance, and the Monsoonality models, only 11 GLOF events were recorded in the relevant 2005 to 2018 period. Even more, these 11 events are split over four to seven groups, depending on elevation, region, or monsoonality. Over the western half of the study region, only 3 GLOFs are found. This leads to very few (often only 1 or 2) or even zero GLOF events per subgroup (cf. boxes for Hindu Kush, Karakoram and Western Himalayas in Fig. 7). I wonder, how any predictor weights can be found in these cases. A very recent study from Zheng et al. (2021) on a slightly larger study region found evidence for a total of 215 GLOF events that presumable have happened since 1900, 176 thereof so far unreported. This does not contradict any of the data used here, but offers at least a potential alternative of a database with much more GLOF evidences (in turn posing challenges on the predictor data of course).

DETAILLED COMMENTS:

L11: I suggest to include something like ‘regional-scale’ (hazard estimations), because at the level of individual lakes, there are many quantitative assessments available, including numerical modeling, geophysical measurements etc.

L21: Maybe change ‘with respect to’ to ‘compared to’?

L81: Indicate the version number of the RGI

L112: Hydrostatic pressure acting on the dam depends mainly on lake depth, not area.

L263: The statement that upstream catchment area is well correlated with lake area is not clear to me. This needs further explanations of references. Also I do not understand why lake area is replaced by upstream catchment area in these model (Glacier-mass balance and Monsoonality), but not in others. This requires some more explanation.

L285: In the Forecasting and Glacier-mass balance models, A* represents lake-area change between 2005 and 2018. Is A* here also referring to this period (and not 1990 – 2018, as written)? If so, please correct, ifnot, another symbol should be used (ΔA?).

L321/Fig. 9: Why are the log-odds ratios negative for the first (few) lakes? Would be interesting to describe in the text.

L323/324 (Caption Fig. 9): ‘. . .in the past four decades’ applies only to the lakes in the x-axes of (a) and (c), for the other panels it’s 2005-2018. I suggest to replace this with ‘in the period 1981 – 2018 (a and c) and 2005 – 2018 (b and d-h). (Or change panel letters, see suggestion below).

Figures and Tables: Fig. 1: According to the caption, white triangles represent GLOFs since 1935. But as the study only deals with GLOFs that have occurred on the periods 1981-2018 and 2005-2018, respectively, only these should be shown here. Preferably with two colors, one for 1981-2005 and another for 2005-2018 to discriminate these to reference data sets. Please also indicate the spacing of the lake bubbles.

Table 1: This is a pretty large table for only presenting the 6 predictor parameter selected for this study. I suggest to present the 6 parameters used here in separate table,

giving some more details as well. (By the way, I think dam type could be ticked as well, at least a tick in brackets. As only moraine-dammed lakes are investigated here, this criteria is inherently considered). If the authors wish to keep having a table with other potentially relevant parameters for GLOF hazard assessment, this could be done in a more compressed format. But in this case, further geotechnical and geomorphic parameters would need to be included, such as permafrost conditions, lithology, seismicity, etc. The annex tables of the GAPHAZ guidelines (GAPHAZ, 2017) might give some indications for this.

Fig. 3: Blue-green combinations are hardly readable in the bubbles. I can see it in the text, slightly see it in the middle (‘mulit-level’) bubble, but do not see any green in the right (‘many models’). Colors to be adjusted.

Figure 4: I suggest to sort sub-groups from highest (top) to lowest (bottom) in (a) and (b), West to East (or East-West) in (c) and highest monsoonality on top to lowest monsoonality in (d). (Same as ordering in Figs. 5-8).

Figs. 5-8 (general): In none of the figures I can see the middle (blueish) line. I only see the purple and orange lines. Similar for the color shades, I guess I only see the purple and the orange and the overlap of the two. Is this middle line represented in the Figures? If so, please adjust coloring, if not please add (or remove from the legend). For all figures it would be very nice to also have a panel for the pooled data, similar to Fig. 4.

Figs. 5 and 6: It would be helpful to indicated elevation bands in m a.s.l.

Fig. 9: To me it would make more sense to number the TP a-d and the TN e-h.

Fig. 10: In the legend (e) (the letter e is not needed in my view) swap ordering, that a is on top and d at the bottom, as in the main panels. Ad ‘%’ to the numbers at the bottom. In the panels it would be helpful to include the locations with a recorded GLOF (for 1990-2018 in (a) and 2005-2018 in (b), (c) and (d)).

FINAL REMARKS:

I am well aware that several of the comments above are difficult to consider for the data analyses. However, I hope these aspects can be reflected somehow in the manuscript, either in the discussion or in the introduction, when describing the scope of the study. As a concluding remark I want to repeat my evaluation of this study, made under the general comments in the beginning, that I think this is an innovative approach and a needed analysis. I encourage the authors to revise this manuscript accordingly, and I am sure this paper will make an important contribution to the field of glacial lake hazard assessments.

REFERENCES CITED IN THIS REVIEW:

Allen, S. K., G. Zhang, W. Wang, T. Yao, and T. Bolch (2019), Potentially dangerous glacial lakes across the Tibetan Plateau revealed using a large-scale automated assessment approach, Science Bulletin, 64, 435–445, doi:10.1016/j.scib.2019.03.011.

Clague, J., and S. Evans (2000), A review of catastrophic drainage of moraine-dammed lakes in British Columbia, Quarternary Science Reviews, 19, 1763–1783.

Emmer, A., S. Harrison, M. Mergili, S. Allen, H. Frey, and C. Huggel (2020), 70 years of lake evolution and glacial lake outburst floods in the Cordillera Blanca (Peru) and implications for the future, Geomorphology, 365, 107178, doi:10.1016/j.geomorph.2020.107178.

Emmer, A. (2021), Interactive comment on “Controls of outbursts of moraine-dammed lakes in the greater Himalayan region” by Melanie Fischer et al., The Cryosphere Discussions, https://doi.org/10.5194/tc-2020-327-RC1,

Fujita, K., A. Sakai, S. Takenaka, T. Nuimura, A. B. Surazakov, T. Sawagaki, and T. Yamanokuchi (2013), Potential flood volume of Himalayan glacial lakes, Natural Hazards and Earth System Science, 13(7), 1827–1839, doi:10.5194/nhess-13-1827-2013.

GAPHAZ (2017), Assessment of Glacier and Permafrost Hazards in Mountain Re-

gions, edited by S. K. Allen, H. Frey, and C. Huggel, Joint Standing Group on Glacier and Permafrost Hazards in High Mountains (GAPHAZ), Zurich, Lima.

Rounce, D. R., D. C. McKinney, J. M. Lala, A. C. Byers, and C. S. Watson (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, doi:10.5194/hess-20-3455-2016.

Zheng, G., A. Bao, S. Allen, J. Antonio Ballesteros-Cánovas, Y. Yuan, G. Jiapaer, M.Stoffel, (2021), Numerous unreported glacial lake outburst floods in the Third Pole revealed by high-resolution satellitedata and geomorphological evidence, Science Bulletin (online first), doi: https://doi.org/10.1016/j.scib.2021.01.014

Interactive comment on The Cryosphere Discuss., https://doi.org/10.5194/tc-2020-327, 2020.