

Interactive comment on “Anthropogenic climate change and glacier lake outburst flood risk: local and global drivers and responsibilities for the case of Lake Palcacocha, Peru” by Christian Huggel et al.

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Received and published: 5 June 2020

Reviewer comment: Based on the prominent case study of Lake Palcacocha in the Peruvian Andes the paper deals with the complexity of “socio-economical, institutional and cultural processes” which become drivers of risk exposure and vulnerability and ultimately shape glacier lake outburst flood risk for the urban agglomeration of Huaraz. Questions of associated responsibilities, causality, and justice in the context of the adverse effects of climate change are also raised. This integration of a “normative responsibility framework” is rather unusual and innovative in scientific studies on GLOFs.

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It extends the research perspective and integrates dimensions of political ecology and glaciology. The paper is very well structured and the line of argument is convincing throughout the text. The introduction presents a clear statement of the problem with relevant references.

Author response: Thanks for this analysis.

Reviewer comments: When the authors mention the “impacts of glacier changes on natural and human systems” (l 32) they might also refer to papers on socio-hydrological interactions in other mountain regions in order to strengthen the global perspective. There are a number of contributions from various parts of the Himalaya. Such references would also be useful when the authors refer to adaptation strategies to cope with cryosphere changes (l 40-44). Socio-hydrological case studies dealing with meltwater dependent irrigated agriculture may be useful in this context (e.g. from Ladakh).

Author response: Yes, good point, we now include additional reference to studies of socio-hydrological interactions in the Introduction section of the paper, specifically we include several references with additional indications on international (incl Himalayas and Ladakh studies) studies on socio-hydrologic and socio-cryospheric research and emphasize the important progress that has been made in this field in recent years. We include the following additional references (included in the paragraph of lines 38-48).

Allison, E. A.: The spiritual significance of glaciers in an age of climate change, *WIREs Climate Change*, 6, 493-508, 2015.

Carey, M., McDowell, G., Huggel, C., Jackson, J., Portocarrero, C., Reynolds, J. M., and Vicuña, L.: Integrated Approaches to Adaptation and Disaster Risk Reduction in Dynamic Socio-cryospheric Systems, in: *Snow and Ice-Related Hazards, Risks, and Disasters*, edited by: Haeblerli, W., and Whiteman, C., Elsevier, Amsterdam, 219-261, 2014.

Drew, G.: A Retreating Goddess? Conflicting Perceptions of Ecological Change near

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the Gangotri-Gaumukh Glacier, *Journal for the Study of Religion, Nature and Culture*, 6, 344-362, 2012.

Gagné, K.: *Caring for Glaciers: Land, Animals, and Humanity in the Himalayas*, University of Washington Press, Seattle, 2019.

Gagné, K., Rasmussen, M. B., and Orlove, B.: *Glaciers and Society: Attributions, Perceptions, and Valuations*, *WIREs Climate Change*, 5, 793-808, 2014.

Mukherji, A., Sinisalo, A., Nüsser, M., Garrard, R., and Eriksson, M.: *Contributions of the cryosphere to mountain communities in the Hindu Kush Himalaya: a review*, *Regional Environmental Change*, 19, 1311-1326, 2019.

Nüsser, M., and Baghel, R.: *The Emergence of the Cryoscape: Contested Narratives of Himalayan Glacier Dynamics and Climate Change*, in: *Environmental and Climate Change in South and Southeast Asia*, edited by: Schuler, B., Koninklijke Brill, Leiden, 138-156, 2014.

Nüsser, M., and Baghel, R.: *Local Knowledge and Global Concerns: Artificial Glaciers as a Focus of Environmental Knowledge and Development Interventions*, in: *Ethnic and Cultural Dimensions of Knowledge. Knowledge and Space*, edited by: Neusburger, P., Freytag, T., and Suarsana, L., Springer, Switzerland, 191-209, 2016.

Nüsser, M., Dame, J., Kraus, B., Baghel, R., and Schmidt, S.: *Socio-hydrology of “artificial glaciers” in Ladakh, India: assessing adaptive strategies in a changing cryosphere*, *Regional Environmental Change*, 19, 1327-1337, 2019.

Orlove, B., Milch, K., Zaval, L., Ungemach, C., Brugger, J., Dunbar, K., and Jurt, C.: *Framing climate change in frontline communities: anthropological insights on how mountain dwellers in the USA, Peru, and Italy adapt to glacier retreat*, *Regional Environmental Change*, 19, 1295-1309, 2019.

Sherry, J., Curtis, A., Mendham, E., and Toman, E.: *Cultural landscapes at risk: Exploring the meaning of place in a sacred valley of Nepal*, *Global Environmental Change*,

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52, 190-200, 2018.

Sörlin, S.: *Cryo-History: Narratives of Ice and the Emerging Arctic Humanities*, in: *The New Arctic*, edited by: Evengård, B., Larsen, J. N., and Paasche, Ø., Springer, New York, 327-339, 2015.

Williams, C., and Golovnev, I.: *Pamiri Women and the Melting Glaciers of Tajikistan*, in: *A Political Ecology of Women, Water and Global Environmental Change*, edited by: Buechler, S., and Hanson, A.-M. S., Routledge, New York, chapter 11, 2015.

Reviewer comment: The authors present their general understanding of this glacier riskscape “as a function of physical hazard, human exposure, and vulnerability of people and assets” (l 60), taking into consideration the IPCC-based framework and classical risk concepts developed by Blaikie, Oliver-Smith, and Wisner. The case of lake Palcacocha is particularly interesting as it is not only a representative case study for cryosphere risks (in the sense of the cryoscape) but it also presents a legal case where different actors are involved, in this case, a local Peruvian citizen and a German energy producer. The case study of Lake Palcacocha is presented in a detailed and historically informed way. The physical and socio-economic drivers of risk are also presented in a convincing way. Section 4 provides important information on the socio-economic drivers of risk, especially the importance of recent urbanization processes, demographic growth, and the role of different actor groups (Quechua-speaking farmers, mine workers, ruling Spanish-speaking classes) together with some remarks on settlement history. It is important to focus on class division, social marginalization and other economic factors to understand decision-making in urban planning and practices of building in hazard prone regions. The authors might also add some examples from other mountain regions in the Global South to have a wider and more global context (people opt for habitat locations in hazard-prone flood plains because of economic gains).

Author response: Agreed, we now put the Palcacocha case in the context of other,

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potentially similar cases in developing countries, specifically, we make reference to cases, including in the Himalayas but also in other parts of the Andes, North America and Europe. We add a paragraph addressing this comment in section 6, on the cultural components of risk.

There are many cases not just in the Cordillera Blanca but internationally where people knowingly inhabit areas exposed to GLOFs. In some cases, they are "forced" into these areas due to cheaper land in the floodplain or nearby job and livelihood opportunities (Carey et al., 2014; Orlove et al., 2019). In other cases, they select GLOF-prone sites to live due to historical and cultural connections to those flood-prone places (Sherry et al., 2018), or they utilize other cultural or spiritual techniques to manage glacier-related risks (Allison, 2015; Gagné, 2019), or they possess different local knowledge about risk that sometimes differs from scientific or institutional assessments of GLOF risks (Drew, 2012; Williams and Golovnev, 2015). Furthermore, in India, there are also documented recent major GLOF disasters due to exposure and high vulnerability of a large number of people due to religious and tourism related reasons (Allen et al. 2013)

Reviewer comment: The last few lines of this section (l 299-300) are quite general (global histories of colonial power, neoliberalism, resource extraction). These aspects might be contextualized with social processes in the context of GLOF disasters.

Author response: These two lines are intentionally general because these lines are at the end of the respective section 4 and they should summarize the points made in the above text of this section. So, the contextualization takes place in the above text. We're not entirely sure how to interpret Marcus Nüsser's comment and whether he thinks this text may appear as an inappropriate generalization if not again put in context. We there add a clarifying statement that this statement specifically needs to be seen in the GLOF disaster context.

Reviewer comment: Section 5 provides detailed information on weak institutional structures and problems in regional governance over the past decades. The set of culturally

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embedded explanations of the 1941 GLOF and the important aspect of local concepts of place attachment are contextualized as other dimensions of explanation. The authors conclude that risk and associated loss and damage "is a multi-faceted construction and the question of causality can often not be fully solved, at least not in a quantitative way" (l 485-486). The paper uses a local case study to provide a multi-dimensional analysis with very relevant implications for international climate policy. This is innovative and deserves publication. The figures are relevant and illustrative.

Author response: Comments and evaluation of our study appreciated.

Reviewer comment: Some few typos need to be corrected, e.g. l 104 two punctuations l 115 Hans Kinzl l 136 delete one bracket.

Author response: Thanks, we corrected these typos.

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., <https://doi.org/10.5194/nhess-2020-44>, 2020.

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