Nat. Hazards Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/nhess-2020-44-AC1, 2020
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Natural Hazards and Earth System Sciences
Discussions

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

We generally would like to express to acknowledge the review comments and suggestions made by the two reviewers and the additional comments contributed by colleagues. We appreciate the time our colleagues have taken to read and analyze the paper, especially during the current difficult times. We found all comments helpful and suggestions constructive and are very positive that we can appropriately address all points.

Response to review comments by Dmitry Petrakov

General comments: The Lake Palcacocha was a source of the most destructive GLOF in human history which happened in 1941. Some mitigation measures to prevent lake outburst have been done. Growing volume of the lake due to glacier retreat is accompanying by growing population of Huaraz city located at the flow path. Thus any attempts to assess risk of GLOF from the Lake Palcacocha are highly relevant both at local and global scale. Authors used the Lake Palcacocha as a representative case for other glacier lakes and related risks around the world. The paper provides high-quality case study with significant conclusions, both locally and globally. It also provides nice synthesis of natural and social sciences which is important for comprehensive risk assessments. Novelty of results is quite clear. Structure of the paper is reasonable, Introduction is well-written, motivation and goals of the paper are fully clear. Authors provide brief but comprehensive description of the Lake Palcacocha evolution and engineering solutions to prevent dam failure. Currently lake growth potential is limited by topographic constraints, but outburst probability is high. Authors analyzed anthropogenic contribution to glacier retreat in Cordillera Blanca based on literature review and concluded that growth of lake Palcacocha has a clear anthropogenic signal. GLOF hazard in the absence of anthropogenic climate change the flood hazard would be much lower due to change of lake volume and increasing impact energy of ice/rock avalanches. Socio-economic drivers of risk are determined and analyzed basing on literature review and survey conducted in 2017. What is important, local residents showed little concern for the risk of flooding. The institutional instability generated only short-term, unsustainable measures to protect downstream populations. Authors note that combined effects of institutional and governance-related risk drivers have contributed to the increase of risk and provide interesting insight on cultural and emotional component of risk. Basing on analysis of risk drivers authors provide implications for responsibility and justice. The manuscript is well written and free of technical errors, well structured, appropriate in length. All figures and the table are high-quality. Supplementary material is very useful for understanding of hazard assessment technology. The conclusions

are clear and precise. The results obtained in this study are highly relevant to assess risk of future GLOFs not just in Huaraz but elsewhere. I definitely support publication of the manuscript.

Author response: Thanks for this analysis of the study and appreciation of our work.

Specific comments: Authors noted that previous studies estimated about 40,000 people living in the inundation zone with a potential death toll of close to 20,000 (Somos-Valenzuela, 2014). Anywhere there is no assessment of current situation despite Fig.7 demonstrates significant growth of population in Huaraz. How many people live in zones with different hazard level (Fig.5) now? Is population density within hazardous area uniform or not? An addition of a figure where population density will be provided solely or overlaid to hazard zonation might be interesting for readers and useful for local communities and decision makers. Being fully agree with author's concept I will be happy to see what components of risk are major and what components are really minor. Furthermore, some recommendation how to minimize GLOF risk in Huaraz basing on risk driver analysis will increase practical and intellectual merit of this really great paper.

Author response: Thanks for pointing out these aspects. We were investigating digital data on population distribution in Huaraz, and thanks to our colleague Marcelo Somos-Valenzuela were able to get access to pertinent GIS based data which allowed us to perform additional analysis to address Dmitry Petrakov's comments and suggestions. This analysis which is supported by a new figure (see below) indicates that high population density intersects with the high hazard zone. We carefully evaluated how we could best graphically represent the different information layers in one figure such that the reader could quickly infer hazard zones vs population density. Our graphic analysis eventually concluded that it is not sensible to bring all information layers together in one single figure and we therefore decide on two panels which will be an extension of the current Figure 5 (see below). However, in terms of risks we also add here a word of caution: population data only refers to residential population, but the GLOF risk

threatens parts of the city center, including markets, touristic attractions, bus stations, etc., which can have much higher concentration of people, depending on daytime. And eventually, the death toll is very difficult to estimate because death depends on multiple factors such as detailed structural building data, physical conditions of people depending on additional factors such as age, health conditions, daytime (see above) etc. We don't think we're in a position to perform such as estimate and therefore mention the estimate given by Somos-Valenzuela (2014).

We include results of all this additional analysis in section 3 of the paper (physical drivers of risk).

Figure 1: New figure showing the population density in Huaraz, to go in tandem with the original Figure 5.

Figure 2: For reference, Figure 5 from the original manuscript.

The point about an evaluation of major and minor components of risk is a very interesting one but at the same time also very challenging to perform in the absence of a fully quantitative risk analysis across all different risk drivers. It is important to consider that risk is a function of hazard, exposure and vulnerability, and hence, if there is no hazard or no exposure no risk exists. So one could argue that without the existence of Lake Palcacocha (or other glacier lakes above Huaraz including Shallap, Cuchillacocha, Tulparaju, and Llaca) no GLOF risk in Huaraz would exist. Likewise if there were no exposed assets such as homes, infrastructure, or agriculture, then no (or minimal) GLOF risk would exist. We think that the question of major vs minor risk components can only be appropriately addressed if different risk components are weighted, which, eventually is a societal or political question. For instance, is a building or a human life weighted higher? We would like to abstain from weighting different risk components, and hence we would not be in a position to make a statement about major/minor risk components. However, we think it is an important discussion and we therefore include this issue in section 7.

Concerning recommendations for risk reduction measures we now include an additional paragraph in section 7 which addresses this point in a comprehensive way and with reference to the different responsibilities.

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

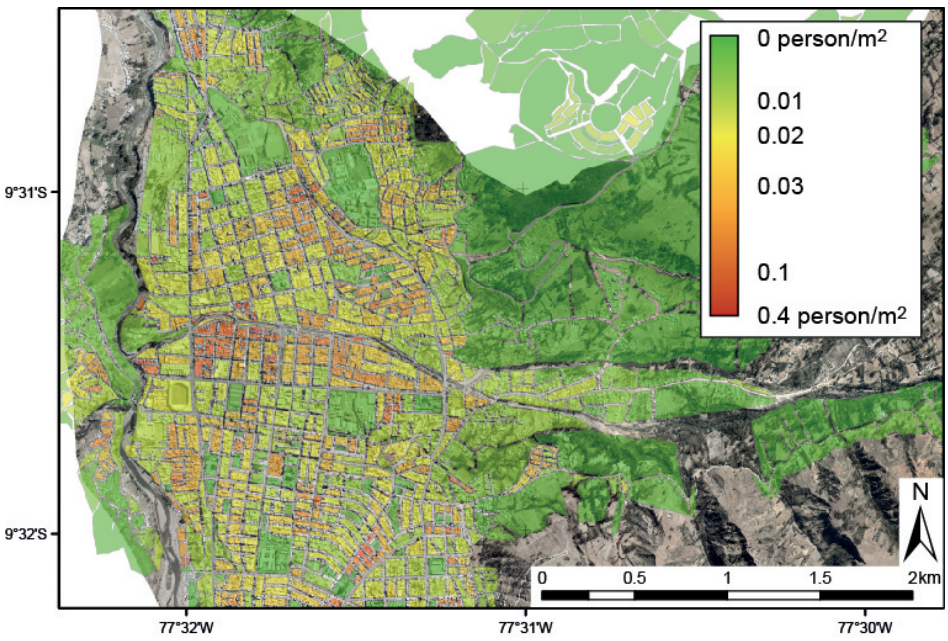

Fig. 1.

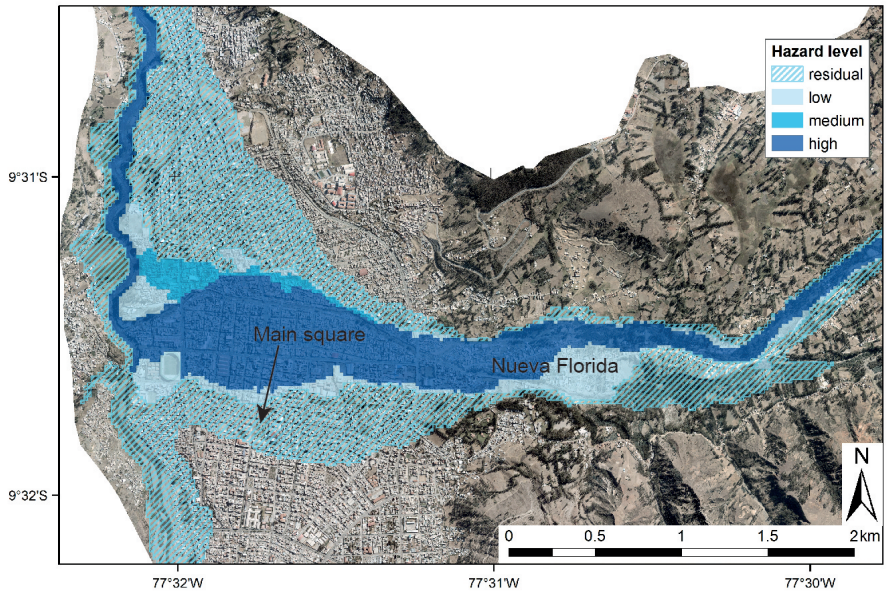
Hazard level
residual
low
medium
high
Main square
Nueva Florida
N
0
0.5
1
1.5
2 km
9°31'S
9°32'S
77°32'W
77°31'W
77°30'W

Fig. 2.