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Glacial Lake Outburst Flood Risk in Himachal Pradesh, India: An Integrative and Anticipatory Approach to Inform Adaptation Planning

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Most research concerning the hazard from glacial lake outburst floods (GLOFs) has focused on the threat from lakes that have formed over the past century, and which continue to expand rapidly in response to recent warming of the climate system. However, attention is shifting towards the anticipation of future hazard and risk associated with new lakes that will develop as glaciers continue to retreat and dramatically different landscapes are uncovered. Nowhere will this threat be more pronounced than in the Himalaya, where the majority of the world's glaciers are found, and where the dynamics of nature interact closely with livelihoods and anthropogenic resources.

Using the Indian Himalayan state of Himachal Pradesh (HP) as a case study, we combine a suite of GIS-based approaches to:

1)Implement a large-scale automated GLOF risk assessment within an integrative climate risk framework that recognizes both physical and socio-economic determining factors.

2)Expand the assessment beyond the current situation, to provide early anticipation of emerging GLOF hazard as new lakes form in response to further retreat of the Himalayan glaciers.

Results clearly demonstrate a significant future increase in relative GLOF hazard levels across most Thesils of HP (administrative units), as the overall potential for GLOFs being triggered from mass movement of ice and rock avalanches increases, and as new GLOF paths affect additional land areas. Across most Thesils, the simulated increase in GLOF frequency is an order of magnitude larger than the simulated increase in GLOF affected area, as paths from newly formed glacial lakes generally tend to converge downstream within existing flood channels. In the Thesil of Kullu for example, we demonstrate a 7-fold increase in the probability of GLOF occurrence, and a 3-fold increase in the area affected by potential GLOF paths.

In those situations where potential GLOFs from new lakes will flow primarily along existing flood paths, any adaptation measures implemented now will offer dual benefits – reducing not only the current GLOF risk, but also responding to the emerging risk anticipated for the coming decades. Such adaptation strategies (e.g. early warning systems, community preparedness, disaster response planning and land zoning) can be considered "low-regret" measures, i.e, responses that offer immediate benefits to the communities now while also offering benefits over a range of possible future scenarios. Conversely in locations where the formation of new lakes over the coming decades will create an entirely new threat, local authorities would be encouraged to consider long time scales in their climate adaptation planning. This is particularly relevant for new infrastructural developments (residential property, road, hydropower dams etc) where new threats could clearly emerge during the intended lifetime of any constructions.