Evolving hazards from Himalayan glacier lake outburst floods

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The ongoing retreat of glaciers has formed several thousands of meltwater lakes in the Himalayas. Hundreds of these lakes have grown rapidly in area and volume in past decades, raising widely publicised concerns of an increasing hazard from sudden glacier lake outburst floods (GLOFs). Some 40 catastrophic lake outbursts have claimed thousands of fatalities and high losses in the Himalayas, mostly as a consequence of moraine-dam failures. Human and public safety along densely populated river reaches may thus be prone to changes in the lake size-distribution and the frequency of outburst floods. Yet multi-temporal inventories of Himalayan glacier lakes and associated outburst floods that we need for hazard appraisals have been collated only for selected basins with few standardised rules. Objectively tracing changes in regional GLOF hazard through time has thus remained elusive.

Here we meet this urgent demand for an improved GLOF hazard assessment. We estimate changes in the 100-year GLOF peak discharge from the late 1980s towards a scenario of completely ice-free Himalayas. We use a Random Forest model to predict land cover from seasonal Landsat images, and automatically extract glacier lakes for four time intervals. We obtain credible lake depths and volumes for each interval from a linear model learned from published bathymetric surveys. We further project possible sites for future Himalayan meltwater lakes from three published models of subglacial topography. We assume that these presently ice-covered depressions could fill completely with water though sediment and debris could decrease the storage space for future lakes. We simulate distributions of peak discharge for historic, present, and future lakes, accounting for different combinations of lake area, breach depth, and dam lithology. Most barrier types are unknown and could range from intact metamorphic bedrock to unconsolidated moraine debris. These two end members help to constrain the physically possible boundaries of GLOF peak discharges, which is supported by data from 82 natural dam breaks with known values of erodibility. To estimate the return periods of outburst floods, we used an extreme-value model to couple our simulations of peak discharge with mean annual rates of outburst floods, which remained unchanged in the Himalayas in the past three decades.

Given this constant rate of outburst floods, we report how hazard—expressed as the 100-year GLOF discharge—varied with regionally changing lake-size distributions in the past decades. We show that the southern Himalayas of Nepal and Bhutan had the largest increase of lake area, feeding notions of a rising GLOF hazard in this region. Hazard in the Western Himalaya,
Karakoram, and Hindu Kush increased marginally, in line with the smallest historic abundance of glacier lakes and outburst floods. Future lake abundance and volumes may increase at least six-fold, with the largest lakes appearing in regions that have large glaciers today such as the Western Himalaya and the Karakoram. All other controls held constant, we find that hazard from these future lakes will largely rest on the erodibility of the barrier type, which needs to be acknowledged better in hazard appraisals.