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Automatically detecting Himalayan Glacial Lake Outburst Floods in LANDSAT time series

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More than 5,000 meltwater lakes currently exist in the Himalayas, and some of them have grown rapidly in past decades due to glacial retreat. This trend might raise the risk of Glacial Lake Outburst Floods (GLOFs), which have caused catastrophic damage and several hundred fatalities in historic time. Yet the growing number and size of Himalayan glacial lakes have no detectable counterpart in increasing GLOF frequency. Only 35 events are documented in detail since the 1950s, mostly in the Himalayas of Eastern Nepal and Bhutan. Observations are sparse in the far eastern and totally missing in the northwestern parts of the mountain belt. The GLOF record is prone to a censoring bias, such that mainly larger floods or flood impacts have been registered. Thus, establishing a more complete record and learning from past GLOFs is essential for hazard assessment and regional planning.

To detect previously unreported GLOFs in the Himalayas, we developed an automated processing chain for generating GLOF related surface-cover time series from LANDSAT data. We downloaded more than 5,000 available LANDSAT TM, ETM+ and OLI images from 1987 to present. We trained a supervised machine-learning classifier with >4,000 randomly selected image pixels and topographic variables derived from digital topographic data (SRTM and ALOS DEMs), defining water, sediment, shadow, clouds, and ice as the five main classes. We hypothesize that GLOFs significantly decrease glacial lake area while increasing the amount of sediment cover in the channel network downstream simultaneously. Thus we excluded shadows, clouds, and lake ice from the analysis. We derived surface cover maps from the fitted model for each satellite image and compiled a pixelwise time-series stack. Customized rule sets were applied to systematically remove misclassifications and to check for a sediment fan in the flow path downstream of the former lake pixels.

We verified our mapping approach on thirteen GLOFs documented in the study period. First evaluations suggest that our processing chain is capable of detecting the majority of the GLOFs independently, paving the way for a first complete inventory of Himalayan GLOFs derived from satellite images. Within the limits set by data quality, we expect to at least double the size of the existing GLOF database in the Himalayas for the study period. We discuss several challenges affecting our automated classification approach, such as the sensor resolution, the magnitude of change necessary for GLOF detection, and the role of ice cover on glacial lakes. The generated surface cover maps are a powerful resource for further applications in geomorphological research like monitoring the variability of supraglacial ponds or sediment dynamics in mountain valleys. Making use of the consistently growing and freely available LANDSAT archive, our workflow can be adapted and extended to various analyses in order to understand and quantify landscape dynamics in the Himalayas.