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# Evolution and hazard analysis of high-mountain lakes in the Cordillera Vilcabamba (Southern Peru) from 1991 to 2014

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In recent decades, glaciers in high-mountain regions have experienced unprecedented glacier retreat since the Little Ice Age (LIA). This development triggers the formation and growth of glacier lakes, which in combination with changes in glacier parameters might produce more frequent conditions for the occurrence of disasters, such as Glacier Lake Outburst Floods (GLOF). Facing such a scenario, the analysis of changing lake characteristics and identification of new glacier lakes are imperative in order to identify and reduce potential hazards and mitigate or prevent future disasters for adjacent human settlements.

In this study, we present a multi-temporal analysis with Landsat TM 5 and OLI 8 images between 1991 and 2014 in the Cordillera Vilcabamba region (Southern Peru), a remote area with difficult access and climate and glaciological in-situ data scarcity. A semi-automatic model was developed using the band ratios Normalized Difference Snow Index (NDSI) and Normalized Difference Water Index (NDWI) in order to identify glacier and lake area changes. Results corroborate a strong glacier area reduction of about 51% from 1991 (200.3 $km^2$) to 2014 (98.4 $km^2$). At the same time, the number of lakes (total lake surface) has increased at an accelerated rate, from 0.77% (0.48%) in 1991 to 2.31% (2.49%) in 2014. In a multiple criteria analysis to identify potential hazards, 90 out of a total of 329 lakes in 2014 have been selected for further monitoring. Additionally, 29 population centers have been identified as highly exposed to lake related hazards from which 25 indicate a distance less than 1 km to an upstream lake and four are situated in a channel of potential debris flow. In these areas human risks are particularly high in view of a low HDI below Peru′s average and hence pronounced vulnerability.

We suggest more future research on measurements and monitoring of glacier and lake characteristics in these remote high-mountain regions, which include comprehensive risk studies linking climate-related hazards and human vulnerability and exposure.