

The recent evolution of glaciers and lakes in the Eastern Himalayas (Nepal) as witnesses of climate change

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This work is aimed at analysing the geometry changes affecting glaciers and lakes in the Sagarmatha National Park (SNP, Nepal) during the second half of the 20th century. Variations in number and surface coverage of glaciers and lakes are evaluated by comparing maps and satellite images in a GIS environment. The data we obtained from the first map (published by Schneider, 1967) were surveyed in the late 1950s, from the second map (GSI, 1967) we acquired information on the geometry of glaciers and lakes in the 1960s; then from the official map of Nepal (HMGN, 1997) we achieved data of the early 1990s and last but not least, two satellite images (ASTER 2002 and ALOS, 2008) permitted us to study the most recent geometry features of glaciers and lakes.

A slight overall decrease in glacier area (by 4.9 %, from 403.9 km² to 384.6 km²) from 1950s to 1990s by comparing cartographic data was found. These results, in spite of the errors which could affect our data due to different cartographic interpretations, agree with the area changes found by other studies performed on Himalayan glaciers.

Moreover our study permitted also to detect differences in glacier geometry changes: during the analyzed period larger glaciers located at the higher elevations showed a general surface increase. This growth resulted stronger and clearer on glaciers with South aspect, which showed larger area gains in the accumulation basin. The glacier terminus, instead, resulted to be retreated thus suggesting the surface increase did not affect lower glacier sectors. Differently, the smaller glaciers we analysed, situated at lower altitudes and on steep basins, showed a general surface reduction. Also in this case, the glacier sector most affected by area changes resulted to be the accumulation zone and the glacier terminus showed changes of opposite sign respect to area changes: the termini of smaller glaciers, in fact, were found to be advancing during the analysed period. As is often the case in these regions, there is a lack of climate data for the high altitudes. Nevertheless, the analysis of meteo-series from weather stations situated in the Park area suggests that, alongside temperature variations, often considered the primary cause eliciting glacier response, changes in precipitation may have also played a significant role, thus accounting for the divergent behaviour of the glaciers.

As regards lake changes, the analysis of the variations occurred between the 1980s and the 1990s in their surface coverage and distribution in the north-east sector of SNP reveals a general increase of surface area, by 15.4 (- 5.5; +5.7)% (median 12.5%), the area growth resulted clearer within hydrographic basins including an important glacial cover. In fact, 96% of the lakes whose surface area increased are located in glacial basins. Conversely, the majority of the lakes without glacial cover in their catchment showed a reduction in surface area, and in many cases they disappeared (83% of the lakes that disappeared were situated in basins without glaciers). The different behaviour of these two types of lakes, though observed over a short time span, seems to be effects of the temperature increases recorded from the beginning of 1980s on a global and local scale. The analysis of the 2008 satellite image permitted to detect an increase in surface area of supraglacial lakes larger than twofold the areas they covered in 1950s.

In addition by the present study a useful tool was produced (i.e.: Limnological Information System , *LIS*); the tool will provide a helpful platform for extending such analysis to entire area of the SNP, as well as for performing successive comparisons among earlier maps and/or more recent satellite imageries.

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