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Glacial Lakes in the Chhombu Chhu Watershed (Sikkim Himalaya, India): Inventory, Classification, Evolution, and Potential GLOFs Assessment

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The Sikkim Himalaya, similar to other mountain regions, has lost considerable ice cover over the years owing to the changing climatic factors leading to enlargement of glacier-fed lakes, and thus posing a potential threat to downstream communities in the mountain and Tarai (*foothills*) region in case of breach anytime in the future. The Chhombu Chhu watershed (CCW) of Tista basin in the Sikkim Himalaya (~694.5 km²) is located in the transitional zone between the Greater Himalayan range with a Tethyan Sedimentary Sequence, is the storehouse of number of glacial lakes covering large areas, and volume. In order to evaluate the critical glacial lakes, we mapped the changes between 1975–2018 and assessed their dynamics based on manual analysis of medium to high-resolution optical images for the years 1975, 1989, 2000, 2010 and 2018, respectively and verified during field surveys. Results show that the number of lakes has increased from 62 to 98, and its total area expanded significantly by $\sim 34.6 \pm 5.4\%$, i.e., from 8.5 ± 0.2 km² in 1975 to 11.4 ± 0.6 km² by 2018, at an expansion rate of $0.8 \pm 0.1\% \text{ a}^{-1}$. It is interesting to note that these lakes expanded faster during 2010–2018 ($+1.18 \pm 2.0\% \text{ a}^{-1}$), i.e. in the recent decade, compared to previous years such as $+1.02 \pm 1.1\% \text{ a}^{-1}$ in 1975–1988, $+0.54 \pm 1.3\% \text{ a}^{-1}$ in 1988–2000 and $+0.20 \pm 1.6\% \text{ a}^{-1}$ in 2000–2010. Lake outburst susceptibility result reveals that a total of twenty-seven potentially dangerous glacial lakes exist in the CCW; 5 have a status of 'high' outburst probability, 17 'medium' and 5 'low'. Accelerating increasing long-term average annual trend of temperature ($+0.283 \text{ }^\circ\text{C a}^{-1}$; 1975–2013) at 95% confidence level also supports the glacier area lost ($-0.66 \pm 0.1\% \text{ a}^{-1}$), and lake area enlargement trend ($+0.80 \pm 0.1\% \text{ a}^{-1}$) between 1975 and 2018, indicating heightened impact of climate change in the CCW of the Sikkim Himalaya.