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Investigating supraglacial ponds in the Everest region, 2015-2018.

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Himalayan glaciers have shrunk rapidly in recent years, but provide a vital water resource for those living in their densely populated downstream catchments. Many of these glaciers are debris-covered, which strongly influences their response to climate change. Surface melt ponds are characteristic of debris-covered glaciers and can greatly enhance local melt rates. Furthermore, surface ponds can grow rapidly in size and coalesce to form large lakes. The growth of these glacial ponds and lakes represents a major hazard in the form of outburst floods, which can cause catastrophic damage downstream. Here, we use high-resolution (10 m) Sentinel-2A satellite imagery to quantify the spatiotemporal changes of 6,425 supraglacial ponds for 10 glaciers in Everest region of Nepal. Our analysis spans the period 2015-2018 and represents the most up-to-date study of ice surface ponds in the region. All 10 glaciers displayed an overall increase in ponded area over the study period, however year to year variation and glacier to glacier variation was observed. On the three larger glaciers (Ngozumpa, Pangbung and Khumbu) pond number reduced over the period, suggesting coalescence, whilst on the smaller glaciers pond number increased, suggesting ponded area is growing via new pond formation. Both Imja and Spillway Lake expanded over the period, and Khumbu Glacier continued to develop a chain of connected ponds, indicative of large lake development. Ice cliffs were found on all 10 glaciers, and a higher percentage of ponds had an adjacent cliff than didn't (54%), however cliffs were found to have little impact on pond growth, with more pond forming without a cliff during the study. Ponds were found to form irrespective of the surface slope, but favored locations of lower surface velocity (e.g. the terminus). Our data demonstrate that high-resolution imagery (<10m) is required to prevent omissions of smaller ponds, which account for 28-59% of the total number of ponds identified here. Finally, we classify the proglacial lakes in our study regions according to stage of glacial lake development (Komori et al., 2008; Robertson et al., 2012). We find that two lakes transitioned between stages during out study period, which indicates that lakes in the region are evolving rapidly. Furthermore, we find that some of the study lakes display characteristics of multiple classes in previous classification systems, so we propose an adapted classification system. Overall, our results demonstrate a continued trend of pond expansion, and thus heightened risk of outburst floods in the coming decades in the Everest Region, and should continue to be monitored closely to support regional hazard assessments.

Key Words: Supraglacial Ponds, Debris, Ice-cliffs, Sentinel-2A, Outburst floods, Hazards.