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Assessing glacier changes and hydrological impacts in the upper Indus Basin under CMIP6 climate scenarios

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https://doi.org/10.1016/j.isci.2025.113200

SUMMARY

Glaciers in the Himalaya are vital for sustaining streamflow in the Upper Indus Basin. This study quantifies future glacier mass and area changes in the Jhelum sub-basin using projections from 13 bias-corrected CMIP6 climate models under SSP245 and SSP585 scenarios. A temperature-index melt model, combined with field-validated glacier thickness, outlines, and mass balance data, is used to simulate glacier response to climate forcing. Results indicate glacier area losses of 34.7 ± 12.1% under SSP245 and 55.3 ± 16.1% under SSP585 by the 2080s, accompanied by a significant decline in glacier streamflow. These projected changes threaten water availability in the region, with serious implications for agriculture, hydropower, and regional water security. By integrating multiple data sources and modeling approaches, the study provides robust estimates of glacier change and highlights the need to incorporate glacier dynamics into long-term climate adaptation and water resource planning in the Upper Indus Basin.

INTRODUCTION

Glaciers in the Himalayas serve as critical natural reservoirs of perennial freshwater[1,2] and are essential for sustaining water supplies to Asia's major river systems, particularly the Upper Indus Basin (UIB). These glaciers directly contribute to the flow of the Indus River, supporting millions of people downstream. Recent studies highlight growing concern about glacier mass loss in this region, with significant implications for water availability.[2–5] The retreat of glaciers in the UIB is not only a pressing issue for regional water resources but also an area of considerable research focus. Orr et al.,[6] identified key research priorities on climate change and water in the UIB, emphasizing the critical need for further investigation. Although the mass of mountain glaciers is much smaller than that of ice sheets in Greenland and Antarctica, the retreat of non-polar glaciers significantly contributes to sea-level rise.[7–9] The observations of the recent studies over the Himalaya-Karakoram (HK) region indicate differential rates of glacier retreat and mass loss,[10–13] largely due to differential climatic and geomorphological conditions.[13,14] This complicates the understanding of glacier response to the changing climate.[15] Several studies over the HK region in recent years suggest that the rate of glacier retreat and mass loss over the region is in line with the other parts of the world,[12,16] except for the reports indicating stability or even mass gain reported from the Karakoram region.[12,17,18] The impact of the projected climate change on the HK glaciers is, however, not adequately investigated.[19] Only a few studies have attempted to investigate the impacts of projected climate change on the glaciers over the region. Radić et al.[20] have investigated the changes in glacier mass at the regional and global levels under different climate change scenarios. Lutz et al.[4] on the other hand reported glacier shrinkage of 20–28%, 36–48%, 31–45% for the Indus, Ganges, and Brahmaputra basins respectively by 2050s under RCP4.5 and RCP8.5 climate change scenarios. At the catchment level, Immerzeel et al.[21] projected glacier shrinkage of 54% and 33% in the Langtang and Baltoro sub-basins, respectively, under the RCP8.5 climate change scenario. In the Nepal Himalaya, Shea et al.[22] projected glacier volume loss of 83%–94.7% for the Khumbo glacier under the RCP4.5 and RCP8.5 scenarios, respectively. Relying mostly on simplified parameterization, all the studies regarding the future glacier changes indicate significant ice mass loss by the end of 21st century over the HK region,[21–24] necessitating a deeper understanding of how this will affect the regional and local water availability and food security[25] in the region.

Existing studies on glacier projections in the Himalayan-Karakoram (HK) region predominantly rely on older climate scenarios, such as the Representative Concentration Pathways (RCPs). These studies project substantial glacier mass loss by the end of the 21st century, with significant implications for water availability and food security.[4,20,22] However, the impact of future climate change on the HK glaciers remains inadequately explored, particularly at finer spatial scales that account for the local topographic conditions.[19]