water

Article

A Comprehensive Inventory, Characterization, and Analysis of Rock Glaciers in the Jhelum Basin, Kashmir Himalaya, Using High-Resolution Google Earth Data

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Abstract: Rock glaciers are crucial freshwater resources, yet detailed knowledge about their distribution, characteristics, and dynamics in the Himalayan region is scarce. This study presents a comprehensive rock glacier inventory of the Jhelum basin, Kashmir Himalaya, India, using high-resolution Google Earth data. We identified 240 rock glaciers covering an area of 41.24 ± 2.2 km^2, with ~76% classified as active, ~20% inactive, and 3.7% relict. The average areas and lengths of these rock glacier types were 0.19 km^2, 0.06 km^2, and 0.29 km^2, and 699 m, 426 m, and 952 m, respectively. Most rock glaciers (~90%) were oriented northwards (N, NE, NW), while only 5% faced southwards (S, SE, SW). The lower limit of permafrost in the Jhelum basin is about 3316 m asl. Furthermore, we estimated the ice storage of rock glaciers in the Jhelum basin at 0.80 ± 0.13 km^3, equivalent to 0.72 ± 0.12 km^3 of water volume. This study enhances our understanding of permafrost distribution and the characteristics and dynamics in the basin. Given their greater resilience to climate change compared to clean glaciers, the hydrological significance of rock glaciers is expected to increase under projected climate change scenarios. This study highlights their importance as a vital water resource amidst the accelerated recession of clean glaciers.

Keywords: rock glaciers; permafrost distribution; ice storage; Kashmir Himalaya; climate resilience

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Original Article

Comprehensive analysis of glacier recession (2000-2020) in the Nun-Kun Group of Glaciers, Northwestern Himalaya

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Abstract: Himalayan glaciers are shrinking rapidly, especially after 2000. Glacier shrinkage, however, shows a differential pattern in space and time, emphasizing the need to monitor and assess glacier changes at a larger scale. In this study, changes of 48 glaciers situated around the twin peaks of the Nun and Kun mountains in the northwestern Himalaya, hereafter referred to as Nun-Kun Group of Glaciers (NKGG), were investigated using Landsat satellite data during 2000-2020. Changes in glacier area, snout position, Equilibrium Line Altitude (ELA), surface thickness and glacier velocity were assessed using remote sensing data supplemented by field observations. The study revealed that the NKGG glaciers have experienced a recession of 4.5%±3.4% and their snouts have retreated at the rate of 6.4±1.6 $m \cdot a^{-1}$. Additionally, there was a 41% increase observed in the debris cover area during the observation period. Using the geodetic approach, an average glacier elevation change of -1.4±0.4 $m \cdot a^{-1}$ was observed between 2000 and 2012. The observed mass loss of the NKGG has resulted in the deceleration of glacier velocity from 27.0±3.7 $m \cdot a^{-1}$ in 2000 to 21.2±2.2 $m \cdot a^{-1}$ in 2020. The ELA has shifted upwards by 83.0±22 m during the period. Glacier morphological and topographic factors showed a strong influence on glacier recession. Furthermore, a higher recession of 12.9%±3.2% was observed in small glaciers, compared to 2.7%±3.1% in larger glaciers. The debris-covered glaciers showed lower shrinkage (2.8%±1.1%) compared to the clean glaciers (9.3%±5%). The glacier depletion recorded in the NKGG during the last two decades, if continued, would severely diminish glacial volume and capacity to store water, thus jeopardizing the sustainability of water resources in the basin.

Keywords: Nun–Kun range; Glacier recession; Glacier snout; Remote Sensing; Himalaya; Glacier velocity

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1 Introduction

Outside the poles, mountain glaciers constitute an important component of the Earth's natural freshwater system (Barry and Gan 2011) with substantial

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Glacier thickness and volume estimation in the Upper Indus Basin using modeling and ground penetrating radar measurements

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Abstract

In the Himalaya, ice thickness data are limited, and field measurements are even scarcer. In this study, we employed the GlabTop model to estimate ice reserves in the Jhelum ($1.9 \pm 0.6\ km^3$) and Drass ($2.9 \pm 0.9\ km^3$) sub-basins of the Upper Indus Basin. Glacier ice thickness in the Jhelum ranged up to 187 ± 56 m with a mean of $\sim 24 \pm 7$ m, while the Drass showed ice thickness up to 202 ± 60 m, with a mean of $\sim 17 \pm 5$ m. Model results were validated using Ground Penetrating Radar measurements across four profiles in the ablation zone of the Kolahoi glacier in the Jhelum and nine profiles across the Machoi glacier in the Drass sub-basin. Despite underestimating ice-thickness by ~10%, the GlabTop model effectively captured glacier ice-thickness and spatial patterns in most of the profile locations where GPR measurements were taken. The validation showed high correlation coefficient of 0.98 and 0.87, low relative bias of $\sim -13\%$ and $\sim -3\%$ and a high Nash–Sutcliffe coefficient of 0.94 and 0.93 for the Kolahoi and Machoi glaciers, respectively, demonstrating the model's effectiveness. These ice-thickness estimates improve our understanding of glacio-hydrological, and glacial hazard processes over the Upper Indus Basin.

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RESEARCH ARTICLE

Explaining the natural and anthropogenic factors driving glacier recession in Kashmir Himalaya, India

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Abstract

Glaciers across the Kashmir Himalayan region are melting at an accelerated pace compared to other regions across the Himalayan arc. This study analyzed the recession patterns of nine glaciers in the Kashmir Himalaya region over 28 years between 1992 and 2020 using satellite images and field measurements. The recession patterns were correlated with debris cover, topographic factors, and ambient black carbon (BC) concentration at glacier sites. HYSPLIT model was used to track the air mass sources at a 7-day time-step from September 1, 2014, to September 28, 2014, over the selected region. All nine glaciers revealed high recession as indicated by changes in the area (average recession: 20.8%) and snout position (~ 14 m a^{-1}). The relative percentage of debris on each glacier varied between ~ 0% (clean glacier) and 43%. Although the investigated glaciers lie in the same climatological regime, their topographical behavior is dissimilar with mean altitude ranging between 4000 and ~ 4700 m asl and the average slope varying from 17 to 24°. All the investigated glaciers are north-facing except G3 (southerly aspect). Our results indicate anomalously high ambient BC concentrations, ranging from 500 to 1364 ng m^{-3}, at the glacier sites, higher than previously studied for glaciers in the Himalayas and neighboring Tibetan Plateau. The backward air-mass trajectory modeling indicated both local and global sources of particulate matter in the study area. A comparative analysis of BC measurements and glacier recession with the studies conducted across high Asia indicated the influence of BC in accelerating the melting of glaciers in the Kashmir region.

Keywords Glacier recession · Kashmir Himalaya · Black carbon · Debris cover · Topography · Trajectory modeling

Introduction

Glaciers across the Himalayan arc have been reported to be in a receding phase (Rashid and Majeed 2018; Hugonnet et al. 2021; Nie et al. 2021; Romshoo et al. 2022a) except for the glaciers in the Karakoram, where stability in glacier mass or even slight mass gain has been reported (Gardelle et al. 2012; Kääb et al. 2012). The glacier recession rates have been reported to be pronounced over Kashmir Himalaya (Rashid et al. 2017a, b; Abdullah et al. 2020; Romshoo et al. 2020a; Majeed et al. 2021a; Murtaza et al. 2021; Rashid et al. 2021) compared to other parts of the Hindu-Kush Karakoram Himalaya (HKH) region (Bhattacharya et al. 2021; Miles et al. 2021). Most of the studies consider climate as the main controlling factor for the glacier recession (Li et al. 2016; Rashid et al. 2017a, b; Tawde et al. 2019; Romshoo et al. 2022b); however, many studies have highlighted the influence of topography (Patel et al. 2018a, b; Remya et al. 2022; Chueca et al. 2007; Pandey and Venkataraman 2013), debris cover (Scherler et al. 2011; Ji et al. 2022), and aerosol deposition (Zeb et al. 2020; Azam et al. 2021; Zheng et al. 2021) on glacier melt. A decrease in the seasonal snowfall has been reported by many studies over the Himalayan arc in response to the warming climate observed over the region in the last couple of decades (Dar et al. 2014; Gusain et al. 2014; Zaz et al. 2019), except for the Karakoram region, where the extremely low temperatures maintain the stability of the glaciers (Kapnick et al. 2014; Romshoo et al. 2022a).

The implications of glacier recession on streamflows in the Himalayas are one of the major concerns (Immerzeel

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Research papers

Direct, geodetic and simulated mass balance studies of the Kolahoi Glacier in the Kashmir Himalaya, India

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ABSTRACT

Knowledge of glacier mass balance (MB) is critical for understanding glacier-climate interactions and projecting future water availability in the data-scarce Himalayan region. In this study, we present the glaciological (2014–2019), geodetic (2000–2014) and reconstructed (1980–2019) MB of the Kolahoi Glacier (KG) in the Kashmir Himalaya, India. During the five-year observation period, the average *in situ* MB of the Glacier was -0.83 ± 0.34 m w.e. a^{-1}, with significant inter-annual variation. The mean annual geodetic MB of the KG between 2000 and 2014 was -0.90 ± 0.09 m w.e. The reconstructed MB revealed four distinct glacier recession episodes since 1980. The Period I (1980–1990) showed a reduced mass loss of -0.27 ± 0.42 m w.e. a^{-1}, with four years of positive mass balance. The Period II (2000–2010), on the other hand, experienced the highest mass loss of -1.18 m w.e. a^{-1} throughout the entire reconstructed MB series. All three MB measurement- in situ, geodetic and simulated agreed well. The MB showed an excellent correspondence with the observed temperature and precipitation. Analysis of the data revealed that the MB is sensitive to temperature at the rate of -0.65 m w. e. a^{-1} °C^{-1}, but the sensitivity is only 0.13 m w.e. a^{-1} for a 10% change in precipitation. Furthermore, there is a good correlation between the simulated glacier mass loss and depleting glacier-melt in the autumn streamflow. The mass loss of the KG is expected to exacerbate in future as a result of the projected climate change, and thus further diminishing the streamflow of the transboundary rivers emanating from the region. It is envisaged that the findings will contribute to a better understanding of glacier-climate interactions and their implications for future water availability in the Kashmir Himalaya.

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Explaining the differential response of glaciers across different mountain ranges in the north-western Himalaya, India

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ABSTRACT

The study investigated a group of 65 glaciers, selected from different mountain ranges in the north-western Himalaya, India to understand and explain their status and response to the changing climate, surface topography and glacier morphology. Two-date Landsat satellite images (1990 and 2014), ICESat altimetry data, HMA DEM and SRTM DEM were used to estimate the changes in glacier area, snout position, Equilibrium Line Altitude (ELA), glacier thickness and volume. The total area of the glaciers under consideration across the five ranges shrunk from 1106 ± 33.6 km^2 in 1990 to 1073 ± 24.6 km^2 in 2014 with the consequent reduction in the glacier volume from 219 ± 6.66 km^3 in 1990 to 211 ± 4.85 km^3 in 2014, a loss of 5.9 ± 0.09 Gt during 24-year observation period. Upward shift in ELA, ranging from 18 ± 17 m to 64 ± 17 m, was observed during the observation period. The glaciers across the study area are losing thickness in the range of −0.59 ± 0.22–1.18 ± 0.40 m a^{-1}. The study revealed that the glaciers situated at altitudes <4500 m have witnessed higher glacier area loss (8.25 ± 1.3%) compared to those situated at altitudes >6000 m (2.72 ± 0.92%). The influence of size on glacier loss is indicated by the higher shrinkage observed for the glaciers <3 km^2 in size (6.75 ± 1.63%) compared to the lower shrinkage of 2.17 ± 1.12% observed for the large-size glaciers (>30 km^2). Significant differences in the glacier response were observed across the five ranges due to the unique topographic and climatic setting endemic to a particular mountain range.

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The satellite observed glacier mass changes over the Upper Indus Basin during 2000–2012

Tariq Abdullah, Shakil Ahmad Romshoo ✉ & Irfan Rashid

Decadal glacier thickness changes over the Upper Indus Basin in the Jammu and Kashmir Himalaya were estimated using the TanDEM-X and SRTM-C Digital Elevation Models (DEMs) from 2000 to 2012. In the study area 12,243 glaciers having 19,727 ± 1,054 km^2 area have thinned on an average of − 0.35 ± 0.33 m a^{-1} during the observation period. The highest thinning of − 1.69 ± 0.60 m a^{-1} was observed in the Pir Panjal while as the marginal thinning of − 0.11 ± 0.32 m a^{-1} was observed for the glaciers in the Karakoram. The observed glacier thickness changes indicated a strong influence of the topographic parameters. Higher thickness reduction was observed on the glaciers situated at lower altitudes (− 1.40 ± 0.53 m a^{-1}) and with shallower slopes (− 1.52 ± 0.40 m a^{-1}). Significantly higher negative thickness changes were observed from the glaciers situated on the southern slopes (− 0.55 ± 0.37 m a^{-1}). The thickness loss was higher on the debris-covered glaciers (− 0.50 ± 0.38 m a^{-1}) than on the clean glaciers (− 0.32 ± 0.33 m a^{-1}). The cumulative glacier mass loss of − 70.32 ± 66.69 Gt was observed during the observation period, which, if continued, would significantly affect the sustainability of water resources in the basin.

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Towards understanding various influences on mass balance of the Hoksar Glacier in the Upper Indus Basin using observations

Shakil Ahmad Romshoo✉, Khalid Omar Murtaza & Tariq Abdullah

Mass balance is a good indicator of glacier health and sensitivity to climate change. The debris-covered Hoksar Glacier (HG) in the Upper Indus Basin (UIB) was studied using direct and geodetic mass balances. During the 5-year period from 2013 to 2018, the glacier's mean in situ mass balance (MB) was -0.95 ± 0.39 m w.e. a^{-1}. Similarly, the glacier's mean geodetic MB from 2000 to 2012 was -1.20 ± 0.35 m w.e. a^{-1}. The continuously negative MB observations indicated that the HG is losing mass at a higher rate than several other Himalayan glaciers. The glacier showed increased mass loss with increasing altitude, in contrast to the typical decreasing MB with increasing elevation, due to the existence of thick debris cover in the ablation zone, which thins out regularly towards the accumulation zone. Rising temperatures, depleting snowfall and increasing black carbon concentration in the region, indicators of climatic change, have all contributed to the increased mass loss of the HG. During the lean period, when glacier melt contributes significantly to streamflow, the mass loss of glaciers has had a considerable impact on streamflow. Water availability for food, energy, and other essential economic sectors would be adversely affected, if, glaciers in the region continued to lose mass due to climatic change. However, long-term MB and hydro-meteorological observations are required to gain a better understanding of glacier recession in the region as climate changes in the UIB.

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Surge of Hispar Glacier, Pakistan, between 2013 and 2017 detected from remote sensing observations

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A B S T R A C T

This study analyses the behaviour of an actively surging glacier, Hispar, in Pakistan using remote sensing methods. We used 15 m panchromatic band of Landsat 8 OLI from 2013 to 2017 to assess the changes in glacier velocity, glacier geomorphology and supraglacial water bodies. For the velocity estimation, correlation image analysis (CIAS) was used, which is based on normalized cross-correlation (NCC) of satellite data. On-screen digitization was employed to quantify changes in the glacier geomorphology and dynamics of supraglacial water bodies on the glacier. Our velocity estimates indicate that the upper part of the glacier is presently undergoing an active surge which not only affects the debris distribution but also impacts the development of supraglacial water bodies. Velocities in the actively surging part of the main glacier trunk and its three tributaries reach up to ~900 m yr^{-1}. The surge of Hispar also impacts the distribution of supraglacial debris causing folding of the medial moraines features present on the glacier surface. Changes in the number and size of supraglacial lakes and ponds were also observed during the observation period from 2013 to 2017.