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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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1. Introduction

Snow and glaciers are crucial sources of perennial freshwater [1] for mountain communities worldwide [2,3], especially in dry regions and during dry seasons [2,4–6]. High-mountain Asia (HMA), with its numerous glaciers, provides vital freshwater that supports billions of people downstream [7]. Existing glacier studies suggest a rapid retreat of mountain glaciers worldwide [8], largely attributed to anthropogenic activities [9,10]. Over the Himalayan region, enhanced glacier melting with a large intra-regional variation has been reported [11,12]. Recently, Romshoo et al. [13] found that glaciers in the Kashmir Himalaya are retreating faster than those in nearby regions like Nanga Parbat [5], Zanaskar [14], and Ladakh [15,16]. The ongoing retreat and mass loss of glaciers worldwide, especially in HMA, is projected to continue throughout the twenty-first century [9,17,18], posing serious risks to food, water, and energy security [19,20]. Mountain glaciers, excluding those in the Antarctic, are projected to lose about 64% of their volume by the end of the 21st century under the RCP 8.5 emission scenario [21,22], with regions such as Central Europe, Caucasus, Southern Andes, and HMA expected to experience mass losses exceeding 75%. HMA is projected to experience a significant mass loss of ~36% by the end of the 21st century, even if global warming is limited to 1.5 °C above pre-industrial levels [23]. In the short-term, glacier recession leads to increased streamflow; however, once the 'tipping point' is reached,