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RESEARCH ARTICLE

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

Irfan Rashid[1] · Tariq Abdullah[1] · Shakil Ahmad Romshoo[1,2]

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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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✉ Irfan Rashid
irfangis@kashmiruniversity.ac.in; irfangis@gmail.com

[1] Department of Geoinformatics, University of Kashmir, Hazratbal, Srinagar 190006, India

[2] Islamic University of Science and Technology, 1-University Avenue Awantipora, Pulwama 192122, India