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Glacial-geomorphic study of the Thajwas glacier valley, Kashmir Himalayas, India

Reyaz Ahmad Dar, Omar Jaan, Khalid Omar Murtaza, Shakil Ahmad Romshoo*

Department of Earth Sciences, University of Kashmir, Srinagar, 190006, India

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ABSTRACT

Glacial-geomorphic studies provide vital information to make inferences about the effect of glacial advance and retreat on the geomorphology of an area. In the present study, glacial-geomorphic landforms of the Thajwas glacial valley in the upper reaches of the Indus, Kashmir Himalayas were mapped using geospatial technology validated with GPS-based field observations and ground photography. The glacial-geomorphic landforms were digitized using ASTER DEM (30 m resolution), Landsat ETM+ satellite imagery (30 m resolution) and Google Earth (1 m resolution) data. Results showed that Google Earth imagery, supported by field validation, is very useful for the interpretation of glacial-geomorphic landscapes and relief features at micro- and meso-scales. However, morphometric characteristics of landforms are best obtained using DEM overlaid onto the Landsat ETM+ satellite data. Glaciers in the valley are presently confined along the south and southwestern slopes. However, the significant role played by glaciers in shaping the geomorphic landforms and their subsequent preservation within the scenic landscape under the Late Quaternary climatic conditions are remarkably evident. The glacial-geomorphic landforms, especially terminal moraine, glacial trough and cirques observed in the valley aided the reconstruction of palaeo-glacial setting of the area. Morphology, shape and location of terminal and lateral moraine ridges were used to establish the palaeo-glacial extents, glacial volume and the number of glacial advances of the Thajwas glacier. The maximum elevation of the lateral moraines was used to define the former Equilibrium-Line Altitude (ELA). The greater rock excavation to form a large valley during the last glacial maximum might have induced isostatic rock uplift/exhumation in the glacier source area. It is observed that the concomitant retreat of the north-facing glacial cirques has played an important role in expanding the glacial valley and limiting the topographic relief.

1. Introduction

The morphological evolution of mountain belts reflects the interplay between tectonics, surface processes and climate (Ramírez-Herrera, 1998; Newnham et al., 1999; Bishop et al., 2003; Seong et al., 2009b; Dar et al., 2014a,b; Joshi and Kotlia, 2014). Numerous studies reveal that glacial processes play an important role in the development of mountain topography irrespective of the rate of tectonic uplift (Raymo et al., 1988; Molnar and England, 1990; Montgomery, 1994; Burbank et al., 1996; Brozović et al., 1997; Whipple and Tucker, 1999; Dumont et al., 2005; Necea et al., 2005; Koppes and Montgomery, 2009; Pérez-Peña et al., 2009). During the movement of glaciers, some important erosional and depositional landforms are formed which serve as a valuable evidence of the past glacial dynamics (Akçar et al., 2007; Persson, 2012; Goswami et al., 2013; Ruszkiczay-Rüdiger et al., 2016). Identification and mapping of such glacial-geomorphic landforms can provide an assessment of the role of glaciation and climate forcing on the landscape evolution of mountainous areas (Porter, 1989; Bishop et al., 2002; Brocklehurst and Whipple, 2002; Seong et al., 2007, 2009b; Fu et al., 2012; Zasadni, 2012; Dar et al., 2014a,b). Besides, the paleo-glacial topography is useful in determining the total ice volume, the thickness distribution and the palaeo Equilibrium Line Altitude (Rodríguez-Rodríguez et al., 2015; Owen and Benn, 2005). Glacial landform mapping is usually done using remote sensing data, global positioning system (GPS), digital elevation models (DEMs) supported by field validations (Clark, 1997; Bolch et al., 2005; Dunlop and Clark, 2006; Smith et al., 2006; Seong et al., 2008; Lytwyn, 2010; Dar et al., 2013a; Kuhlemann et al., 2013; Fu et al., 2012).

* Corresponding author.
E-mail address: shakilrom@kashmiruniversity.ac.in (S.A. Romshoo).

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The Kashmir Himalayas exhibit complex topography and an intricate interplay of surface processes that provides a good opportunity to examine the relationship between glaciation and landscape evolution. The majority of glaciers in the region are valley type delimited by topography and are the most distinctive relief forming agents in the high mountains. The evidence of glacial advance is found preserved in the upper reaches of the Pir Panjal range (Grinlinton, 1928) and the Great Himalayan mountain ranges bordering the Kashmir Valley (Rashid et al., 2017). However, presently the Greater Himalayan slopes of the valley exhibit widespread and more significant glaciation as compared to the Pir Panjal slopes (Rashid et al., 2017). The important glaciers existing on the Great Himalayan flank of the Kashmir Valley are Kolahoi, the largest glacier in the Kashmir Himalayas, Haramukh, Panjtarni, Machoi, Shieshnag and Thajwas. Sediments and landforms associated with glaciation, such as moraines, cirques, glacial-fluvial outwash, drumlins, and melt-water channels, etc., are well preserved in most of the above mentioned glacial valleys which provide valuable insights for inferring past glacial dynamics. However, despite the importance of the region for palaeo-glacial and palaeo-climatic studies, relatively very little work has been carried out on the Late Quaternary glacial history. Although some workers have previously documented the glacial history of the Kashmir Valley (Dianelli, 1922; De Terra and Paterson, 1939; Holmes and Street-Perrott, 1988; Holmes and Street-Perrott, 1989), however, none of these studies have used a systematic analysis of landforms to define the major glacial advances and the consequent glacial-geomorphic evolution of the Kashmir Valley. Studies carried out in the Kashmir Himalayas suggest that the boat shaped Kashmir Valley owes its origin to the Himalayan tectonic activity which resulted in the changes in drainage and the climatic conditions. Due to the rise of the Pir Panjal range, the ancient drainage was impounded in the form of a lake known as Karewa Lake in which the sediments, currently exposed, were deposited. These sediments, known as Karewas, preserve the record of the tectonic and climatic changes witnessed by the Kashmir valley during the last 4 million years (Burbank and Johnson, 1983; Kotlia, 1985a,b; Agrawal et al., 1985, 1988, 1989; Bronger et al., 1987; Kotlia and Mathur, 1992; Basavaiah et al., 2010; Dar et al., 2013a, 2014a, 2014b; Kotlia, 2013).

In this study, we mapped the glacial geomorphology of the Thajwas glacier valley on the Great Himalayan flank of the Kashmir Valley (Fig. 1), using high resolution remote sensing data at various spatial scales supplemented by detailed field observations, to examine the role of Late Quaternary glaciation in the landscape evolution of the basin. Glacial-geomorphic mapping has been previously tested as an important evidence for knowing the extent and role of glaciations on the geomorphic evolution of the mountainous basins worldwide (Taylor and Mitchell, 2000; Rippin et al., 2003; Palacios et al., 2011; Stroeven et al., 2013; Blomdin et al., 2014). By tracing the past extents of the existing glaciers, changes in the area and volume, ELA depression, glacial valley width, cirque development and moraine morphology, etc., the palaeo-glaciology and palaeo-climate of a region can be reconstructed (Small and Anderson, 1998; Porter et al., 2001; Montgomery and Brandon, 2002; Lachniet and Vazquez-Selem, 2005; Owen and Benn, 2005; Blomdin et al., 2014). Taking advantage of the geospatial technology, we mapped various glacial erosional and depositional landforms at various spatial scales that provided important information and insights into the Late Quaternary climatic conditions of the Thajwas valley.

The study area receives significant amount of precipitation (mostly snow) during winter brought about by the western disturbances (WDs) as opposed to the southwestern monsoons prevalent in most of the Central and Eastern Himalayas. The WDs are most active during the winter and spring seasons and decrease substantially as summer progresses (Dar et al., 2014a,b). Snow- and ice-melt predominantly contributes to the streamflows in the region. Recent studies suggest that glaciers in the Kashmir Himalayas are depleting at varying rates (Romshoo and Rashid, 2010; Dar et al., 2013b; Bahuguna et al., 2014; Murtaza and Romshoo, 2016; Rashid et al., 2017) and the recession is mainly attributed to the recent warming observed in the region (Romshoo et al., 2015). Panjal Volcanics are the main bedrock lithological formations characterized by quartz veins, joints and fractures in the study area. These rock formations are intercalated with pyroclastic material and intertrappean beds. The Panjal Volcanics consist mostly of basaltic rocks with minor basaltic-andesites, rhyolites and dacites (Shellnutt et al., 2012; Stojanovic et al., 2016).

2. Materials and methods

The study makes comparative use of the satellite data with

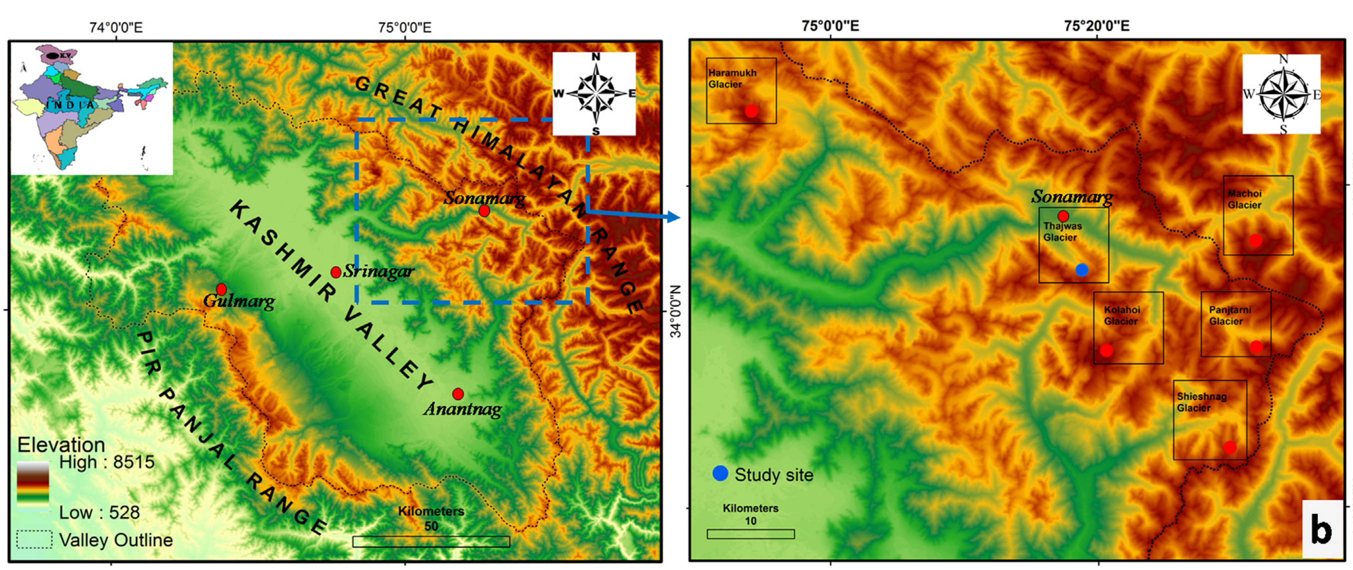

Fig. 1. Map of the study area (a) shaded relief map of the Kashmir Valley and (b) the location of the Thajwas glacier and other important glaciers on the Great Himalayan flank of the Kashmir Valley.