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Full length Article

The recent deglaciation of Kolahoi valley in Kashmir Himalaya, India in response to the changing climate

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ABSTRACT

In the present study, the retreat of Kolahoi glacier was mapped from the satellite observations and historical maps supplemented by the extensive field observations to understand the recent deglaciation of the Kolahoi valley, Kashmir Himalaya, India. The glacier has retreated by 2.85 km during the last 157 years from 1857 to 2014 with an average retreat of about 18.2 m $year^{-1}$; however, the glacier snout has shown higher recession during the last decade. The geomorphological evidence reveals glaciation of the Kolahoi valley during the Quaternary. These evidences include glacial till at Pahalgam and Aru besides terminal and lateral moraines at Lidderwat, Satlanjan and Kolahoi Gunj in the Kolahoi valley. The glacier has shrunk by 2.81 km^2 during the last 51 years (1962–2013) losing an ice volume of 0.30 km^3. The observed glacier changes were correlated with the climate data from PMIP3-CMIP5 models. The temperatures are predicted to increase almost ten times more than that observed during the Last Glacial Maximum (LGM). The future temperature is predicted to rise between 0.18 °C and 0.61 °C per decade under RCP 2.6 and RCP 8.5 respectively. The projected rise in the temperature, if realized, will have an adverse effect on the glaciers and would, in all likelihood, adversely affect the water availability for various sectors in the region.

1. Introduction

The indicators of climate change are very evident over Himalaya (Beniston, 2003; Kang et al., 2010; Romshoo et al., 2011; Wang and Chen, 2014) and these changes have exacerbated glacier recession (Akhtar et al., 2008; Immerzeel et al., 2010; Romshoo et al., 2015). It, therefore, becomes imperative to understand the magnitude of the climatic changes and how these changes influence the cryospheric and hydrological processes in the region. Recent studies have demonstrated that the glacier cover in the Kashmir Himalaya, India is declining at an increasing rate compared to other parts of the Hindu Kush Himalaya (HKH) (Kääb et al., 2012; Murtaza and Romshoo, 2016). Hence, it is very obvious that the Himalaya may lose the glacier cover in response to the climate change which will have serious impacts on the regional hydrology (Barnett et al., 2005; Cogley, 2011; Nepal et al., 2014). However, some studies suggest that Himalayan glaciers, especially in the Karakorum region, are stable (Bahuguna et al., 2014; Ganjoo and Koul, 2013; Raina, 2009). The past glaciological, climatological and hydrological studies in the Himalaya have focused, on spatio-temporal changes in glacial extents (Frey et al., 2012; Kääb et al., 2014), mass balance (Berthier et al., 2007; Brahmbhatt et al., 2012), snow cover dynamics (Hall, 2012; Rittger et al., 2013), hydrological modelling (Naz et al., 2014; Nepal et al., 2014), climate change impacts (Hock, 2014; Sorg et al., 2012) and anthropogenic activities (Ginot et al., 2014; Kaspari et al., 2014; Ming et al., 2009). Despite the vulnerability of Kashmir Himalayan glaciers to the environmental changes, very few glaciological studies have been carried out to understand the glacier recession in the region.

Mapping the glacio-geomorphological features is vital for assessing the historical glacier extents, fluctuations and glacial controls on landscape development in montane systems (Barnard et al., 2004; Hughes et al., 2005; Kamp et al., 2004; Owen et al., 2006). These features provide valuable information about the past glacial extents (Owen et al., 2002; Zawiska et al., 2015). Earlier efforts to map glaciogeomorphology in the Himalayan region were mostly restricted to small-scale field surveys that include the notable studies of Dainelli (1924–1935), Norin (1925), Klute (1930), Trinkler (1930), De Terra and Paterson (1939) and Holmes and Street-Perrott (1989). Most of the glaciological studies carried out so far in Kashmir Himalaya are restricted to mapping and understanding the short term dynamics of glaciers (Bolch et al. 2012; Romshoo et al., 2015) with a little emphasis on glacial geo-

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morphology. As such, the timing and extent of past glacier fluctuations are crudely documented in the region (Lee et al., 2014; Mitchell et al., 1999; Owen and Dortch, 2014; Sharma and Owen, 1996). The utility of high resolution remote sensing data together with the field observations for glacio-geomorphological mapping has been well documented (Sati et al., 2014; Schneevoigt et al., 2008; Smith and Pain, 2009). Remotely sensed data together with Digital Elevation Models (DEM) are helpful in mapping geomorphological features of deglaciated valleys (Jansson and Glasser, 2005; Rose et al., 2013; Stokes and Clark, 2003).

The climatological studies on Himalayan glaciers indicate a decrease in the seasonal snowfall possibly as a consequence of warming observed in the region over the last few decades (Ren et al., 2006; Wiltshire, 2014), except in the Karakoram range where the extremely low temperatures are responsible for the stability of glaciers (Kapnick et al., 2014). One of the major concerns pertaining to the glacier recession in the Kashmir Himalaya is the impact of changing climate on the streamflows (Bhutiyani et al., 2008; Immerzeel et al., 2012; Miller et al., 2012; Romshoo, 2012). The melt waters from the Kashmir Himalayan glaciers are source to the headwaters of Indus river and support agriculture, tourism and energy generation, the backbone of the economy downstream in the basin. It is, therefore, very important to analyse and understand the causes and consequences of the past and future changes in the alpine cryosphere so that a robust strategy is developed to sustain and conserve the depleting water resources in the region.

In this study, we mapped the glacial geomorphology of Kolahoi valley, Kashmir using high resolution remotely sensed data, historical maps and field observations. We also looked into the past and future climate regimes over the region; assessed the spatio-temporal changes of Kolahoi glacier since 1857 and corroborated the observed glacier changes with the climate data to draw a few valid inferences about the changing cryosphere in the region.

2. Data sources and methods

2.1. Study area

The study is focused on Kolahoi valley (Fig.1), which is situated in Himalayan mountain system of Kashmir with the altitude ranging from 2102 to 5141 m a.m.s.l. The valley is spread over an area of about 405 km^2 and lies between the geographical coordinates 34°00′–34°15′N latitude and 75°06′–75°24′E longitude. The area has a unique geomorphic and climatic setting making it a suitable niche, for 26 glaciers including the largest glacier in the Kashmir valley, the Kolahoi glacier (Odell, 1963). It is pertinent to mention here that the snout of Kolahoi glacier is covered by a thin layer of debris (Shukla and Ali, 2016). One of the biggest tributaries of Jhelum river, Lidder, originates from the Kolahoi glacier (Rashid and Romshoo, 2013). The valley has a typical temperate climate with four seasons; spring, summer, autumn and winter. The area receives precipitation both in the form of rain and snow. The mean annual precipitation recorded at the nearest India Meteorological Department (IMD) station, Pahalgam (2150 m a.m.s.l.), is 1240 mm. The area receives highest precipitation during winter and spring while summers and autumns are usually drier. The long-term average minimum temperature during the coldest month, January, is −6.85 °C. The average maximum temperature of the hottest month, July, can shoot up to 25 °C. However, the maximum temperature can rise above 30 °C during summer and the minimum temperature can drop below −18 °C during winter.

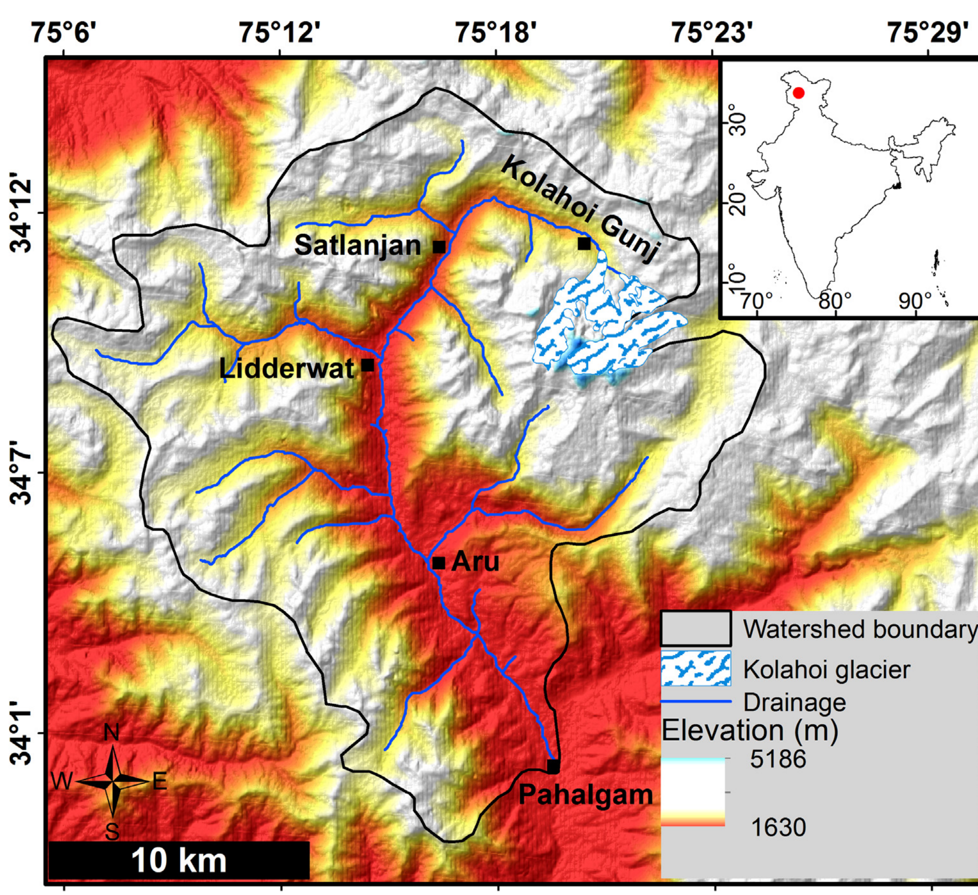

Fig. 1. Location map of the study area.