Earth Syst Environ (2017) 1:1
DOI 10.1007/s41748-017-0001-2

ORIGINAL ARTICLE

Remote Sensing-Based Study for Evaluating the Changes in Glacial Area: A Case Study from Himachal Pradesh, India

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Received: 2 November 2016 / Accepted: 19 March 2017 / Published online: 30 March 2017

Abstract
Purpose Glaciers influence a variety of natural systems in the environment and act as a key source of freshwater worldwide. Remote sensing satellite data has proved to be important tool for defining the glacier inventory and retreating pattern of a glacial region.
Methods An attempt has been made to investigate changes in glacial area of five selected glaciers i.e. Bara shigri, Chota shigri, Hamtah, G4 and Parvati glacier in Himanchal Pradesh from 1976 to 2013 through the LANDSAT data of MSS (1976), TM (1989 and 2009), ETM+ (2001) and OLI-TIRS (2013) whereas ASTER-DEM data was used for relief information. Glacier snout positions were demarcated by identifying glacier features such as the origin of the stream from the terminus, supraglacial lakes, and disposition of end moraines. The uncertainty (U) was calculated for multi-temporal measures of the glacier front position using these images.
Results Amongst the selected five glaciers in which snout could be demarcated accurately for all the datasets, three glaciers experienced very nominal retreat of their terminus; the maximum retreat (6.63 m) was calculated in the case of G4 glacier while Humtah glacier exhibited advancement in 37 years. However, Bara shigri glacier experienced a retreat of 1.50 m. The study shows that the glacial covered area reduced from 154.58 to 123.39 km^2 indicating 20.17% deglaciation during the period from 1976 to 2013.
Conclusion The outcome of this study may obligatory to monitor spatio-temporal changes in glaciers and their conservation towards the sustainable management of water resources in Himalayan river watersheds.

Keywords Glacier · Retreat · Inventory · Landsat · ASTER-DEM · Remote sensing

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1 Introduction

Glaciers are not only a dynamic component in energy and mass exchange within the earth's atmosphere, but also natural freshwater reservoirs. It contributes in the global water cycle and is an essential component of the water balance (IPCC 2007). The present study covers a part of the Himalayan region. Himalayas connotes 'abode of snow' in 'Sanskrit texts' and snow in the world after Antarctica and Arctic. It encompasses a large number of glaciers. It is assumed that about 15,000 glaciers are located throughout its ranges which normally fall in remote inaccessible parts of the mountainous terrain. The research of glacier melting is important for studies of sea level changes that also may have a significant risk for the residents of coastal areas.

That is one of the most negative impacts of modern climatic change on mankind. The above mentioned facts put into agenda the necessity for detailed study of the glaciers (Kordzakhia et al. 2015). The Himalayan glaciers are valuable national as well as global assets and act as main reservoir of snow and ice pouring almost all major and minor rivers of north India and their conservation are helpful to the sustainable development of fresh water resources in Himalayan region. Besides, the Himalayan glaciers respond directly and promptly to the atmospheric conditions (Favier et al. 2004; Thayyen and Dimri 2014). It has been established that the regional meteorological conditions have a bearing on the hydrological features associated with these glaciers (Bollasina et al. 2002).

Majority of Himalayan glaciers are valley type and controlled by topography (Bahuguna 2003) and a major source of fresh water, and all the rivers in northern India are sustained by melted waters of these glaciers, thereby affecting the quality of life of millions of people (Vohra 2006). There are around 9575 glaciers present in the Indian administered part of the Himalaya (Sangewar and Shukla 2009) covering an area of approximately 37,466 km^2 (Raina and Srivastava 2008).

Glaciological inventory have been proved as an important tool in revealing the advancement and retreating of glacier. Changes in the regimen of glaciers give clue in determining the state of advancement, recession and/or stagnation (Thayyen and Dimri 2014). The glaciers retreat has been significant since the mid of the nineteenth century (Hastenrath 1995; Kaser 1999); therefore, glaciers have more recently become the subject of intensive observation.

The Himalayan glaciers have also allured researchers who used different methodologies to unveil its different aspects particularly retreating phenomena. The International Panel of Climate Change (IPCC 2007) stated that 'Himalayan glaciers are shrinking faster than any other parts of the world'. The statement created reverberations of different tones in the scientific communities; some were in its favor, where as some opined different views.

Several researches in the Himalayan area found that the glaciers have melted considerably during the last two decades (Ageta et al. 2001; Fujita et al. 1997; Kadota et al. 2000; Naithani et al. 2001). Several analyses have shown that it is not only increased temperature and/or decreased precipitation that are responsible for recession of glaciers in lower latitudes, but also changes in humidity (Hastenrath and Kruss 1992; Kaser and Noggler 1991; Kaser et al. 1996; Kaser and Georges 1997; Kaser 1999; Wagnon et al. 1999).

Besides, a numbers of studies using satellite data were made by Bhambri et al. (2011, 2012), Dozier and Hall (1987), Kulkarni et al. (2002, 2004, 2005, 2007, 2011), Kordzakhia et al. (2015), Pandey et al. (2012) and Rai et al. (2009, 2013, 2016). It was showed that the best method for analysis of glaciers is application of combined approach of satellite remote sensing with terrestrial observations and expert knowledge of separate glaciers.

Most of the studies on shrinkage of glacier area in Himalaya are related to climatic variations (Bhutiyani 1999; Bhutiyani et al. 2008; Hasnain 2008; Kulkarni and Bahuguna 2002; Kulkarni et al. 2007). Recession also leads to volume loss in glaciers and increase sea level water rises (Dobhal et al. 2004). Kulkarni et al. (2011) have assessed glacial retreat for 1868 glaciers in 11 basins of Indian Himalaya since 1962 and presented a total deglaciation of about 16%. A detailed study through mapping of Chota shigri, Patsio and Samudra Tapu glaciers in Chenab basin, Parbati glacier in Parbati basin and Shaune Garang glacier in Baspa basin has reported an overall deglaciation of 21% from 1962 to 2001 (Kulkarni et al. 2007). Cruz et al. (2007) have previously studied on two adjacent glaciers of Chandra basin i.e. Bara shigri and Chota shigri and found that these glaciers retreated about 36.1 and 6.7 m/year during 1986–1995 and 1977–1995, respectively.

Since freshwater is vital for human society, there is a critical relationship between the fate of glaciers and sustainability of water resources. Therefore, mapping of Himalayan glaciers is very significant to conservation and sustainable management of water resource. In the present study, an attempt has been made to analyses the changes in area of five selected glaciers during the period 1976–2013 by earth observation data.

2 Study Area

The study area is located in Lahul and Spiti district of Himachal Pradesh in India covering an area of 3944.46 km^2 (Fig. 1). The area also covers a small portion of Kullu and Kinnaur district of the state. It ranges from the Shivalik hills in the south to the Greater Himalayan ranges in the north. Geographically the area is situated between 31°44′8.971″N to 32°27′42.191″N latitude and 77°7′32.103″E to 78°1′4.625″E longitude and its altitude varying between 1081 and 6582 m in the central Himalayan ranges of Lahul and Spiti. Geographically the region relates to the warm temperature zone of Mediterranean region, but the high Himalayan mountains range and southwest monsoon act a key role in changing the climate from time to time. Slightly, rainfall on the glacier surface and heat from bedrock also adds to melting from the glaciated zone (Rizvi 1987; Upadhyay et al. 1989). This area also experience rainfall in summer season due to Asian monsoon in the months from July to September and in lesser amount in winter, i.e., from January to April.

Five selected glaciers-Chota sigri, Bara sigri, Hamtah, G4 and Paravati were selected for the study. These glaciers

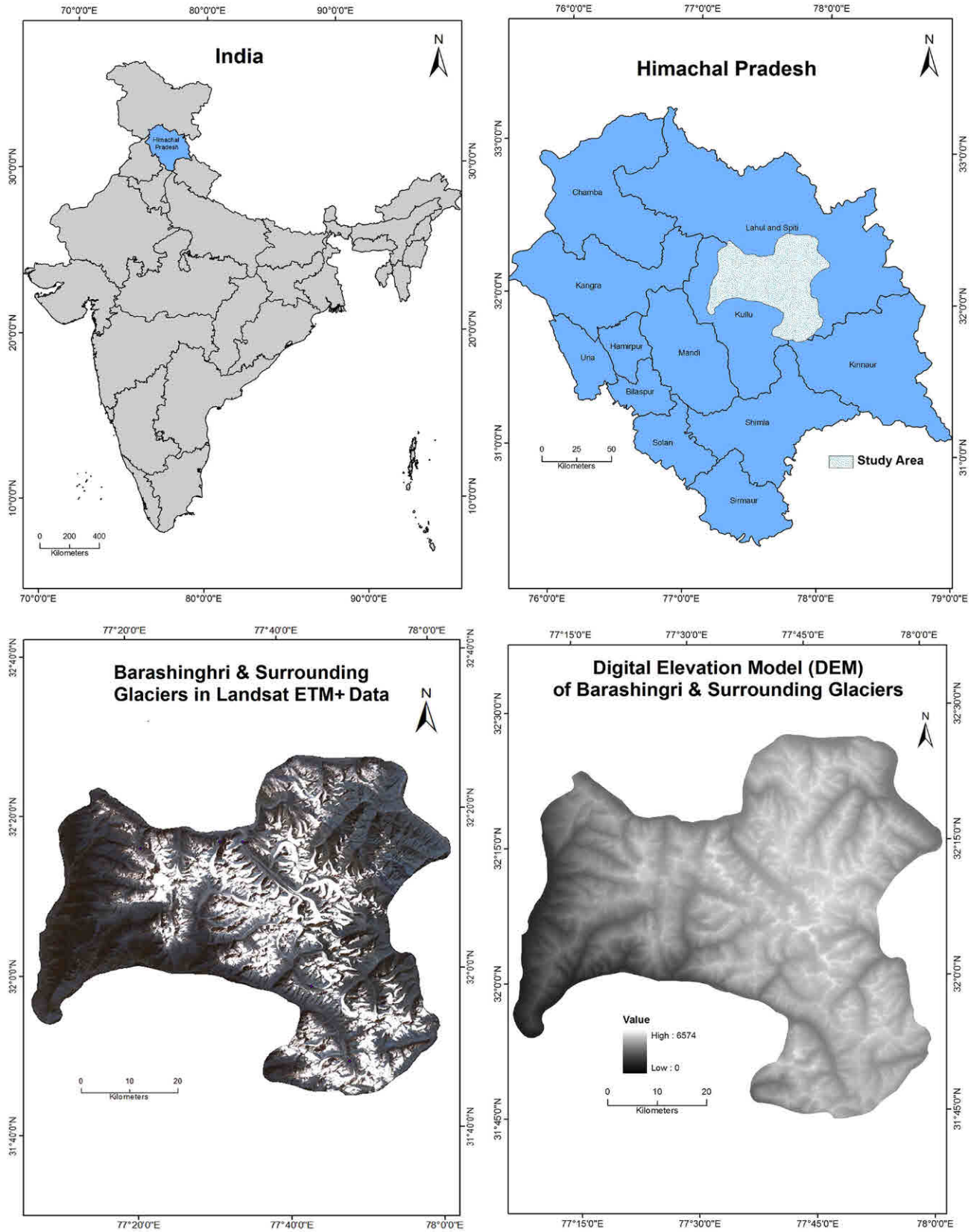

Fig. 1 Study area as viewed on Landsat ETM+ data and ASTER-DEM