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Research Article

Decadal Change in Glacier Area in the Chorabari Sub Watershed

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Abstract This area looks at glacier area change in Chorabari Sub Watershed for 1962-1990 and 2000-2016 periods. Study area of Chorabari Sub Watershed extends between the latitudes of 28º-31ºN to longitudes 77º-81°E. Chorabari Sub Watershed is the part of Mandakini basin and it has total number of 40 glaciers covered an area of 81.64 km^2 with the ice reserve of 5.9856 km^2. The reduction in the glacier area has been observed on the lateral side of Chorabari glacier and not on the snout position. Overall reduction in the basin glacier area was observed 1.23 km^2 during the year 1990 to 2016. In addition, this paper describes a method for estimating the ice surface elevation changes using the SRTM (2000) and elevation data generated from topographic maps (1962) to quantify the ice thickness change for the 1962-2000 periods.
Keywords *Glacier; Ice thickness; Moraine-dammed lakes; Sub-watershed*

1. Introduction

Himalayan glaciers are the major source of water as it lies over almost 6000 glaciers and occupied by an aerial extent of 20000 km^2. They can affect the supply of water to a large number of people in the Indian subcontinent. This is almost half of the glacier-covered area in the region and it suggests that the glaciers are losing an average 0.4% area per year (Bolch et al., 2010, 2012; Yong et al., 2010; Bhambri et al., 2011; Kulkarni et al., 2011; Bahuguna et al., 2007). In the other side the variation of glaciers are uncontrolled and they can be the major risk prone zone for various types of calamities especially in the context of climate change scenario. Most of these studies related to glacier retreat in Himalaya are attributed to climatic variations or global warming (Bhutiyani, 1999; Kulkarni et al., 2002a, 2005; Kulkarni et al., 2007; Bhutiyani et al., 2008; Hasnain, 2008). Glaciological studies carried out by various researchers in the Himalayas suggest that many of the glaciers are in a state of retreat due to climate forcing (IPCC report 2010).

The Himalayan region is one of the most vulnerable and complex region. Recent climate changes patterns have had significant impact on high-mountain glacial environment. This region has the past of natural devastations i.e. various landslides and flash flood in the past. The earlier studies enlightens that the formation and expansion of moraine-dammed lakes, creating a potential danger from dammed lake outburst floods are the result of rapid melting of snow/ice and heavy rainfall (Dobhal et al., 2013).

The aim of this paper is to identify the general trends of glacier area change using change - detection method based on multi-temporal satellite data for 1976-2014 time intervals. We used NDSI image differencing and change vector analysis methods.

1.1. Study Area

The study area is the part of Mandakini river basin. The Study area lies between the latitudes of 28º-31ºN to longitudes 77º-81°E. The upper part of the sub-watershed is covered by two glaciers i.e. Chorabari and Companion glacier shown in Figure.1. The Chorabari glacier is the major glacier and origin of Mandakini River. Total area of Chorabari glacier is around 4.23 km^2, and length of the glacier is 7 km approx. Companion glacier covered around 3.59 km^2 and length of this glacier is around 5.79 km. Thickness of the glacier is around 30 meters (98ft) to 75 meters (246ft), terminus of the Chorabari glacier is Chorabari Tal. The study area lies between 53N and 53J SOI sheets.

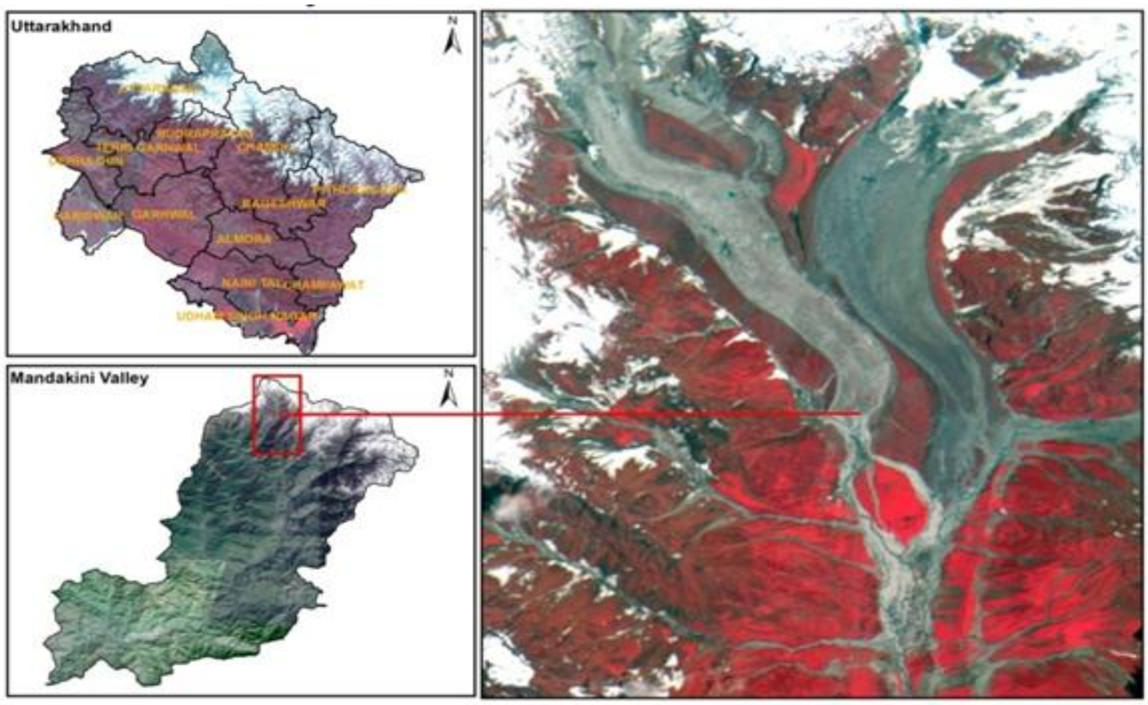


Figure 1: *Study area locating Chorabari sub-watershed in Uttarakhand Himalaya, India*

1.2. Physiography of the Mandakini River Basin

The Mandakini River basin lies between latitude 300 15'N and 300 45'N and longitude 780 48'E and 790 20' E, comprising an area of 2250 km^2. The elevation in the basin ranges from 640 to 6940 m asl. Mandakini is the main river of the Mandakini valley, which is a major tributary of Alaknanda River and originates from the Chorabari Glacier, located just 2 km upstream from Shri Kedarnath shrine. The major tributary of this river is Madhyamaheshwar, whereas smaller tributaries include Laster Gad, Helaun Gad, Kakra Gad, Kyunja Gad, Kyar Gad, Ghasta Gad, Markanda Ganga, Kali Ganga and Vasuki Ganga. The valley has complex topography having high mountain chains with glacierised basin in the north and fluvial terraces in the central and lower parts. The Chorabari and Companion are two largest glaciers besides a few other small glaciers. The area has a couple of high altitude lakes which are directly fed by snow/ ice melt and rain water.

1.3. Geology of the Region

The upper part of the sub-watershed is covered by two glaciers i.e. Chorabari and Companion glacier besides a few other small glaciers including ice apron, hanging glaciers, Glacierete and cirque glaciers. The Chorabari glacier is the major glacier and origin of Mandakini River. Total area of Chorabari glacier is around 4.23 km^2, and length of the glacier is 7 km approx. Companion glacier covered around 3.59 km^2 and length of this glacier is around 5.79 km. The area has a couple of high altitude lakes which are directly fed by snow/ ice melt and rain water. Geomorphologically this area comes under valley glaciers and highly dissected hills and valley with moraines and piedmont slopes.

1.4. Glaciers of the Region

The majority of the glaciers in Mandakini basin are mountain glaciers with simple basins with their major source of recharge being from snow or avalanches. Glaciers in this region generally occur above the elevation of 3800 m asl. The distribution of glaciers in area is maximum of southwest and southeast aspect (15 and 12 in respectively). The north and west aspect glaciers are nil and rest on other aspects are few glaciers in number. The glaciated area in the Mandakini River basin extends from 30º 35’ N to 30º 49’ N latitude to 78° 59’ E to 79° 22’ E longitude. The basin has a total number of 40 glaciers occupying an area of 81.64 sq km with the ice reserve of 5.9856 km^3. The largest glacier recognized in this basin is Chorbari glacier which occupies 8.34 km^2 with the ice reserve of 0.7441 km^3. Four grid of SOI sheets and 17 grids of 3'x3' are mapped on 1:10,000 scale.

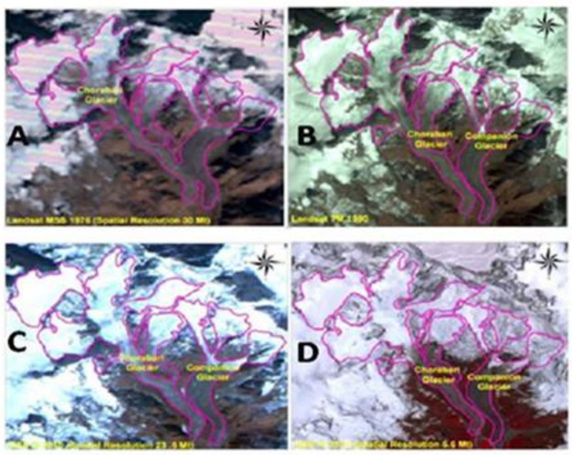
2. Methodology

In this study the multi temporal satellite imageries acquired over the Chorabari Sub Watershed. Based on image interpretation using multi temporal satellite imageries glacier morphological layer is generated and update for different years such as 1962, 1976, 1990, 2010 and 2016. The glacier inventory and glacier lake with details of the glacier features has been prepared using multi temporal satellite data and ancillary data.

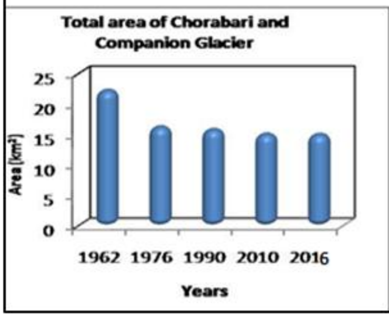
Glacier Area change of Chorabari and companion glacier (1962 to 2016)

Year	Area (km^2)
1962*	22.23
1976	16.23
1990	15.8
2010	15.04
2016	15.0

*: *Based on SOI Maps*



Chorabari Glacier Retreat from 1976 to 2016 A) 1976, B) 1990, C) 2010, D) 2016



Glacier Retreat of Chorabari and Companion Glacier based on Survey of India toposheets (1962) and LISS-IV data (2016)

Figure 2: *Chorabari Glacier retreat from 1976 to 2016 A) 1976, B) 1990, C) 2010, D) 2016*

2.1. Data Integration and Analysis

In the present work integration of Satellite Data and SOI Top sheets by geometric correction was done for the Chorabari Sub Watershed. The glacier boundary and glacial area was digitized on multi-temporal satellite and change area Analysis was done.

3. Results and Discussion

3.1. Change in Glacier Area

Based on image interpretation using multi temporal satellite imageries glacier morphological layer is generated and update for different years such as 1962, 1976, 1990, 2010 and 2016. The glacier inventory and glacier lake with details of the glacier features has been prepared using multi temporal satellite data and ancillary data. For long term change monitoring, Survey of India (SOI) topographical maps of 1962 at 1:50 000 scales have been used as reference maps. The Chorabari glacier retreat was observed from year 1976 to 2016 shown in Figure 2.

The following observations are:

- Total glacier area has been observed from 1962 to 2013, maximum changes has been observed during 1962 to 1976 period . In 1962 the total glacier area of Chorabari and Companion has been found 22.23 km^2 which has reduced up to 16.23 km^2 in 1976 and thus the overall reduction is 6 km^2.

- The retreat rate was very less from 1976 to 1990 period. The overall reduction in the glacier area was noticed 0.43 km^2.

- The overall reduction in the glacier area from 1990 to 2013 was also found very slow, which is only 1.23 km^2.

- In 1962 it has been observed that Chorabari glacier is the single glacier but in 1976 onwards fragmentation has been started from the snout position which was clearly visible in year 1990.

- In 1990 total glacier has been fragmentated into two seprate glacier. i.e Chorabari and companion glacier Srivastava et al., 1994 has reported the total area of Chorabari glacier is 12.28 km^2 and companion glacier is 2.12 km^2 which is 14.39 km^2as the total glacier area, which is approximately similar to our observation in year 1990.

- The reduction in the glacier area has been found on the lateral side of chorabari glacier not on the snout position.

In Chorabari glacier retreat is estimated and maximum change in the glacier was noticed during 1962-1976 period. The reduction in the glacier area was very slow from year 1990 to 2016, which is only 1.23 km^2.

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