Comparison and Monitoring of Glacier Retreat using Satellite and Ground Methods

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Abstract*—The study aimed to make the comprehensible thought about the actual recession over the Gangotri glacier using reiteration photographs of glacier. Here we summarizes the understanding and responding to glacier retreat during the period of 1866 to 2011, on the basis of scientific evidence for glacier retreat particularly at Goumukh snout. The ground photographs were taken from internet (http:// www.cseindia.org/userfiles/repeat_photography). Change in snout position was carried out by Elevation transfer method, interpretation of expedition photographs and panochromatic rectified images. Contours at 30 m resolution generated from ASTER satellite data and overlay on Cartosat DEM to locate the shift in snout position. Retreat over the glacier region is compared with the previous studies carried out in the region. Shift in demarcation also observed with overlaying DEM of Quick Bird Satellite data of 2011 and panchromatic image of Gaomukh. Interpretation was carried out of camera photographs over the Gangotri glacier for year-1866 and 2011 and it is concluded that Gaumukh has receded in between 3.25 to 3.5 km within 144 years, while on the basis of satellite data investigation the snout position shift is found to be 3.37 Km. This retreat may be due to direct or indirect effects of climate change and it is caused largely by human activity and may be other anthropogenic activities.

***Index Terms*— Himalaya, Gaumukh Snout, DEM, Snow Retreat**

I. INTRODUCTION

The glacier terminates at Gaumukh which is a place of pilgrimage and glacier has 258.56 sq km area and is about 30.20 km in length with its width varying from 0.5-2.5 km. It is a valley type glacier, situated in the Uttarkashi district of Garhwal Himalaya, Uttarakhand and the meltwater flows in the northwest direction. The glacier is bound between 30°43' 22"–30°55' 49" latitude and 79°4'41"–79°16'34" longitude, the elevation varies from 4120 to 7000 m.a.s.l. [Naithani et al. 2001]. The Gangotri glacier originates at the northern slope of Chaukhamba range of peaks. It is a valley glacier mainly flowing towards northwest and the length is about 32.2 km, constitutes an area of 262.53 sqkm and ice reserve of 71.3174 sqkm. It is combination of several other valley glaciers as well as mountain glaciers and form huge mass of ice Bhrigupanth, Kirti stambh, Sumeru Parvat respectively and Raktavarna bamak, Chaturangi bamak and Swachand bamak lie on the northeast slope of Srikailash, Man Parvat, Satopanth and un-named group of peaks. Himalayan glaciers in the Indian subcontinent are broadly divided into the three river basins, namely the Indus, Ganga and Brahmaputra. The Indus basin has the largest number of glaciers (3500), whereas the Ganga and Brahmaputra basins contain about 1000 and 660 glaciers, respectively [Kaul, 1999; Hasnain, 1999].

Glaciers in this region generally occur above the elevation of 4,000 masl. It has been estimated that there are 1439 glaciers altogether inventoried within the territory of Uttarakhand, covering an area of 4060.04sq km with an ice reserves of 475.43 km3. The highest number of glaciers (457) lies in Alaknanda River basin and the lowest numbers of glaciers are seven in the Ramganga River basin. The glaciated area in the Bhagirathi river basin extends from 300 43' N to 310 23' N latitude to 780 33' E to 790 25' E longitude. This is the main river of the Ganges basin fed by numerous glaciers and second largest river of the Uttarakhand. Altogether 374 glaciers have been identified in the Bhagirathi River basin. They cover an area of 921.46sq.km and an ice reserve of 129.928 km3. Sustainability of Himalayan region especially Uttarakhand depends on glaciers as most of the community in the state lies in the lap of these glaciers.

The warming rate in this region are increasing relatively high over the last few decades implicating changes in climate and local weather conditions that has impacted the world's glaciers both in terms of structure and characteristics, reflecting in the form of advancement or retreat of glacial snouts. A significant and alarming fact is the recession of the Gangotri glacier, 25-30m/year [Naithani et al. 2001; Mukherjee and Sangewar, 2001]. Majority of glaciers in Himalaya are valley type constrained by topography and highly threatened of retreat [Bahuguna, 2007]. The changes in the length, width, area, volume and mass balance of the glaciers are among the most direct visible signals of global warming and these changes are the primary reasons why glacial observations have been used for climate system monitoring for many years, especially in areas where time series data on climate (mainly temperature and precipitation) is difficult to get and where climate change signals are not yet clear [Yadav *et al*., 2004]. Black carbon or anthropogenic activities have been reported as one of the major factors for depleting the Himalayan glaciers [Hansen et. al. 2004; IPCC 2007; Yasunari et al. 2010]. Other non-climatic factors, topography and wet snow avalanches may affect the glacier health [Racoviteanu et al., 2008; Dobhal et al., 2004]. Kulkarni et al. (2011) estimated the glacial retreat for 1868 glaciers in 11 basins in Indian Himalaya since 1962 and shown an overall deglaciation of 16%.

Advanced remote sensing and GIS techniques offer abundant potential for mapping and monitoring the glaciers in extensive high and remote mountain areas, whereas conducting a survey based on conventional methods demands a great deal of time and capital through involving enormous risks. In recent year a comparative analysis of the glacier's snout position was carried out using data from secondary sources and interpretations from various satellite imageries over the past three decades. Satellite imageries available since 1976 formed the baseline for the analysis of the snout fluctuations.

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Therefore, it is necessary to study and monitor the Himalayan glaciers precisely as in the few years maximum retreat was observed from the Gangotri glacier. During the last few years, there has been much controversy and conflicting statements being issued on the status of the Gangotri glacier and its melting.

II. STUDY AREA AND DATA SOURCES

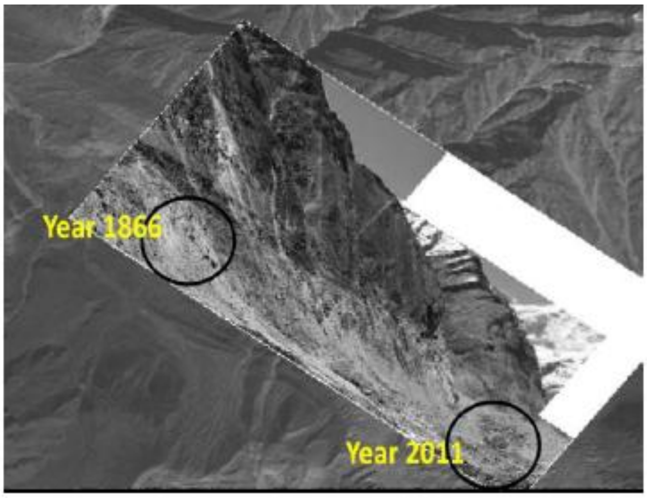
The largest glacier of the state, Gangotri is located at the south-eastern part of the basin at latitude 300 43' 31" N to 300 57' 30" N and longitude 780 59' 11" E to 790 17' 15" E. It is a well-known glacier in Garhwal Himalayas, situated in Uttarkashi district.

The ancillary information and data required for the analysis and interpretation of satellite data was generated and collected from various primary and secondary sources. An exclusively designed field work and ground truth exercise was carried out for obtaining information about the discrimination of various features or classes. The following ancillary data has been used for the present study. The topographic map 53o N/1, (1:50 000) was used as a base map, which was prepared by the Survey of India in the 1960s using aerial photographs with limited.

Ground photographs were taken from website (http:// www.cseindia.org/userfiles/repeat_photography) and literature survey was carried out for the validation of the research study. The available satellite datasets for different year was used i.e. Landsat MSS data of year 1976, Landsat TM data of year 1990 and 1999, LISS III data of year 2011, Cartosat satellite imagery of year 2011 (spatial resolution of 2.5m), Quickbird satellite imagery (spatial resolution of 0.6m (panchromatic) and 2.5m (multispectral)).

III. METHODOLOGY DETECTION OF SHIFTS IN THE SNOUT POSITION

The RGB composition is used to validate the past photographs of glacier regions. The visual interpretation, comparison of demarcation in panochromatic Camera photographs, and change analysis is carried out by Elevation transfer on actual position of snout. Shift in snout position of the glacier was located on the basis of 30m contours generated from ASTER satellite data overlay on Cartosat DEM. The Panchromatic data was overlaid on the rectified photographs to analyze the snout shift or changes in position with respect to elevation. Shift in demarcation also observed with overlaying DEM of Quick Bird Satellite data and panchromatic image of Gaumukh.



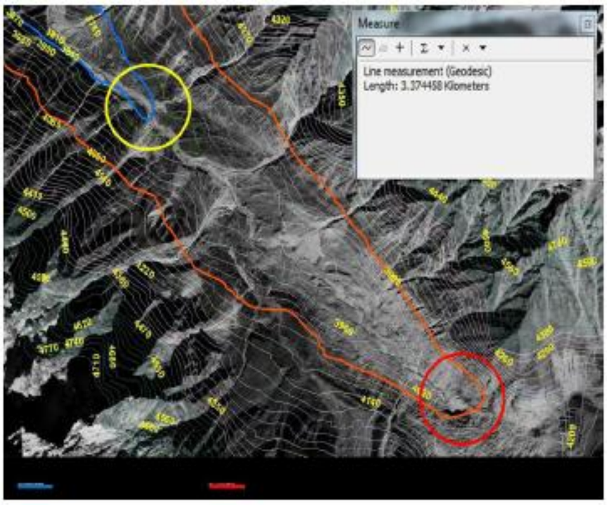


Fig 1: Contours at 30 m resolution generated from ASTER and overlay on Cartosat DEM and Panochromatic image between the years 1866 and 2011 overlaying on Cartosat DEM ***(Source of ground photograph***

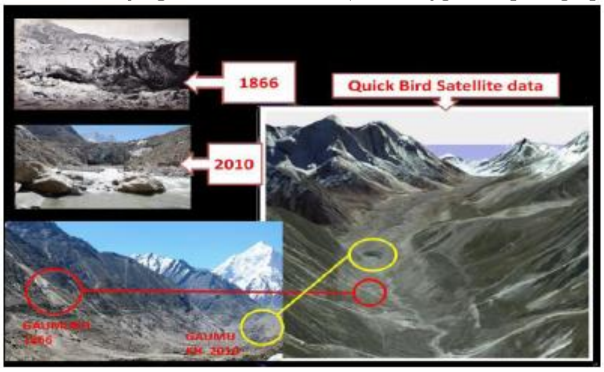


Fig 2: panchromatic view of Gaumukh at Gangotri glacier between 1866 & 2010, and Shift in demarcation observed in DEM of Quick Bird Satellite data and overlay with panchromatic view of Gaumukh.

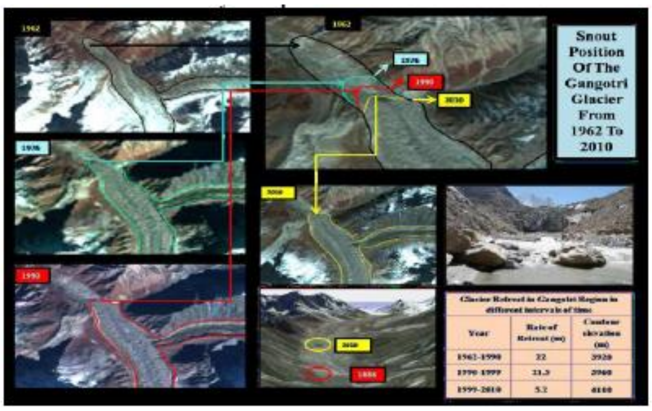


Fig 3: Decadal change analysis using satellite and panochromatic imagery datasets

IV. RESULTS AND DISCUSSION

The change in snout position is as a function of shift in altitude and surface as a function of shift in altitude and surface distance from past ground photograph and satellite datasets for different years, i.e. 1976, 1990, and 2010. The shift of demarcations or locations was computed using GIS techniques by extracting the elevational information from DEM by subtracted populate the shift values in the vector table. Surface length was also computed using DEM were subtracted layer. GIS queries were made to locate the maximum shift zones to spot the direction and magnitude of the changes. The 3.37 Km shift in snout position of Gaumukh (figure 1) is observed between the year 1886 to 2010.

The 144 years old photographs of this Gangotri glacier and satellite data for this glacier, is used to comment on the changes that have occurred in this glacier and the region (figure 2). Shift in the demarcation was estimated form comparison of previous study which proves the retreat of snout from 2005 to 2010 was about 30 meters and recent position of the snout ice wall is around 70-75 meters high. From year 1886 to 2011, the total snout has retreated by approximate 3.37Km. Many smaller glaciers join the main stream of the main glacier to form the Gangotri group of glaciers. The main trunk area and length of the glacier is 56.59 sq. km and 29.13 sq. km respectively with an average width of 1.85 km. Five decadal glacier studies over the Gangotri glacier has been carried out by Dhobal et al., (2007; 2008) and reported that the Dokriani glacier has retreat by 480m during the period of 1962 and 1991and vacated the area of 0.74km2.

Glacier snout position change analysis was carried out using the satellite datasets in the decadal periods i.e. years between 1976-1990, 1990-1999, and 1999-2010. Landsat MSS data-1976, Landsat TM data-1990, LISS III -2010, Quickbird satellite imagery was used to locate the actual position. For year 1962 snout demarcation was done by using SOI toposheet due to unavailability of satellite dataset. A comparative analysis (figure 3) of the glacier's snout position using past and present data from secondary sources and interpretations from various satellite imageries and panochromatic camera photographs proves the snout fluctuations. 30m Contours from the Aster data overlay on the rectified ground images which clearly indicates that the snout position in the decadal years 1962-1976, 1990, 2010, was at 3920m, 3960m, 4110m elevation respectively.

On the basis of field observations between the 1991 to 2000 and 2000 to 2007 the glacier has reduced about 161.5 m and 110m with an average rate of 17.8 m/year and 15.7 m/year respectively. Mizra *et al*., (2002) estimated the retreat of 20m in year 1998 and compared an annual average of 16.5m over 1993-1998 at Dokriani glacier. Gangotri glacier is receding at the rate of around 26m/year between 1935 and 1971, 17m/year gradual decline in between 1971 and 2004, and in recent years has shown a recession rate of about 12m/year during 2004-2005 [Kumar *et al*., 2008]. The deglaciation of 6% in overall area of Gangotri glacier was observed by Negi et al. (2012) between the years 1962 to 2006. The rate of recession of the Pindari glacier has come down to 6.5m/year in comparison to the earlier reported rate of 26m/year between 1996 and 2007 and the Milam glacier has been observed as 16.5 m/year in the last 150 years (Bali et al., 2009). In a study, Nainwal *et al*., (2008) reported that the snout of the Donagiri glacier has shown signs of moderate recession, and the Satopanth glacier which has been receding at the rate of 22.86m/year earlier, has lately shown a recession rate of 6.5m/year during 2005-2006. Shift in demarcation also observed with overlaying DEM of Quick Bird Satellite data of 2010 and panchromatic image of Gaumukh.

V. CONCLUSION

Shift in the demarcation proves the retreat of snout from 2005 to 2010 was about 30 meters and recent position of the snout ice wall is around 70-75 meters high. Shift in demarcation also observed with overlaying DEM of Quick Bird Satellite data of 2010 and panchromatic image of Gaumukh. From year 1886 to 2011, the total snout has retreated by approximate 3.37Km. Change in snout position may be due to direct or indirect effects of climate change and it is caused largely by human activity and may be other anthropogenic activities. Glaciers retreat impacts are beginning to be felt and will degenerate in the decades ahead unless we take action. The solution to climate change will involve a broad array of technologies and policies-many tried and true, and many new and innovative. This understands about the glacier retreat during the century and directly or indirectly responding to global Climate Change. Shift in the demarcation proves the impacts in greater depth, and explaining the damage caused by unavoidable climate change, as well as the long-term costs of responding to climate-related impacts. To address the enormous challenges of climate change over the glacier region, long term and micro level approaches are needed.

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