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Change Monitoring of Gangotri Glacier using Remote Sensing

M Anul Haq, Kamal Jain, KPR Menon

Abstract— Himalayas has one of the largest resources of snow and ice, which act as a freshwater reservoir for all the rivers originating from it. Monitoring of these resources is important for the assessment of availability of water in the Himalayan Rivers. The mapping of Glaciers is very difficult task because of the inaccessibility and remoteness of the terrain. Remote sensing techniques are often the only way to analyze glaciers in remote mountains and to monitor a large number of glaciers in multitemporal manner. This paper presents the results obtained from the analysis of a set of multitemporal Landsat MSS, TM and ETM+ images for the monitoring and analysis of Gangotri Glacier main trunk change. The investigation has shown an overall reduction in glacier area from 63.227 sq km to 62.412 sq km between 1972 and 2010, an overall deglaciation of 1.3% percent. To monitor seasonal snow cover, NDSI based algorithm was used to monitor the Gangotri glacier main trunk.

Index Terms— Ablation, Digital Elevation Model, Glacier, NDSI, Snow

I. INTRODUCTION

Glaciers are ancient rivers of compressed snow that creep through the landscape, shaping the planet's surface. They are the Earth's largest freshwater reservoir, collectively covering an area the size of South America [Dyurgerov, M.B. and Meier, M.F. 2000]. Snowfields are under increasing pressure due to growing demand for fresh water, industrialization and urbanization. Besides, owing to their high sensitivity to changes in the climatic environment, they are also considered as key indicators of some consequences of global warming. Therefore, it has become very important to monitor. About 15,000 Himalayan glaciers form a unique reservoir which supports perennial rivers such as the Indus, Ganga and Brahmaputra which, in turn, are the lifeline of millions of people. The Gangetic basin alone is home to 500million people, about 10% of the total human population.[IPCC WGII]. Philip and Ravindran (1998) have also mapped glacier landforms of Gangotri glacier using Landsat TM data; they demonstrated that selected digitally processed TM band combination could help to map selected glacial features. The Survey of India has prepared topographic maps of the glaciated terrain of the Himalaya during 1961–1962surveys with limited use of aerial photographs on 1:50,000 scale. After this survey, no revised maps have been published even after the terrain was resurveyed using air photos. Kulkarni et al. (1999) provide an inventory of glaciers in the Satluj river basin that includes the Beas and Spiti sub-basins using Georeferenced IRS-1A and IRS-1B-LISS-II data and Landsat satellites on 1:50,000 scale. Various features such as accumulation area, ablation area, transient snow line/ equilibrium line, moraine-dammed lakes, deglaciated valleys and permanent snowfields were mapped relying on unique repentance characteristics.

Datasets are necessary to track glacier changes over a long time period. Few monitoring programs exist because of limited financial resources. Of the 160,000 estimated glaciers in the world, less than 1% are monitored [Haeberli, W., 1990]. Lack of informative data makes it especially important to use all historic information from maps, aerial photographs and other sources to assess glacier change. Measurements of snow cover in the mountainous basins are very difficult. Conventional methods have limitations in the monitoring of snow covered area in high-altitude glacierized basins because of highly rugged terrain and harsh weather conditions. In this perspective, Remote sensing techniques are often the best way to analyze glaciers in remote inaccessible places and also to important to monitor the glaciers for environmental surveillance. Long-term monitoring is required to gain a better understanding of the relationships between glaciers, climate, hydrology and hazards. Extensive monitor large number of glaciers at the same time.

II. STUDY AREA

The Gangotri glacier, one of the largest ice bodies inthe Garhwal Himalayas, is located in the Uttarkashi district of the state of Uttarakhand in India(See figure 1). It is one of the most sacred shrines in India, with immense religious significance. Being the main source of the river Ganga, it attracts thousands of pilgrims every year. The Gangotri glacier is a vital source of freshwater storage and water supply, especially during the summer season for a large human population living downstream. There are around 5000 glaciers exist in the Indian part of the Himalayas covering approx. 38,000 km^2 of the mountain area[GSI. (1999).].Himalayan glaciers form the largest body of ice outside the Polar caps and are the source of water for the innumerable rivers that flow across the Indo-Gangetic plains.

The north-west facing Gangotri glacier is a valley type glacier originating in the Chaukhamba group of peaks. Numerous smaller glaciers join the main stem of the main glacier to form the Gangotri group of glaciers. The complete Gangotri glacier system along with its tributaries covers an area of 210.60 sq km (ETM+2000).

The area and length of the main trunk of the glacier is 62.112sq km and 29.85 km respectively. The average width of the glacier is 1.85 km. The glacier, lies between 79^{o}4' 46.13" E-79^{o}16' 9.45" E and 30^{o}43' 47.00" N-30^{o}55' 51.05" N (ETM+2000). It has varying elevation of 4,015–6,145 meters above sea level (SRTM Data Analysis).

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The snout of the glacier occurs at an altitude of about 3,949 m above sea level, and this is the place from where the Bhagirathi originates). Its snout position is at 79º4’ 47.26” E and 30º55’ 36.45” N.

III. DATA SOURCES

The multi-spectral satellite data of Landsat MSS for the year 1972 and 1976, Landsat ETM+ data for the years 2000 and 2010 have been ETM+ have been procured in the present study.

Table 1.Details of Satellite data

Satellite Data	Date of acquisition	Spatial resolution
Landsat MSS	26/10/1972	79
Landsat MSS	19/11/1976	79
Landsat ETM+	25/05/2000	30
Landsat ETM+	13/11/2010	30

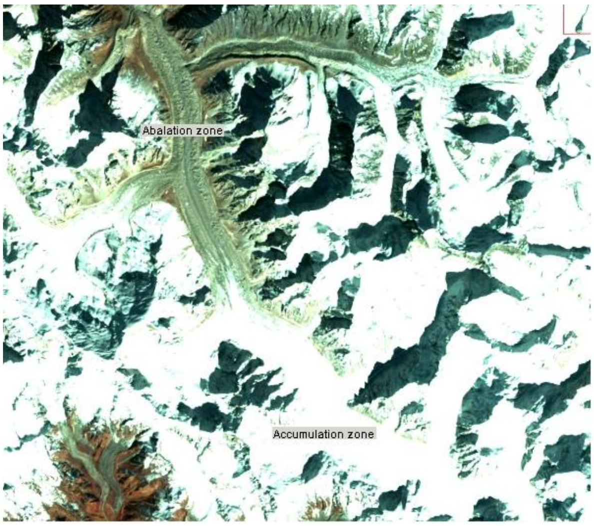

Fig 1 False Color Composite(FCC) of RED(4) Green(3) Blue(2) in the Gangotri Glacier, Subset of Landsat-7 ETM+ Image

IV. METHODOLOGY

Phase I: For Landsat MSS data

Landsat MSS data of 1972 and 1976 are classified by both supervised and unsupervised classification techniques. After classification process the data is associated with DEM and finally the glacier area of Gangotri glacier main trunk is calculated by measurement techniques using ENVI 4.7.

Phase II: For Landsat ETM+ data

Landsat ETM+ data of Nov 2010 have strips, preprocessing has been done to destripe the Landsat ETM+ data using ENVI 4.7. The spectral distinction does not exist for all the glacial features in any single band thus identification of all features in single band data. The standard FCC of ETM+ 2, 3 and 4 bands (Blue, Green, and Red) may not be sufficient for snow cover type study because of its spectral saturation in two of these bands. Although the ETM+ bands 1 to 3 are found to be useful to detect dusty surface on glacier ,their utility is limited in the higher reaches of many glaciers because of the saturation. However, ETM+ Band 5 and 7, as they do not show detector saturation, are found to be extremely useful for snow mapping [Philip and Ravindran, 1998]. The snow coverage are clearly discriminated from the other features in ETM+ Band 4 irrespective of the amount of saturation. Considering all the above, it is found that despite redundancy in ETM+ bands 5 and 7, a color composite of the bands 4, 5 and 7 (RGB) yields interesting results in discriminating glacial features and the landforms[Philip and Ravindran, 1998]. (Fig. 2).

The terrain of Himalayan glaciers has undulating surface and steep slopes, so the radiance reaching the sensor greatly depends on the orientation (slope and aspect) of the target. The incoming radiance is highly depend on the orientation of the object Therefore, for better recognition of the classes for effective mapping, the DN numbers have to be converted into topographically corrected reflectance images. In a first step the satellite imagery has been topographically normalized by C- correction Method. In second step segmentation of ratio images were calculated using a threshold value of1.

By performing second step we identify the all debris free ice. In order to distinguish snow from similarly bright soil, rock and cloud we have calculated NDSI (normalized difference snow index) by following formulae:

$$NDSI = \frac{(TM2 - TM5)}{(TM2 + TM5)} \quad (1)$$

where: TM2,TM5- Landsat ETM+ band data

Due to the debris cover and dark shadow the manual delineation is very difficult to perform, the solution for that problem has been carried out by combining the images with Digital Elevation model. Now the glacier area was calculated using the combination of satellite images and DEM for the years 1972, 1976, 2000 and 2010 by delineating the glacier boundary. (See Fig 3 FCC of Landsat ETM+ associated with DEM).

V. RESULTS AND DISCUSSIONS

The Gangotri glacier, one of the largest glaciers in the Himalayas. Numerous small sized glaciers also join the main Gangotri glacier from all sides and form the Gangotri group of glaciers. The main glaciers as well as its tributaries are valley glaciers .The total ice cover is approximately 200 km^2 and has about 20 km^3 of ice in volume Vohra C P (1981)**.**

The area and length of the main trunk of the glacier is 62.412 sq km and 29.38 km respectively. The average width of the glacier is 1.85 km. The glacier, lies between 79^{o}4’ 46.17” E-79^{o}16’ 10” E and 30^{o}43’ 46.98” N-30^{o}55’ 50.96” N (ETM+2000). It has elevation range from 4,017–6,146 meters above sea level (SRTM data analysis).

VI. CONCLUSIONS

Loss in main trunk of glacier area was estimated using high and medium resolution of Landsat ETM+ and MSS data .In this investigation, glacial area loss from 1972 to 2010 was estimated. The investigation has shown an overall reduction in glacier area from 63.227 sq km to 62.412 sq km between 1972 and 2010, an overall deglaciation of 1.3% percent.

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To monitor seasonal snow cover, NDSI based algorithm was used to monitor the Gangotri glacier main trunk.

In the visible bands of Landsat ETM+, the highly reflecting surface of snow and glaciers reach saturation limits and are not useful in discriminating snow types and mapping landforms in these areas. But the TM Bands 4, 5 and 7 in the NIR and SWIR regions are found to be very useful not only in snow mapping but also in identifying various glacial landforms.

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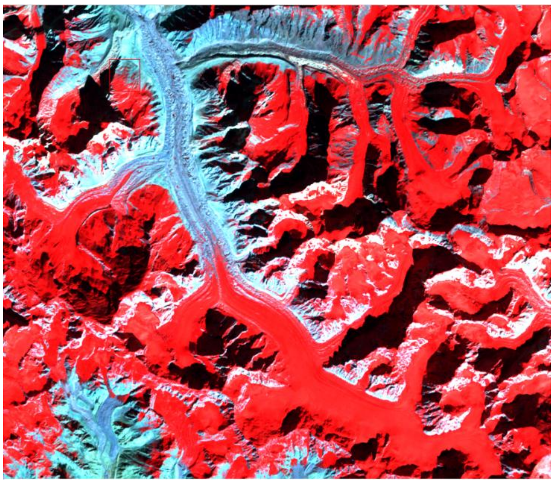

Fig. 2: Landsat ETM+ FCC of Band4(Red) Band5(Green) and Band7(Blue) of Gangotri Glacier

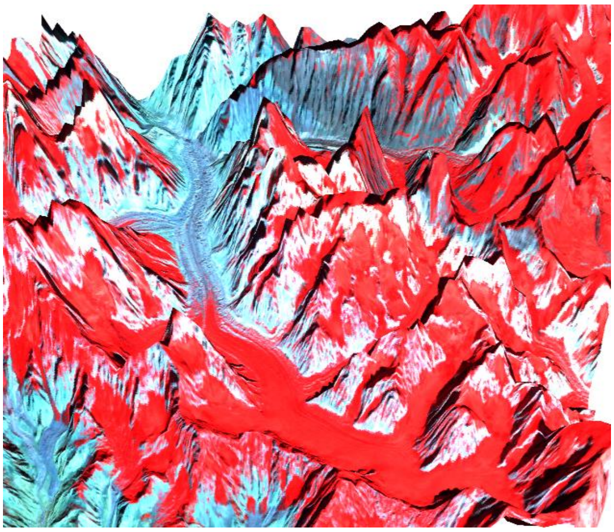

Fig. 3: Landsat ETM+ FCC of Band4(Red) Band5(Green) and Band7(Blue) of Gangotri Glacier associated with Digital Elevation Model(ASTER)

Table 2: Changes in Gangotri Glacier Area in different Years of Observation

Year of Observation	Area of Gangotri Glacier Main Trunk (km^2)	Loss in Area from 1972
1972	63.227 km^2	____
1976	63.164 km^2	0.063 km^2
2000	62.662 km^2	0.565 km^2
2010	62.412 km^2	0.815 km^2

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