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THEME: Geo-Budget: Enabling Sustainable Growth

Monitoring of Glacial lakes on Himalayan Glacier using Remote Sensing

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Abstract- Mountain glaciers interact sensitively with climate and therefore they are considered as climate indicators. The changing climate has had a significant impact on the accelerated retreat of many glaciers globally. Warmer climates of the past 100 to 150 years have resulted in widespread glacial retreat and the formation of glacial lakes in many mountain ranges. The glacial lakes are situated in remote areas and are very difficult to monitor through field measurement due to the rugged terrain and extreme climatic conditions. Remote sensing mapping techniques are particularly valuable for investigating inaccessible glaciers and their lakes. These enable preliminary assessments to be under-taken on a catchment-wide scale more cheaply and quickly than is possible with traditional field investigations. This paper depicts the mapping of glacial lakes on Himalayan Glacier based on the observations made from Corona, Landsat TM, and Landsat ETM+ and ASTER data.

Keywords: Landsat, Interpretation, Multitemporal, Glacial lakes

I Introduction:

Remote sensing mapping techniques are particularly valuable for investigating inaccessible glaciers and their lakes. These enable preliminary assessments to be under-taken on a catchment-wide scale more cheaply and quickly than is possible with traditional field investigations. Remote Sensing technique has been used for delineation and mapping of glacial lakes in Himalaya (Kulkarni 1990, Randhawa 2005) using false color composites. An automatic detection method of the lake surface using a normalized difference water index (NDWI) was attempted on Imja Glacial Lake by Bolch et al (2008). Wessel's et al. (2002) performs ASTER ratio image (GREEN/NIR) to detect and monitor supraglacial lakes on glaciers in the Mount Everest region in Tibet (Xizang) and Nepal. However for lakes of Gangotri Glacier no detailed investigation has emerged so far using direct or Remote Sensing Methods. In this study, we attempt to describe the changes in the area and number of Glacial Lake on Gangotri Glacier using Landsat and ASTER imagery. ASTER offers powerful capabilities to monitor supraglacial lakes in terms of (1) surface area, growth and disappearance [spatial resolution =15 m], (2) turbidity [15 m resolution], and (3) temperature [90 m resolution](Wessel's et. al, 2002).

II. STUDY AREA

In current investigation we mapped the supraglacial and proglacial lakes of Gangotri Glacier. Gangotri glacier originates in the Chaukhamba massif (6853–7138 m a.s.l.) and flows northwest towards Gaumukh. The Gangotri glacier, one of the largest ice bodies in the Garhwal Himalayas, is located in the Uttarkashi district of the state of Uttarakhand in India (See Fig 1). Gangotri glacier between 79°4' 46.13" E-79°16' 9.45" E and 30°43' 47.00" N-30°55' 51.05" N (Haq et. al., 2011). It has varying elevation of 4082–6351 meters above sea level (ASTER and SRTM Data Analysis) Flash floods caused by bursting of glacial lakes are well known in the Himalayas (Coxon et. al., 1996). The progressive thinning of the Himalayan glaciers during the past century has resulted in the formation of new moraine dammed lakes (Mayewski et. al., 1980).

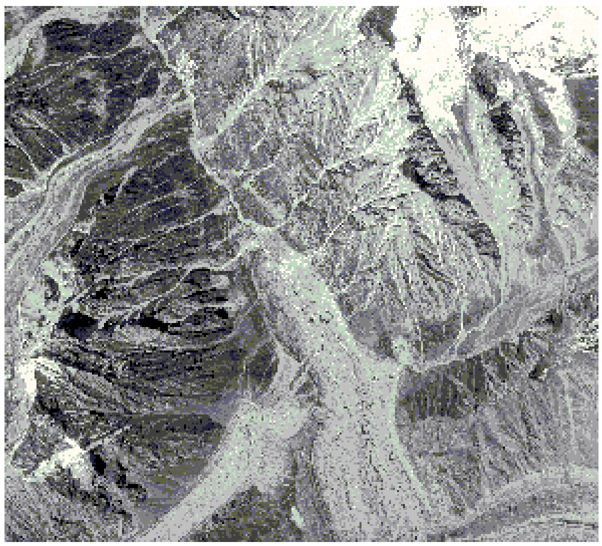

Fig. 1 Subset of Corona Air Photo of the Gangotri Glacier 1968

III DATA SOURCES

The Corona Air Photo of 1968 and multi-spectral satellite data of Landsat MSS for the year 1972 and 1990, ASTER data for 2001 and 2010 have been procured in the present study (see table 1). The Landsat data used in current investigation system was downloaded for free from the USGS Global Visualization Viewer (GLOVIS) AND ASTER data is provided by ECHO under the umbrella of NASA LPDAAC. Orthorectified VNIR images of the advanced spaceborne thermal emission and reflection radiometer (ASTER) on Terra satellite with a spatial resolution of 15 m(2001,2010), Landsat MSS(1972), Landsat TM(1990)are used for this analysis. The Landsat data used in current investigation system was downloaded for free from the USGS Global Visualization Viewer (GLOVIS) AND ASTER data is provided by ECHO under the umbrella of

NASA LPDAAC. The images used in the analysis are listed in table 1.The Lake areas were identified using the Normalized Differenced Water Index (NDWI). Visual interpretation and editing were also performed to rectify errors due to ice areas and shadows on the lake.

Satellite Data	Date of acquisition	Spatial resolution
Corona	27/09/1968	8
Landsat MSS	26/10/1972	79
Landsat TM 5	21/10/1990	30
ASTER	09/09/2001	15(VNIR)
ASTER	29/10/2010	15(VNIR)

Table-1 Details of Satellite data used in the analysis

IV. Methodology

The Corona data is only panchromatic therefore radiometric correction and georefrencing procedures are required. For Corona image we take 35 GCPs acquired from ASTER imagery for Image to Image registration processing. We focused on the adjustment of the area around both glaciers on Corona images in respect of ASTER imagery for consistency of results during rectification of Corona imagery. Landsat MSS and TM images were co- registered with the ASTER DEM and ASTER imagery. To align two or more images geometrically that represents the same object. We obtain the geometric relationship between the warp image and base image through 30 tie points and modeled the relationship using transformation capabilities.

Glacial lakes were automatically identified using the Normalized Differenced Water Index (NDWI, [NIR-BLUE]/[NIR+BLUE]). This method was successfully applied for the detection of water bodies (Huggel et al., 2002). The NDWI performed slightly better than the band ratio ASTER1/ASTER3 (GREEN/NIR)(Bolch et. al., 2008.In some scenes the glacial lakes were partly covered by ice (Table 1). Therefore, visual checking and editing was necessary. Manual delineation had to be applied for the Landsat MSS and TM data. The contrast of the latter was stretched in order to improve the image quality. It was, however, still difficult to identify small, partly ice-covered lakes. Due to these problems and the coarse resolution of the Landsat MSS scene we consider the changes of the glacial lakes which are larger than 0.0036 km^2.The results show that the identification of glacial lakes using the NDWI leads to accurate results. This also confirms earlier studies (Bolch et al., 2008). Lake Identification based on ASTER is slightly more accurate than of Landsat as the comparison with the referenced data. The automated lake identification can be problematic with turbid lakes and lakes with partial ice cover/icebergs, and in shadow areas. In these cases an improvement based on visual interpretation had been performed with the help of DEM.

V. Results

Due to determinations based on spaceborne imagery the overall area of the proglacial and supraglacial lakes in the study region increased from 89520 m^2 in 1968 to nearly 103975 m^2 in 2010. The number of supraglacial lakes on the Gangotri Glacier increased from 8 in 1968 to 22 in 2010.There was 8 lakes identified in 1968 having total surface area 89520 Sq m (0.08952 km^2) based on Landsat MSS scene, however in 1990 the number of lakes identified and mapped was 15 but the total are decreased to 83661 Sq m(0.0837 Km^2) based on Landsat TM scene. In 2001 the total number of lakes identified were 18 and covers an area 138600 m^2 (0.1386 Km^2), However in 2010, total number of lakes identified were 22 and covers an area 103975 m^2 (0.1039 Km^2).

Year of Observation	No of Supraglacial and proglacial lakes	Overall Area of lakes (sq m)
1968	8	89520
1972	10	97200
1990	15	83661.75
2001	18	138600
2010	22	103975

Table 2. Total number and overall area of glacial lakes of Gangotri glacier in different observation years

Conclusion

The application of Multitemporal remote sensing has made possible to map small lakes formed at the higher altitudes, which would have not been possible by field investigations. In addition, remote sensing is the best way to investigate a larger number of glaciers, glacial lakes As shown in this study, changes in Himalayan glacial lakes have been observable from repeated remotely sensed images since 1968. In particular, frequent multitemporal imaging will be valuable for understanding the underlying expansion mechanisms of glacial lakes in detail. Remote sensing-based measurements of glacier characteristics can provide area-wide information of glacier activity for entire glacier tongues instead of point wise measurements. During the investigation a total of 8 lakes were mapped of the Gangotri glacier in 1968 and 22 lakes in 2010. (Landsat and ASTER Data analysis). The monitoring of all of Gangotri glacier lakes has suggested that however the number of lakes are increasing but area of all lakes are not increasing up to manageable level in last 42 years.

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