Remote Sensing Based Hazard Assessment of Glacial Lakes – A Case Study from Kumaon Himalaya, India

K. Babu Govindha Raj

Abstract

The climate change of the 20th century had a pronounced effect on glacier environments of Himalaya. The formation of moraine dammed glacial lakes and outburst flood from glacial lakes (GLOF) is major concern in countries such as Bhutan, China (Tibet), India, Nepal and Pakistan. Indian Himalaya possesses about 30 dangerous lakes out of 549 glacial lakes. The hazardous lakes, however, are situated in remote areas and very difficult to monitor through ground surveys due to rugged terrain and extreme climatic conditions. Study using temporal satellite data on one of the glacial lake in Kumaon Himalaya showing the glacial lake grown to an extent of 0.078 Km^2 areas in 2005. Empirical relations showing the lake can generate a discharge vary from 10.3 m^3/ sec to 118.2 m^3/ sec.

Keywords: *Glacial lake; Kumaon Himalaya; GLOF; Satellite Data; Remote Sensing*

Introduction

Global climatic change during the 20th century had a significant role in modifying the high mountainous glacial environment. Many glaciers retreated rapidly resulting in the formation of a large number of glacial lakes bounded by moraine dams. Warmer climates of past 100 to 150 years have resulted in widespread glacial retreat and formation of moraine-dammed lakes in many mountain ranges (Clague and Evans 1994). Eventually, either the volume of water becomes too great for the moraine to support or an event such as a large ice block detachment occurs and the moraine is

RS & GIS APPLICATIONS AREA, National Remote Sensing Centre
Indian Space Research Organisation (ISRO), Balanagar, Hyderabad - 500 625
email: babugovindraj@gmail.com

breached. Sudden discharge of large volumes of water along with debris from these lakes causes glacial lake outburst floods (GLOFs) in downstream areas. This results in destruction of valuable natural resources such as forests, farms, and expensive mountain infrastructures and human lives. Such flash floods are a common problem in countries such as Bhutan, India, Nepal and Pakistan.

During August 2000, in Tibetan Plateau, GLOF occurred and destroyed more than 10,000 houses and 98 bridges and financial losses were about 75 million US dollars (Shen 2004) . In 2008, GLOF from Gulkin glacier, Karakoram Himalayas also damaged many properties (Richardson and Quincey 2009). The GLOF event in Nepal during 1981 damaged the Friendship Bridge of the China-Nepal Highway and destroyed the Koshi power station in Nepal and caused serious economic losses (Bajracharya *et al.* 2006). Most of the glacial lakes in the Himalayan region are known to have formed within the last 5 decades, and a number of GLOF events have been reported in this region and many of which have trans-boundary impacts (Table 1).

Table 1. List of some of the Recorded GLOF events in Himalayan Region (Source: [3] and [4])

No	Year	Lake	River Basin/Area	Country affected	Cause of GLOF
1	September 1964	Gelhaipuco	PumQu / Arun	China and Nepal	Glacier surge
2	September 1977	Nare	Dudh Koshi	Nepal	Moraine collapse
3	June 1980	Nagma Pokhari	Tamor	Nepal	Moraine collapse
4	July 1981	Zhangzangbo	Boqu / Sun Koshi	China and Nepal	Glacier surge
5	August 1985	Dig Tsho	Dudh Koshi	Nepal	Ice avalanche
6	October 1994	Lugge-Tsho	Pho Chu	Bhutan	Moraine collapse
7	September 1998	Sabai Tsho	Khumbu Himal	Nepal	Not known
8	2008	Ghulkin Glacier lake	Karakoram	Pakistan	Moraine collapse

The hazardous lakes, however, are situated in remote areas and very difficult to monitor through ground surveys due to rugged terrain, inaccessibility and extreme climatic conditions. Most glacial lakes in Indian Himalayan region have not yet been identified or studied completely because of their remote locations (Richardson and Reynolds 2000). Remote sensing is found to be one of the best techniques for identifying such glacial lakes and offers strong advantages for first and qualitative hazard assessments of glacier lakes.

A first level inventory of glacial lakes and their characteristics were done by the International Centre for Integrated Mountain Development (ICIMOD), Nepal for Himalaya (Bajracharya *et al.* 2006). A compiled list of some of the glacial lakes in Indian Himalaya is given in Table 2.

Table 2. List of some of the glacial lakes in Indian Himalaya, (Source: [4] and *[13])

River Basin/ State	Glacial Lakes		
	Number	Area (sq Km)	Potential GLOF
Himachal Pradesh	156	385.22	16
Uttarkhand	127	2.49	0
Tista River	266	20.20	14
Sikkim*	6	7.6	Not available
Chandra basin*	01	1.04	01

Study Area

The moraine dammed glacial lake (30° 26’ 45.53” N, 80° 23’ 18.74” E) situated at an elevation of 5000 m at the snout of the glacier (no name exists) in the Lassar Yankti river basin of NE part of Pithorgarh district, Uttarakhand, India (Figure 1). The glacier is a simple mountain basin glacier orientating NE-SW having well developed lateral and terminal moraines.

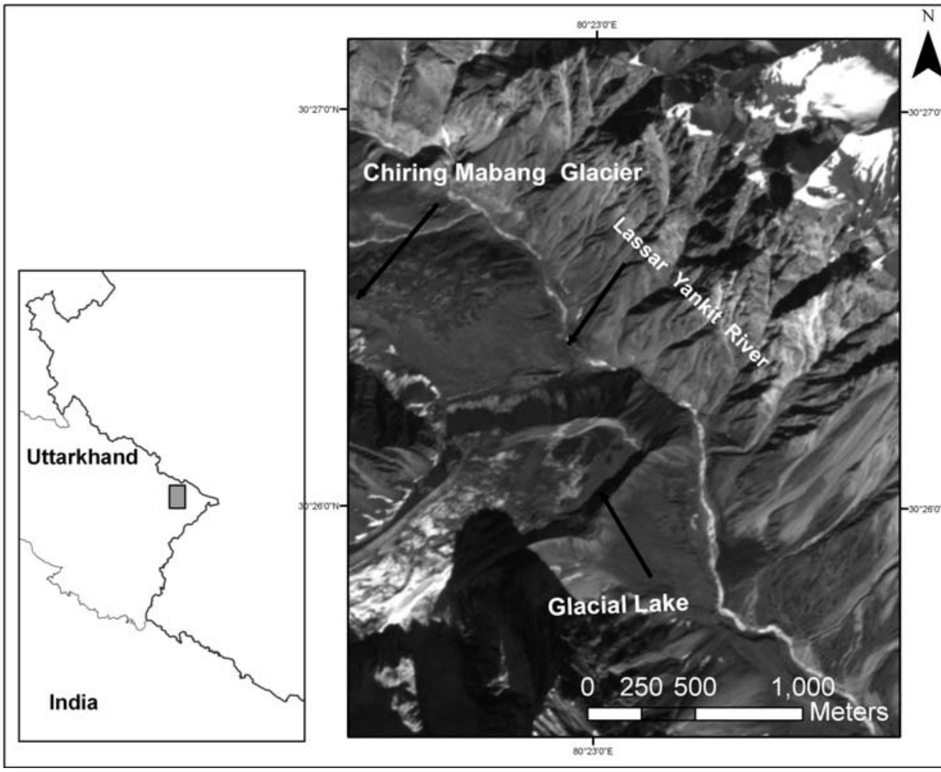


Fig 1. Lassar Yankti river basin of NE part of Pithorgarh district, Uttarakhand, India

Data Used

Landsat MSS and TM and Resourcesat-1 LISS III satellite data were used in this study. Apart from satellite data, Garhwal Himalaya OST map (1955) on scale 1:1, 50,000 (provided by Swiss Foundation for Alpine Research) and ASTER DEM were also used. Table 3 shows details of the data used in the present study.

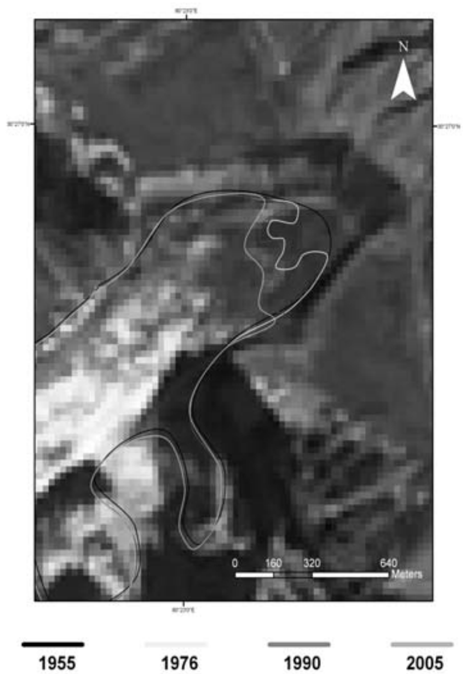
Table 3. Details of Satellite data used in the present study.

Satellite	Sensor	Spatial Resolution (meters)	Acquisition Date / Remarks
Landsat -2	MSS	57	15-11-1976
Landsat -5	TM	30	15-11-1990
IRS P6	LISS III	23.5	18-11-2005
TERRA	ASTER	~20 (vertical)	ASTER GDEM

Methodology

For this study, Garhwal Himalaya OST map prepared in 1955 was used as the base data. The glacier extent was mapped from the Georeferenced OST map. The lake is not shown on the OST map. Therefore, it can be assumed that the lake is formed after 1955. The first occurrence of the lake is marked in the Landsat MSS data of 1976. The glacier boundary and lake areal extent mapped from the MSS data. From 1955 the glacier receded about 177meters and the lake formed in the cavity created by the retreating glacier. The length measurements were carried out along the centre line of the glacier. In 1976, the lake is having an aerial extent of 0.03 km^2 and the lake is attached to the glacier terminus bounded by the lateral moraines and terminal moraines.

Figure 2. Retreat map of the glacier in different time periods



In 1990 the glacier boundary and areal extent of lake mapped from Landsat TM data. The glacier retreated 18 meters and the lake grown by 0.013 Km^2 from the earlier extent of 1976. The latest extent measured in 2005 shows the glacier receded 128 meters and the lake has grown to an extent of 0.029 km^2 from 1990 (Figure 2).

The depth measurements of the lake carried out from ASTER DEM. The difference in height of the bounding lateral moraines and center part of the lake is considered for calculating the depth of the lake. For further analysis the depth of the lake is taken as 25 m. The areal extent of the lake is measured as 0.078 km^2 in year 2005. The volume of lake is estimated as the product of area and depth and calculated volume is 1.97 million m^3.

The magnitude of a flood caused by the breach of moraine dam is relevant for further hazard analyses. The empirical equations used for estimating the maximum discharge Q_{max} are given in Table 4. The parameters in these equations are lake volume (V in m^3) or potential energy (PE) of the lake. *P*E is expressed as the product of dam height (m), volume (m3), and the specific weight of water (98000 N/m^3) (Costa and Schuster 1988).

Discussion and Conclusion

Estimation of discharge from the lake was done using empirical equations (Table 4).

Table 4. List of models used for estimation of maximum discharge (Q_{max}).

Code	Formulae or models	References	Results (m3/sec)
1	$Q_{max=}75V^{0.67}$	[6]	118.2
2	$Q_{max=}0.72V^{0.53}$	[7]	10.3
3	$Q_{max=}0.0048V^{0.896}$	[8]	88.12
4	$Q_{max=}0.045V^{0.66}$	[9]	70.40
5	$Q_{max=}0.063PE^{0.42}$	[10]	12.20
6	$Q_{max=}70.00077V^{1.017}$	[11]	15.34

For all the equations the lake volume is assumed as 1.97 million m^3, average depth as 25 m and PE as 4.82×10^{11}. The resultant maximum instantaneous discharge from the lake is given in the Table 4. Subsequent to the development of the above formulas many physical based models were developed to estimate peak discharge. Due to non-availability of other parameters such as ice thickness, lake temperature, length of drainage tunnel, bathymetry of the lake etc., it is difficult to apply such models for this kind of investigations. Therefore, above mentioned models are used for initial assessment of lake discharge.

As mentioned in the earlier section, maximum possible lake volume is 1.97 million m3, and lake depth is 25m; peak discharge is estimated by using the formulas (Table 4). Due to the lack of field data the modeled discharge error is unknown. In Indian Himalayan region flash floods from sudden downpour due to cloudburst is very common in monsoon period. The formation of cloudburst over glacial lakes can cause dangerous GLOFs.

This paper presents the utility of remote sensing in detecting and monitoring the hazardous nature of glacial lakes in highly glaciated terrain of Indian Himalaya. Empirical models allow an approximate estimate of a potential GLOF hazard. If the preliminary study indicating a severe hazard potential, more detailed field survey may be required to establish the risk of GLOF. In view of fast retreating glaciers in Himalaya to establish the hazard potential of glacial lakes a systematic inventory of glacial lakes using remote sensing and in situ field survey is recommended and adaptation measures like early warning systems and mitigation measures are required in potential GLOF areas.

Acknowledgements

The author would like to thank Director, NRSC and Deputy Director (RS & GIS), NRSC for providing support during the course of work. Thanks to GLCF, University of Maryland, USA for the Landsat MSS and TM data, Swiss Foundation of Alpine Research, Zurich for providing the Garhwal Himalaya OST Map and ERSDAC for ASTER GDEM.

References

1. Clague, J.J. and Evans, S.G.(1994) Formation and failure of natural dams in the Canadian Cordillera, Geological Survey of Canada Bulletin(464).
2. Shen, Y. (2004) An Overview of Glaciers, Retreating Glaciers and Their Impact in the Tibetan Plateau, Chinese Academy of Sciences (CAS) Report(42).
3. Richardson, S. D. and Quincey, D.J.(2009) Glacier outburst floods from Ghulkin Glacier,Upper Hunza Valley, Pakistan, Geophysical Research Abstracts, EGU2009-12871, EGU General assembly, 19-24 April 2009, Vienna, Austria.
4. Bajracharya, R.S., Mool, P.K. and Shrestha B.R.(2006) The impact of global warming on the glaciers of the Himalaya. International symposium on Geo-disasters, infrastructure management and protection of world heritage sites proceedings :231 - 242.
5. Richardson, S.D. and Reynolds, J.M.(2000) An overview of glacial hazards in the Himalayas, Quaternary International (65-6): 31-47.
6. Clague, J.J. and Mathews, W.H.(1973) The magnitude of Jökulhlaups, Journal of Glaciology (12): 501-504.
7. Evans, S.G. (1986) The maximum discharge of outburst floods caused by the breaching of man-made and natural dams, Canadian Geotechnical Journal (23): 385-387.
8. Popov, N.(1991) Assessment of glacial debris flow hazard in the north Tien-Shan, In Proceedings of the Soviet-China-Japan Symposium and field workshop on natural disasters :384-391.
9. Walder, J.S., and O'Connor, J.E.(1997) Methods for predicting peak discharge of floods caused by failure of natural and constructed earthen dams, Water Resources Research (33): 2337-2348.
10. Clague, J.J. and Evans, S.G.(2000) A review of catastrophic drainage of moraine-dammed lakes in British Columbia, Quarternary Science Reviews (19): 1763-1783.
11. Huggel, C.; Kääb, A.; Haeberli, W.; Teysseire, P. and Paul, F.(2002) Remote sensing based assessment of hazards from glacier lake outbursts: a case study in the Swiss Alps, Can. Geotech. Journal (39):316-330.
12. Costa J.E. and Schuster, R.L.(1988) The formation and failure of natural dams, Geological Society of America Bulletin (100): 1054-1068.
13. Kulkarni, A. V. (1996) Moraine- Dammed Glacial Lake Studies using Remote Sensing Technique, Himalayan Geology (17): 161-164.