

A NOVEL APPROACH TO MEASURE THE CHANGES IN GLACIER EXTENT OF GANGOTRI GLACIER

M Anul Haq¹, Dr. Kamal Jain¹, Dr K.P.R. Menon²

¹Department of Civil Engineering, Indian Institute of Technology, Roorkee, India

²Head Data Dissemination, NRSC Balanagar, Hyderabad

Abstract:

Accurate multitemporal monitoring of glaciers actuates scientific interest for two major reasons. Firstly, monitoring of glacier change has been used for climatic change investigation. The surface extent and volume of individual glaciers are monitored to estimate the future water availability. Secondly, glaciers in Indian Himalayas, have been recognized as an important water storage systems for municipal, industrial and hydroelectric power generation purposes. This paper discusses a novel approach for the study of the surface patterns of Gangotri Glacier. Change detection using multitemporal satellite images of Gangotri glacier is of widespread interest due to a large number of applications in diverse disciplines such as climate change, remote sensing, landslide susceptible zone mapping and so on. The proposed technique uses GIS and image processing techniques to derive regression models of selected glacier segments, these models are then used to measure area under the curve to estimate the surface area changes of the glacier. The surface area changes thus obtained have also been validated by standard method.

About the Author:



M Anul Haq

Name: **M Anul Haq**

Date of Birth: 01/01/1984

Designation: Ph.D. Research Scholar

Organization: Indian Institute of Technology Roorkee

Specialization: Remote Sensing, GIS, GPS

E mail ID: anulhaq@gmail.com,

Contact No: +91 – 9258307163

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Introduction

The Himalaya comprises one of the largest collections of glaciers outside the Polar Regions, with a total glacier cover of 40,563 km² and around 16,627 glaciers exist in the Indian Himalaya (ISRO-SAC, 2011). Himalayan glaciers are the important source of fresh water for the innumerable rivers that flow across the Indo-Gangetic plains. The rivers flow trans-boundary and meet the potable water, irrigation, hydropower, fishery, inland navigation and other needs of more than 1.3 billion people living downstream. With about total 32,392 small and large glaciers in the Himalayas (ISRO-SAC, 2011), they hold the largest reserves of water in the form of ice and snow outside the Polar Regions (IPCC, 2007).

Glacier change monitoring over time can be achieved using change detection of satellite images or maps. Change detection techniques such as image differencing, image rationing, and image regression are main techniques used for glacier monitoring. In this paper we attempt a new approach by using multitemporal image change detection with polynomial regression.

Study Area and Data Sources

Gangotri Glacier originates in the Chaukhamba massif (6853–7138 m a.s.l.) and flows northwest towards Gaumukh (Anulhaq et al. 2011). It lies between 79°4' 46.13" E-79°16' 9.45" E and 30°43' 47.00" N-30°55' 51.05" N (Anulhaq et al. 2011). 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 (Figure 1). Snow and glaciers contribute about 29% to the annual flows of the Ganga (up to Devprayag) and hence any impacts on these glaciers are likely to affect this large river system (Singh et al. 2009). In this investigation we analyze Gangotri glacier main tongue without tributary glaciers.

Table 1. Details of data sources used in current investigation

Data	Date of acquisition	Spatial resolution(m)	Scene ID
Landsat TM	21/10/1990	30,120	p146r39_5t19901021
Landsat TM	09/09/1998	30,120	LT51460391998252BIK02
Landsat TM 5	24/10/2011	30,120	LT51450392011297KHC00

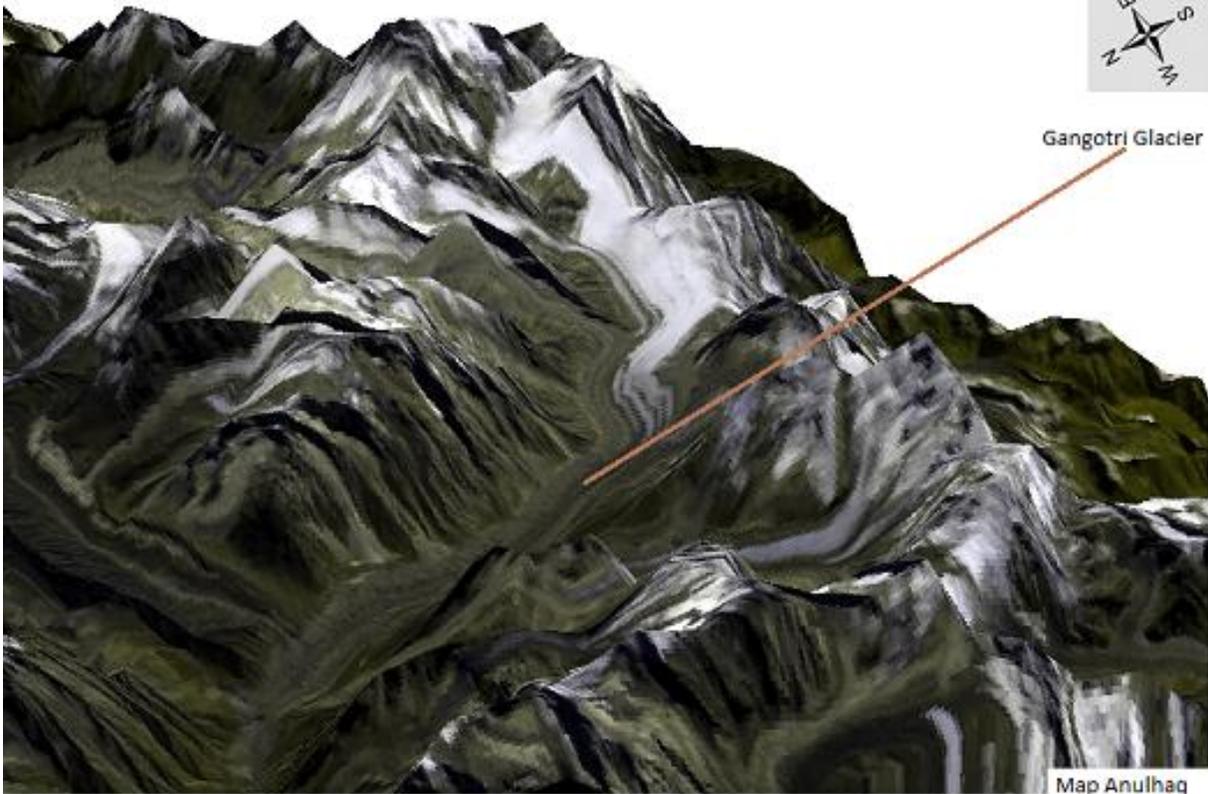


Figure 1. Gangotri Glacier, Subset of ASTER 3-3-1 band image (2010) overlaid on the ASTER DEM (perspective view, not to scale).

Methodology

We used ArcGIS 10 and inbuilt python script to perform all steps for change monitoring. The steps are as follows

- 1) Image to image registration
- 2) Identical subset of all images
- 3) Canny Edge detection using developed python script
- 4) Change detection of image using XORing operation of images derived from step 3.
- 5) Polynomial regression and area change estimation

Step 1 and Step 2:- First two steps did not require any coding so we done it manually using ArcGIS 10. We use Canny algorithm which is well known algorithm used for edge detection developed by John F.Canny in 1986. We use grayscale image rather than RGB or colored image for Canny's edge detection because of two reasons first is color typically isn't need when looking for edge and second is less computation in gray scale.

Step 3: We developed a python script that was used for Canny edge detection, the major steps of this script contains

- i) Smoothing using Gaussian filter: Smoothing was done using Focal Statistics function of ArcGIS with Gaussian filter.
- ii) Calculate gradient and direction: We used Sobel operator for finding gradients. Sobel operator is a kind of a discrete differentiation operator, computing an approximation of the gradient of the image intensity function. At each point in the image, the result of the Sobel operator is either the corresponding gradient vector or the

norm of this vector. The Sobel operator is based on convolving the image with a small, separable, and integer valued filter in horizontal and vertical direction and is therefore relatively inexpensive in terms of computations. On the other hand, the gradient approximation that it produces is relatively crude, in particular for high frequency variations in the image.

- iii) Non-maximum suppression: Only local maxima should be marked as edges.
- iv) Edge tracking by hysteresis: Final edges are determined by suppressing all edges that are not connected to a very certain edge.

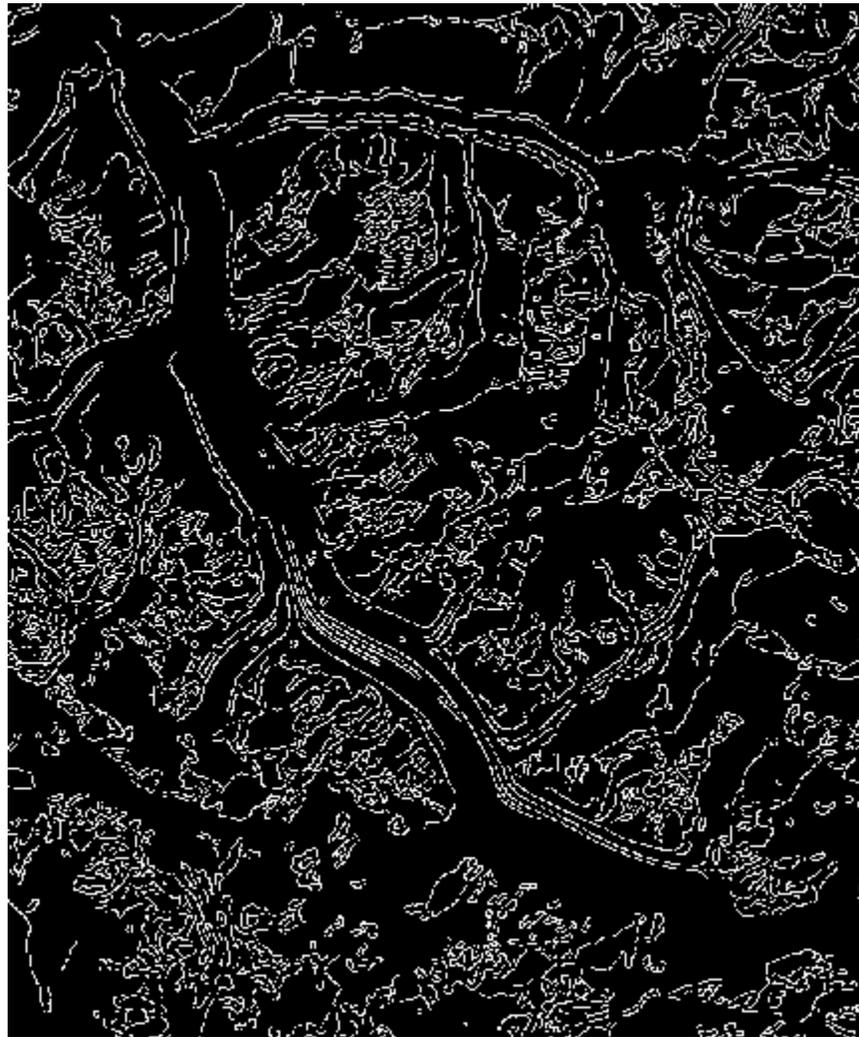


Figure 2. Landsat TM image subset of 2011 after applying Canny edge detection

Step 4: Change detection of images using Bitwise XOR function of images derived from step 3. We derive change detection from 1990 to 1998 and 1998 to 2011 Landsat scenes. The idea of XOR operation is quite simple if there is a no change in both images then the output pixel was set to 0 otherwise 1.

XOR Truth Table

Input		Output
A	B	
0	0	0



$$\begin{matrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{matrix}$$

Step 5. We used polynomial regression based on histogram values of two resultants change detected images i.e 1990 to 1998 and 1998 to 2011 images. Mathematical functional mapping was done until we reached the optimal value of R² and focused on the fact that every increase in the order of equation must contribute to the increase in R² value. For glacier area change measurement between two periods, the polynomial equations for each image (derived from step 4) are overlaid on each other and the differential area of the curves was calculated using integral calculus.

$$dA = (y_1 - y_2) dx$$

or

$$A = \int_a^b [f(x) - g(x)] dx$$

Where y1 is top curve and y2 and bottom curve, f(x) is upper function and g(x) is lower function.

Results and discussions:

The results derived from our approach were compared with expert manual digitization using high resolution satellite imagery.

Pixel involves in Area change/ Periods	Our approach	Manual Digitization(High Resolution Imagery)	Error	Change of Area in Sq Km
1990-1998	400	412	12	0.36
1998-2011	566	574	8	0.51

The errors obtained for the area change estimation by the two methods manual digitization and our method is very small as shown in Table 1 which strengthen the usability of the proposed method for the area change estimation for glacier monitoring. The area loss of main trunk of Gangotri glacier was estimated using multitemporal data shown an overall reduction in glacier area 0.36 sq km between 1990 and 1998, 0.51 sq km between 1998 and 2011. However, the rate of retreat is less than previously estimated by remote sensing. For example Kumar et al. (2009) estimated that Gangotri glacier reduced by 15.5 km² between 1976 and 2006 using coarse resolution Landsat MSS data and field survey, another study by Ahmad and Hasnain (2004) found that Gangotri glacier reduced by 10 km² between 1985 and 2001 using SOI toposheets, which is known to be one of the major challenges in glacier inventories (Paul and others, 2009; Racoviteanu and others, 2009; Bolch and others, 2010, Bhambri et al. 2011).

Conclusion:-

We proposed a novel method for area change estimation that has been applied to estimate the change in spatial extent of Gangotri glacier. This method can be used for its capability to measure the spatiotemporal changes in a glacial area. The area loss of main trunk of Gangotri glacier was estimated using multitemporal data shown an overall reduction in glacier area 0.36 sq km between 1990 and 1998, 0.51 sq km between 1998 and 2011. We also attempted to evaluate the capabilities of ArcGIS 10 for this current investigation and found that ArcGIS is capable of handling not only GIS aspects but also for advanced image processing operations using Python script.

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