Glacier Retreat/Advance for the Baspa Bamak Glacier – Remote Sensing Data

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Abstract: In this research work an attempt has been made to estimate the glacier retreat/ advance for the Baspa Bamak glacier of the Baspa basin, Himachal Pradesh with the help of remotely sensed data. The position of snout is not remained stationary in space and time. To study such changes there is need to generate a time series of snout position by using satellite imageries for different time period of the region. The main criteria needed to be fulfilled while selecting the imageries under this study is that the images should be cloud free (keeping additional criteria as cloud cover below 10%) and acquisition date should be correlate with end of ablation season to get snow free and fully exposed snout. Landsat images having high spatial and radiometric resolution have been chosen to map and extract the snout of glaciers. Additionally, they have uniformity and historical availability too.

Index Terms – remote sensing, climate change, glacier, Baspa.

Introduction

The natural tendency of a glacier is to acquire a stable state. Disequilibrium implies sustained input of climate forcing that impel the glacier to adjust its position and or dimensions according to the changing climate regime. All glaciers respond to signals of climate change either by decreasing or increasing their total mass; changes in mass eventually reflect in the changes of the glacier area and the position of the glacier terminus i.e. in its retreat or advance. (Pandey, 2014)

The dimensions of the glacier, particularly the length, change in response to climate i.e. the glacial advance or retreat. However, the advance or retreat of glacier terminus or snout involves complex dynamic aspects of ice flow and, hence, is an indirect, delayed and filtered but also enhanced and more easily observed signal of climate change. Change in glacier length is an intuitively understood and easily observed parameter to illustrate the impact of climate change (Shi-Jin WANG, 2019). The quantitative relationship between the response of the glacier terminus to climate change is, however complicated by the time lag between the two.

The simplest method to monitor change in mountain glacier length is by recording the annual location of the glacier terminus, the location at which the glacier extends furthest down valley. Glacier changes are widely recognized as the best natural indicators of climatic change which is also a result of their systematic and globally coordinated monitoring for more than a century, 1894 onwards (Zemp, 2016-17). Today, this monitoring follows a tiered strategy within the global terrestrial network for glaciers (GTN-G) as part of the global climate terrestrial/ observing systems (GCOS/GTOS) (Glaciers, 2023). The network includes the annual measurement of mass balance at about 60 glaciers and of length changes at about 500 glaciers. Front variations (commonly called length changes) for these glaciers are usually obtained through annual measurements of the glacier terminus position (Zemp, 2016-17). Aerial photography and satellite imagery have lately been utilised to quantify glacier length changes over the previous decades, particularly in difficult-to-access areas.

Despite their heterogeneity due to varied response times and local conditions, the annual recorded glacier terminal fluctuations from about 500 glaciers around the world show a broadly homogeneous trend of retreat (Zemp, 2016-17). Over a 120-year observation period, the cumulative values of retreat for major, land-terminating valley glaciers generally approach a few kilometres. For mid-latitude mountain and valley glaciers, typical retreat rates are of the order of 5 to 20 m per year. Under certain conditions, such as the full loss of a tongue on a steep slope or the dissolution of a very flat tongue, rates of up to 100 m per year (or even more) have been observed.The general tendency of retreat in the 20th century was interrupted in several regions by phases of stability lasting one or two decades, or even advance, for example in the 1920s, 1970s and 1990s (regionally variable). In regions where long-term field measurements of multiple glaciers of varying sizes are available, terminus fluctuations typically follow a pattern, with the largest (flatter) glaciers tending to retreat continuously and by large cumulative distances, medium-sized (steeper) glaciers showing decadal fluctuations, and smaller glaciers showing high variability superimposed on smaller cumulative retreats.

The location of a glacier's terminus is not a comprehensive assessment of total glacier condition or health. It is possible that a glacier may be gaining in total mass from one year to the next, due to increasing amounts of snow arriving at the higher elevations by precipitation, wind deposition, and avalanching, while the terminus, at the lowest elevation, is retreating. Therefore, to get reliable conclusions the recession or advancement data of a particular glacier must be supported with other glacial parameters like mass balance, volume change, flow velocity etc.

Abbreviations –

GTN-G - Global Terrestrial Network for Glaciers

GCOS/GTOS - Global Climate Terrestrial/Observing Systems

NDPCSI - Normalized Difference Principal Component Snow Index

GIS - Geographical Information System

Research Methodology

In total 8 imageries of Landsat satellite have been selected for this study. The required imageries were downloaded in L1T data type and GeoTiff format from USGS's Earth Explorer Website (http://earthexplorer.usgs.gov).

Table 6.1: List of Satellite images used for snout demarcation and their specifications.

	Satellite Image	**WRS Path/Row (Lat./ Long.)**	**Sensor Identifier**	**Date Acquired**	**Image Quality**	**Scene Cloud Cover**
1	LT51460381994273ISP00	146/ 038	5_TM	30/09/1994	9	01.00
2	LT51460381997265ISP00	146/38	5_TM	22/09/1997	9	03.57
3	LE71460382001252SGS00	146/38	7_ETM	09/09/201	9	5.32
4	LE71460382003274ASN01	146/38	7_ETM	01/10/2003	9	08.34
5	LE71460382008256ASN00	146/38	7_ETM	12/09/2008	9	02.12
6	LE71460382011264PFS00	146/38	7_ETM	21/09/2011	9	01.34
7	LC81460382014264LGN00	146/38	OLI_TIRS	21/09/2014	9	03.78
8	LC81460382015251LGN00	146/038	OLI_TIRS	08/09/2015	9	6.05

Methodology:

- Glacier watershed boundary and ice divides are demarcated by overlaying the satellite images on the Aster GDEM digital elevation model.
- Image pre-processing (a) Ortho-rectification: Geocoded image in WGS84, UTM Zone no 44 (b) Radiometric Calibration: Conversion of DN value to reflectance. (c) Pan Sharpening: for Landsat 8 and 7 images pan sharpening has been done with their respective panchromatic bands. For earlier images pan band was obtained from Landsat 7 images.
- Delineation of glacier boundary: The glacier boundary has been delineated using a semi-automatic approach, which includes the visual interpretation and band ratio - NDPCSI (Normalized Difference Principal Component Snow Index) techniques.
- Identification of snout position: Snout positions on satellite images are identified using the clues from associated features such black tone due to the shadow of ice wall, origin of stream from glacier, red tone of vegetation present near the terminal moraines and moraine-dammed lakes (Vinay Kumar, 2016).

GLACIER RECESSION/ADVANCES MONITORING METHODS

The worldwide retreat of glaciers is an essential tool in monitoring climate change. This recession has been of keen interest to researchers and scientists around the world, who attempt to map and better understand how and why it is occurring. There are numerous different methods for mapping glacial retreat, including field based measurements, remotely sensed data based measurements, paleo glaciation measurements etc.

Field based measurements

Historically, glacier snout position has been demarcated manually by means of field investigations which are extremely labour intensive, expensive and potentially dangerous. These data are more reliable and due to use of sophisticated instruments like differential GPS, Laser distance finder etc. they have achieved the spatial accuracy of sub-meter level but, they represent only a point (a single glacier) which may or may not be representative of a large area or basin. At the same these measurements of glacier changes are biased towards glaciers that are easily accessible, comparatively small and simple to interpret, a large proportion of all glaciers in the world is debris covered or tidewater calving and changes of such glaciers are more difficult to interpret in climatic terms. Again, field-based data in remote glaciered locations such as the Himalayas are sometimes limited to a few measurements and are typically limited to easily accessible glaciers at lower elevations, so the sample is biased by elevation. Moreover, obtaining glacier retreat/ advance information on repetitive basis for vast glaciated areas of Himalaya using conventional field techniques are very difficult due to high altitude, inaccessible and rugged mountain terrain. Thus, the data obtained through field investigations are ideal for the glacier level study but cannot be used for basin level investigations as generating glacier terminus position data using survey techniques is expensive, tedious and time consuming and is not provide a spatial and temporal cover of enough detail.

Remote-sensing-based measurement

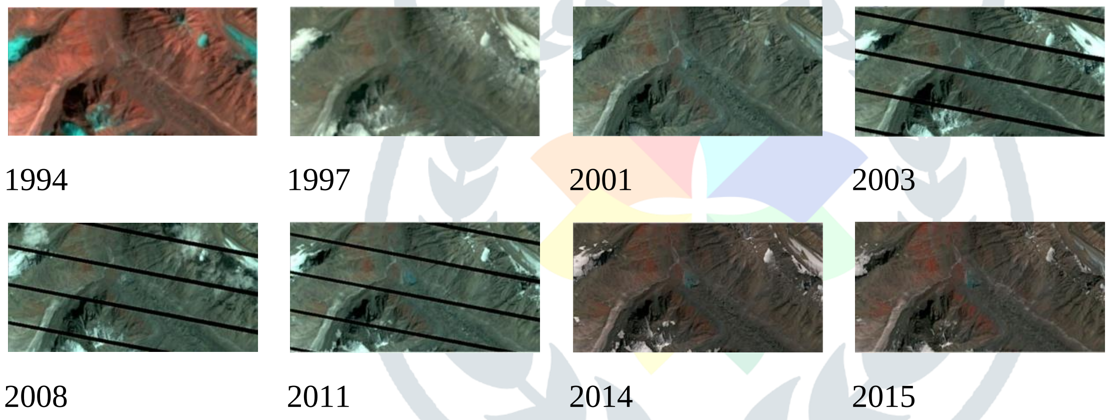
Alternatively, remote sensing offers a new and valuable tool for obtaining glacier snout position data. In the recent years, this technique has emerged as a popular viable substitute for real-time and large spatial coverage for monitoring and process studies related to glaciers over vast, rugged and remote areas (Gao, 2001). Glaciers are often concentrated in remote or inaccessible regions, making remote sensing the most feasible approach for comprehensive glacier recession/ advances monitoring. Remote sensing technology along with Geographical Information System (GIS) facilitate fast and efficient ways to analyse, visualize and report glacier dimensions changes (Kaur, Saikumar, Kulkarni, & Chaudhary, 2009). From a remote sensing perspective, glaciers are one of the most readily identifiable features from aerial photography or satellite imagery due to their distinct spectral signature. It could provide better change estimation due to its spatial and temporal resolution.

Initially, the mapping of glacier snout was largely based on the air photos. The spatial arrangement of objects, in particular glacial landforms, vegetation, and bedrock outcrops, are used as reference points to compare aerial photographs. By comparing images taken in different years it is possible to model the rate of change in length of the glacier. But nowadays satellite based remote sensing data is available which has high spatial, temporal and radiometric resolution and can store information of different wavelengths in various bands, hence enhance the usability to demarcate the snout position.

The major difficulty in monitoring glacial extent using remote sensing techniques in mountainous region particularly in Himalayas, is presence of excessive debris cover in the ablation region which inhibit the peculiar spectral signature of glacier (snow/ice) and make it difficult to recognise the snout position. Therefore, visual interpretation is required with any semi- automatic or automatic technique for identification of snout position.

RESULTS AND DISCUSSION

The results show that the Baspa Bamak glacier retreated 279.5 m from 1994 to 2015. On an average the glacier is receding at the rate of about 13.30 m/y (average of about two-decade observation).



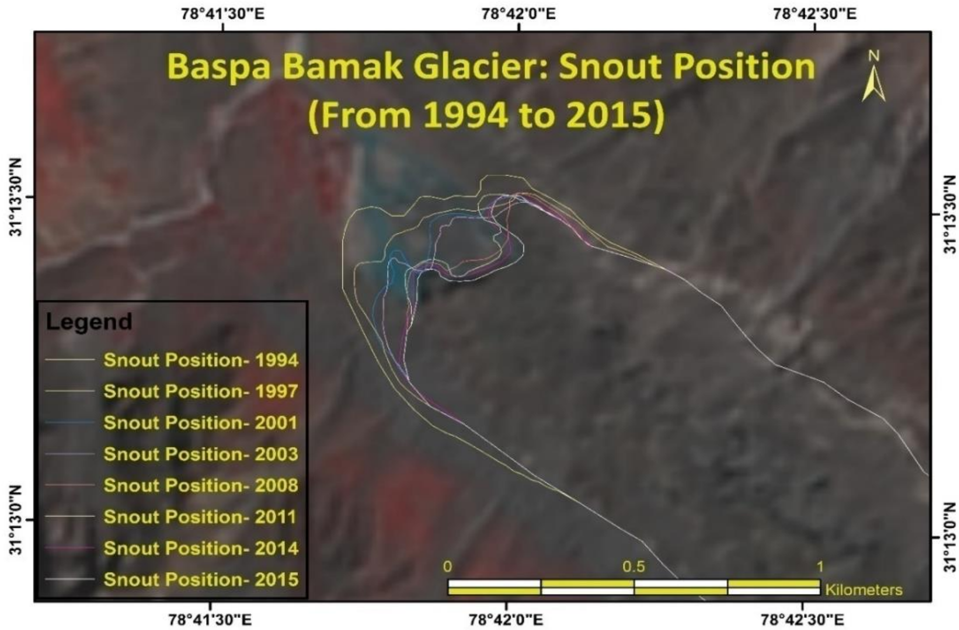


Figure 6.1: Baspa Bamak glacier's snout positions from 1994 to 2015 derived from different high resolution Landsat satellite data overlaid on Landsat 8 OLI (2015) pan sharpening imagery.

Baspa Bamak glacier retreated at the rate of 14.83 m/y from 1994 to 1997 and 6.77 m/y from 1997 to 2001, and between 2001 to 2003 about 19.26 m/y. The recession rate reached its maxima during 2003-2008 and the glacier receded at a rate of 20.4 m/y. After that the rate of recession declined during 2008-2011 and the glacier receded at a rate of 10.96 m/y. after 2011, there was a period of three year from 2011 to 2014 when the glacier has shown minimum recession rate and receded at a rate of 3.93 m/y. For the year 2014-2015, the rate was again shoot up with 19.73 m/y.

The study reveals that the Baspa Bamak glacier has lost 0.18 km^2 area between 1994 and 2015 from its front. The results also reveal that Baspa Bamak glacier has receded with various amount in different years. This could be due to several factors like flow, input parameters, climatic factors and other factors which are not well understood.

The slow rate of retreat of glacier and the oscillations in east and west lobes of the glacier is due to thick debris cover on it which not only retards the ablation rate but also induced differential ablation in the snout area.

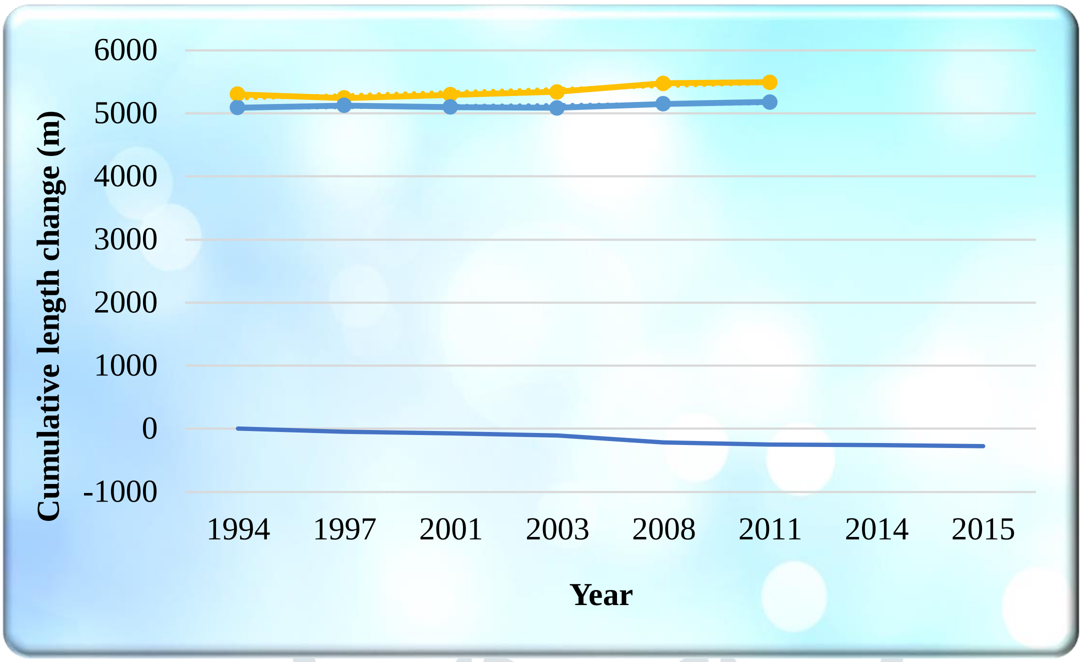


Figure 6.2: Recession of Baspa Bamak glacier from 1994-2015.

It is depicted from the figure 6.1 that the concave shape of terminus is increasing with time and it again indicates the recession of glacier. During the whole studied period, the snout of the Baspa glacier has shown both vertical lowering and horizontal shortening.

Impact of glacier ice mass loss due to ice melting is chiefly marked in the snout and lower lateral margins of the glacier. These regions of glacier are good indicators for assessing the impact of micro climate on glaciers. The retreat of the glacier ultimately results in upward shift in the location and elevation of glacier snout (terminus of the glacier).

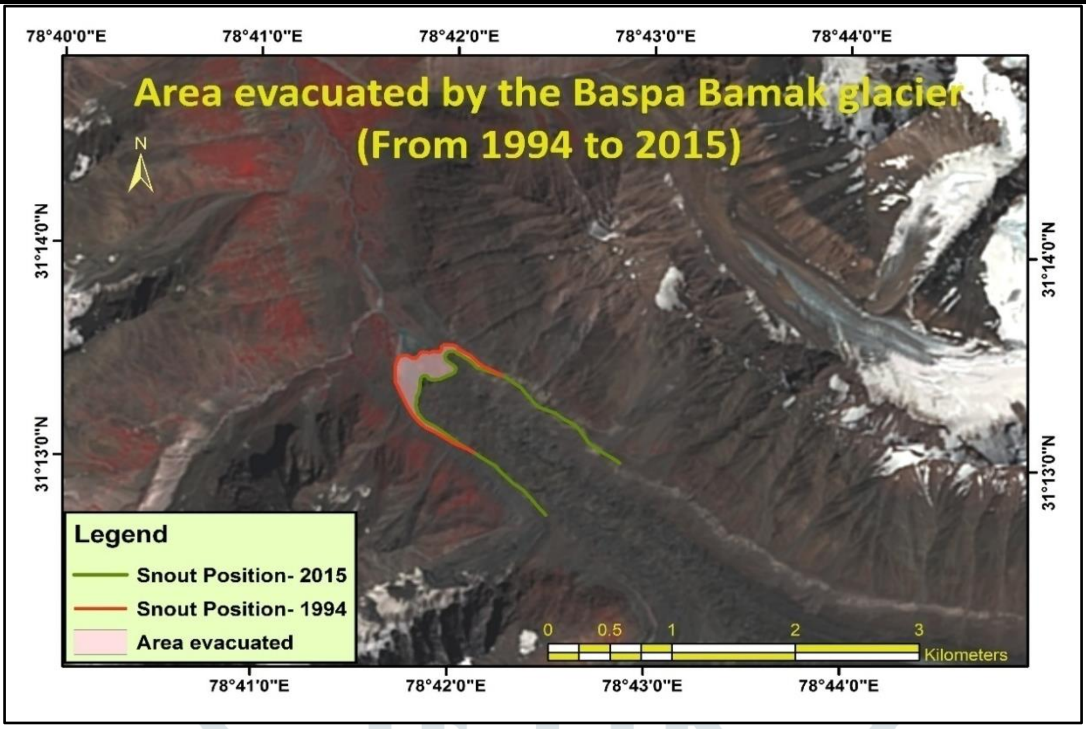


Figure 6.3: Area evacuated by the Baspa Bamak glacier during the period of 1994-2015.

The study reveals that the Baspa Bamak glacier has lost 0.18 km^2 area between 1994 and 2015 from its front.

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