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Research Article

CHANGE DETECTION OF DEBRIS FREE GLACIERS FROM IRS LISS III IMAGES

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ABSTRACT

Thus, a number of studies have been carried out so far on the glacier mapping and change detection of Himalayan and other ranges glaciers using satellite images in digital or analogue format. In most of these studies, mapping has been done based on digitization of glacier extents using visual interpretation technique. Visual interpretation technique is subjective and depends on the spatial and radiometric resolution of the sensor, scale of mapping and experience of analyst, thus causing uncertainties in the mapping accuracy. The interpretation becomes more debatable when glaciers are heavily debris covered on their ablation zones and interpretation becomes tedious. Therefore, in order to see the effect of climatic variations on glaciers, debris free glaciers should be given the priority. In view of this, it has been attempted to find changes in extents of debris free glaciers using IRS LISS III images of 2001 and 2016 during ablation time. This has been done using an algorithm based on Normalized Difference Snow Index (NDSI). It has been confirmed that there is no significant retreat of debris free glaciers (approx. 0.75 % loss in area for 50 debris free glaciers) between 2001 and 2016.

INTRODUCTION

"Glaciers are sensitive indicators of climatic variations" is a common quote in almost all the research articles pertaining to glacier retreat or advance studies. This statement warrants a high accuracy of the results as the climate change analysts and climate policy makers depend on such studies. In view of the so called climate variations undergoing in earth's atmosphere, the research pertaining to changes in extents of glaciers of Himalayan and other mountain ranges has taken a quantum jump in the last one and a half decade, thanks to the globally available multi resolution and multi-temporal images, many such images freely available, acquired by sensors orbiting the earth and advancement in the image processing techniques.

However, the quantitative opinion surrounding the changes in the extents of glaciers has been differing from one study to other. The reasons for this debate are accuracy of the mapping (interpretation accuracy), techniques of mapping (visual or digital), use of multi sensor data and variations in period of monitoring etc.

Thus, a number of studies have been carried out so far on the glacier mapping and change detection of Himalayan glacier extents and glaciers of other ranges using satellite images in digital or analogue format (Kulkarni & Bahuguna. 2001; Kulkarni *et al*. 2007, Trivedi *et al*. 2007, Bhambri *et al* 2011a; Deota *et al* 2011, Ganjoo *et al*. 2014; Pandey *et al*. 2011; Bhambri *et al* 2011b; Bhambri *et al*. 2013; Brahmbhatt *et al*. 2012; Bahuguna *et al*. 2014, , Brahmbhatt *et al*. 2015; Kaul *et al*. 2016). In most of these studies, mapping has been based on digitization of glacier extents using visual interpretation technique. Visual interpretation technique is subjective and depends on the spatial and radiometric resolution of the sensor, scale of mapping and experience of analyst, thus causing uncertainties in the mapping accuracy. The interpretation becomes more debatable when glaciers are heavily debris covered on their ablation zones and interpretation becomes tedious. The difficulties in the interpretation of debris covered glaciers occur not only on the images but sometimes on the ground too. Image classification techniques can not be applied to extract debris covered glaciers as the signature of surrounding rocks and debris cover appear similarly. In order to resolve this issue, (Shukla *et al*. 2009; Bhambri *et al*. 2012; Ajai *et al*. 2011) have developed a technique using integration of optical and thermal data which extracts the glacier ice below debris cover due to difference in temperature between glacier surface and outside it. This is a very useful development in the

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mapping of debris covered glaciers. Moreover it is generally understood that debris covered glaciers block the heat exchange with atmosphere and therefore are less sensitive to climatic variations. (Takeuchi *et al*. 2000) have shown the difference in heat balance over debris covered and debris free glaciers in Nepal Himalayan glaciers. Based on this notion, (Scherlar *et al.* 2011) found the variability in the response of Himalayan glaciers to climate change affected by debris cover. Though it further depends on thickness, density, type and composition of debris load. Therefore, in order to see the effect of climatic variations on glaciers, debris free glaciers should be given the priority. It is because, debris free glaciers are directly exposed to net radiations and turbulent heat exchange with atmosphere rendering them more sensitive to climatic changes and since the snow in the accumulation zone and bare ice of debris free glaciers can be quickly identified visually and digitally, it is easy to monitor debris free glaciers. In view of this, it has been attempted to find changes in extents of debris free glaciers using ablation time images of 2001 and 2016. This has been done using an algorithm based on Normalized Difference Snow Index (NDSI). The debris covered glaciers have also been extracted using a combination approach using a ratio of TM band 3 and band 5 and DEM. However due to lack of ground truth and regular validation of changes in glaciers, the change detection has not been applied on debris covered glaciers. The purpose of using the semi-automated approach is to demonstrate that the inaccuracies due to interpretation errors are minimized and automated methods save lot of time and efforts in glacier studies. The results of this study have been presented in this article.

Two IRS LISS III scenes (Path Row: 95-48) acquired on 02 August 2001 and 06 September 2016 were chosen for this study. The specifications of LISS III and Landsat sensors are given in Table 1.

The year 2001 has been chosen as the images of this year are the best images in the last 16 years to carry out glacier mapping. Ice of debris free glaciers and debris cover ablation zones are exposed to their maximum due to minimum snow cover in the year 2001. The data of 2016 has been chosen as it is the latest data of ablation time. Though a little more snow has been seen on the data of 2016 than of 2001 (it is of early September), but during early winters the snow remains confined to only the extent of glaciers due to difference in temperature on the glacier and outside the glacier. So this data can also be used for the purpose of mapping. This scene covers glaciers of a part of Bhaga, Chandra and Spiti sub-basins in Himachal Pradesh (Figure 1). Bhaga and Chandra are sub-basins of Chenab basin and Spiti sub-basin is a tributary sub-basin of Satluj basin. Additionally, Landsat data dated 9 October, 1989 and ASTER DEM were used. These two data were used to attempt extraction of debris covered glaciers.

METHODOLOGY

Registration

The LISS III scene covers more than 250 glaciers varying in size. Some of them are totally debris free, some partially covered and some are totally covered in their ablation zones. Figure 2 shows debris covered and debris free glaciers as seen on LISS III data. Two scenes were georeferenced with orthorectified Landsat TM data to sub–pixel accuracy using ground control points, such as sharp bends or junctions of streams. A second order polynomial was used to warp each image to the base image. Later two scenes were themselves georeferenced.

The registration error while registering the IRS LISS-III images (23.5 m resolution) to the TM image (28.5 m resolution) was sub-pixel.

Table 1 *Specifications of the images used in study*

Sensor	Spectral bands (μm)	Spatial resolution (m)	Swath (km)	Radiometric res. (Bits)	Repeativity (days)	Date of acquisition
LANDSAT 5 TM	0.45-0.52 0.52-0.59 0.62-0.68 0.75-0.90 1.55-1.75 2.08-2.35 10.40-12.50	28.5	185	8	16	09 October 1989
LISS-III	0.52-0.59 0.62-0.68 0.77-0.86 1.55-1.70	23.5	141	8	24	02 August 2001 06 September 2016

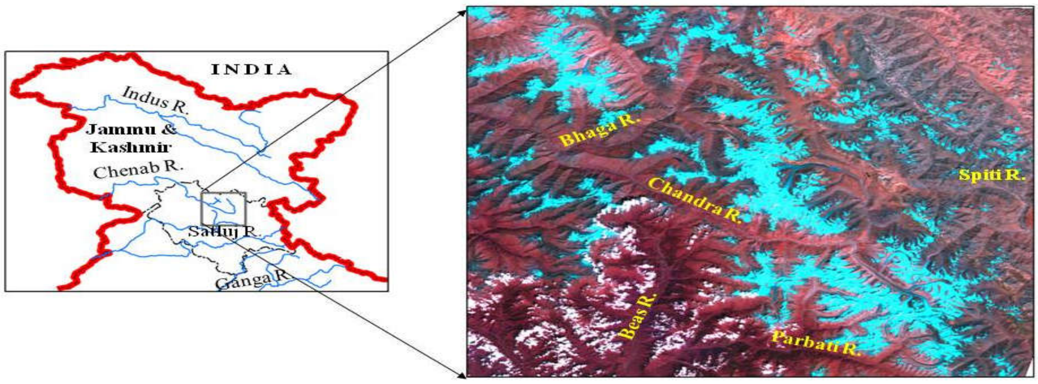

Figure 1 Study area shown here as the coverage of LISS III in Himachal Pradesh(Path Row: 95-48) Dated 06 September 2016

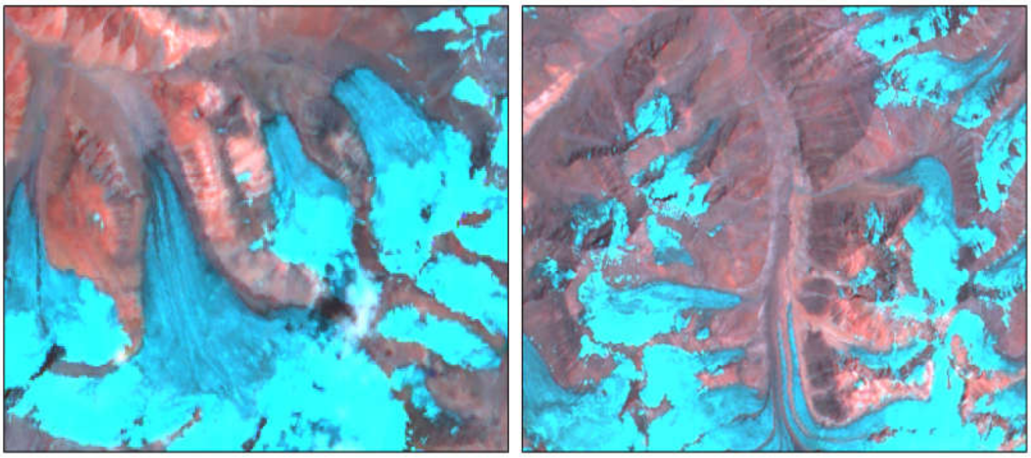

Figure 2 IRS LISS III image showing debris free glaciers (left) and debris covered glaciers (right)

Again the LISS-III scene of dated 02-August-01 was georeferenced with another LISS-III scene dated 06-September-2016. This gives the RMS error of sub-pixel.

Extraction of debris free glacier extents

Two methods were attempted to extract debris free glaciers i.e. generating a normalized Difference snow Index (NDSI) image and unsupervised classification of the scene using ERDAS imagine image processing software. NDSI image is generated by an algorithm based on ratio of difference of reflectance and sum of reflectance of LISS bands corresponding to green and short wave Infrared or SWIR. Computation of this ratio requires extraction of reflectance for each band which differs from sensor to sensor. An algorithm based on reflectance of LISS III and AWiFs data has been developed at Space Applications Centre which is used for snow cover studies. Earlier (Silverio & Jacquet., 2005) also used NDSI based approach to map debris covered and debris free glaciers. The NDSI image is further processed to generate a snow and ice image by defining a threshold of > 0.4. NDSI distinguishes snow from similarly bright soil and rock, as well as from clouds in TM imagery (Dozier *et al*.1989; Hall *et al*.1995a). NDSI also removes some of the illumination effects present on glaciers yielding satisfactory results in shaded ice (Racoviteanu *et al*.2008b).

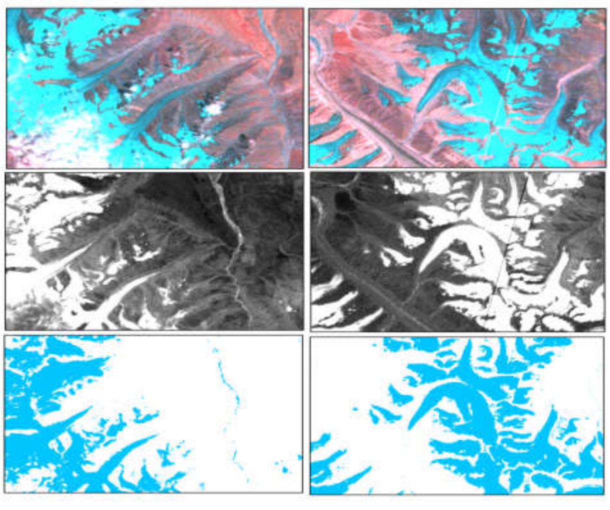

Figure 3 A part of IRS LISS IIII images (top), NDSI image (middle) and Snow and Ice image (Bottom).

It was also found that demarcations of stream emerging at snout and transverse crevasses developed near the snout are also better identified in NDSI image. This has been also shown in mapping of glaciers (Pandey *et al*.2011). This is also shown in figure 3. Another method to extract debris free glaciers was tried based on unsupervised classification of the entire scene. Since snow and ice have clear signatures as compared to the surrounding surfaces of rocks, soil or vegetation and therefore can be picked up directly by the remote sensing images. It uses the ISODATA algorithm to perform an unsupervised classification (Aniya *et al*.1996) as shown in Figure (3a, 3b, 3c). This method was not adopted as the unsupervised classification is based on only spectral recognition and the features such as dry sand etc also are classified as one class.

Though debris cover on the glaciers can be visually identified based on its association, and texture , even then a criteria is assigned to classify the glaciers into two classes i.e. debris covered or debris free based on checking whether stream originates directly from bare ice or from dark coloured debris cover part of glacier.

Extraction of debris covered glacier extents

A ratio image of Lands at TM bands 3 and 5 was generated (Bhambri *et al.* 2013). It was clubbed with slope image generated from ASTER DEM. (Paul *et al*. 2004) have shown the utility of using DEM along with multispectral images for extraction of glacier extents. ASTER DEM has a foot print of 30m with approximate vertical accuracy of ±15m (Kamp *et al*.2005). DEM has been downloaded from website of USGS. Lands at TM data of the year has been used for extraction of debris covered glaciers along with DEM. The threshold of > 2º and < 14º on the slope image was defined to subtract the slope of mountains surrounding the glaciers. Another difficulty is faced while auto delineation of glacier boundary in the accumulation zones when many glaciers originate from a large snow field. It requires delineation of extents by manual methods. The accuracy of debris covered glaciers was then checked with respect to extents already mapped earlier using visual interpretation. A total difference of > 5 % was observed. The auto extraction of debris covered glaciers require a rigorous and complex algorithms and rigorous ground truth of sample glaciers before using them as part of change detection. Therefore change detection was not applied on debris covered glaciers.

Change detection

The changes in extents of glaciers were executed only in debris free glaciers of LISS III scenes of two dates. Change detection involves changes in area around the ablation zones as the net change in glaciers is reflected near the snout of glaciers.

RESULTS AND DISCUSSION

Study of debris free glaciers is more important than of debris covered glaciers to understand the impact of climatic variations on sensitivity of glaciers. This is because these glaciers are directly exposed to atmosphere and are more sensitive to climatic variations. The major difference in the debris covered and free glaciers are the area of glaciers. Their area is smaller than those of debris covered glaciers. In this study 50 sample of debris free glaciers were taken. All the glaciers are independent and do not share any common extent in their accumulation zones. This helps in easy extraction of debris free glaciers. Whereas the many debris covered glaciers originate from very large snow fields and have common boundaries at the highest ridges or highest elevations of their accumulation zones. This creates a difficulty in auto extraction of complete glacier extents. Their area varies from 0.33 to 12 sq km. smaller in size, located at higher altitude and with a higher mean slope as compared to debris covered glaciers. It is necessary to know these characteristics in order to see the effect of climatic changes on glaciers with different altitude area and slope besides the presence or absence of debris cover.

In this study, we have not tried to estimate the changes in debris covered glaciers as the uncertainty in mapping due to debris cover are higher which might yield erroneous results. It is understood that smaller glaciers are more sensitive as their response time change in mass balance is smaller. Therefore changes have been checked only on debris free glaciers (Figure 4).

Based on data of 2016, the total area of debris free glacier comes out to be 146.94 sq km. yielding a loss of 0.95 sq km. Since both the data are of same sensor, the registration is better than half pixel and extraction is based on same algorithm, there is no scope of uncertainty in results. Yes, the uncertainty lies due to mixed pixels at the margins of glaciers but that is true for both the data sets which get nullified. Since it is a pixel based method, the scale of mapping does not come in picture. The main aim of this study is to suggest that instead of mapping debris covered glaciers using visual techniques, it is better to extract debris free glaciers by some automatic approach to see the effect of climatic variations on glacier

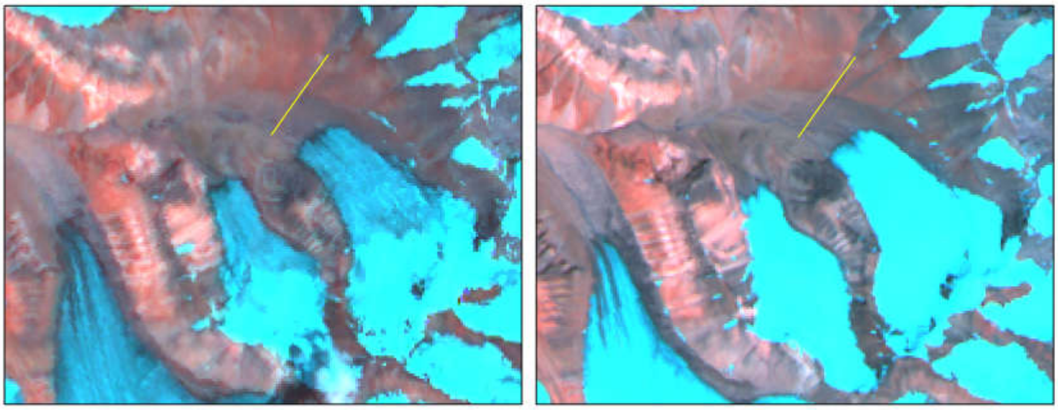

Figure 4 Three debris free glaciers as seen on LISS III data of August 2001 and October 2016. There is either no change or insignificant change in area of glaciers.

The total area of these glaciers is 147.9 sq km based on data of 2001. The mean area of these glaciers is 2.9 sq km. The area of another sample of 50 debris covered glaciers comes out to be approx., 568 sq km. the mean area comes to be 11.36 sq km. The altitude of snout of debris free glaciers varies from 4699 to 5457m. The mean altitude of snout of debris free and debris covered glaciers is 5149m and 4507m respectively. Since the length of debris free glaciers are smaller than those of debris covered glaciers and altitudinal difference between maximum and minimum altitudes are less in debris free than in debris covered glaciers, slope of former are higher than those of later. In other words the slopes of debris covered glaciers are gentler than debris free glaciers. This is the reason for higher carrying capacity of debris covered glaciers to carry debris load. The debris covers are mainly confined to ablation zones. The percent of debris cover with respect to ablation area of glaciers varies from 2 to 90-95 %. 90-95 % indicates that in some glaciers the entire ablation zone is covered with debris load. The aforementioned data indicates that debris free glaciers are extents,. Since debris free glaciers are more sensitive, it is desirable to see the effect on debris free glaciers. However the location of debris free glaciers normally remains higher than debris covered, it makes them less vulnerable to change in temperature. It has been confirmed that there is no significant retreat of debris free glaciers between 2001 and 2016. This is an important result for those arguing on the rapid or alarming retreat of Himalayan glaciers. Some authors also argue that there are elevation changes on the glaciers based on the studies of differencing of DEMs, but the large scale retreat of glaciers have been suggested based on the area changes rather than elevation changes. Moreover studies based on elevation changes require a high accuracy and registration of DEMs to compute the changes in elevations of glacier surface. The purpose of using the semi-automated approach for area extraction of debris free glaciers is to demonstrate that in the studies of glacier retreat/advance, the inaccuracies due to interpretation errors are minimized and automated methods save lot of time and efforts. Additionally results of such studies can be verified by more than one research groups by using same set of data and procedures.

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