DETECTING GLACIER SURFACE CHANGES USING OBJECT-BASED CHANGE DETECTION

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ABSTRACT

The concerns about global warming and climate change have produced widespread scientific interest in the response of glaciers. One of the important indicators of climate change is glacier change. The glaciers in Indian Himalaya have been retreating which can have several effects. Therefore, there is a need of precise and timely mapping and monitoring of the glacier changes. The advent of high spatial resolution images that provide more detailed information has now allowed analyzing glacier changes at a local level. However, change detection using high spatial resolution images faces additional challenges due to, for example, small spurious changes, etc. Fortunately, these effects are reduced by using object-based approaches rather than pixel-based approaches. In this study, object-based approach has been explored to detect the glacier surface changes from high spatial resolution images of WorldView-2 and Linear Imaging Self-Scanning System (LISS) IV which has not been done till date in Indian Himalaya.

Index Terms— change detection, glacier, glacier surface changes, high spatial resolution, object-based

1. INTRODUCTION

The response of glaciers is governed by global warming and climate change. One of the important indicators of climate change is glacier change (retreat/advance). The glaciers in Indian Himalaya have been retreating which can have several effects such as it affects the drinking supplies of the millions of people who rely on melt water of rivers. Therefore, there is a need of precise and timely mapping and monitoring of the glacier change so as to minimize the loss of life and property downstream. Remote sensing images and associated digital image processing are being opted widely to assess glacier change. The advent of high spatial resolution images that provide more detailed information has now allowed analyzing glacier changes at a local level. But, change detection using high spatial resolution images faces additional challenges due to, for example, small spurious changes, etc. Fortunately, these effects are reduced by using object-based approaches rather than pixel-based approaches. The process of detecting changes in geographic objects at different times using object-based image analysis (OBIA) is object-based change detection (OBCD).

OBCD has been used in numerous applications related to urban, forest, military, landslides, etc. However, OBCD has received little or no attention within the glaciological community. Hence, it is now possible to explore the OBCD approach for glacier change detection.There is only one study [1], which demonstrates the use of OBCD in detecting changes over glacier surface. Robson et al. [1] estimated decadal scale changes in glacier area in the Hohe Tauern National Park, Austria. A combination of Landsat 5 and Landsat 8 imagery with a LiDAR-based DEM was used to map glacier outlines and transient snowlines for the years 1985, 2003, and 2013 and assess the changes. Multi-scale segmentation was performed on the multi-temporal images and several band ratios and spectral indices were used in OBIA. The overall accuracy of 98% was reported.

The literature review on OBCD indicates that OBCD has been sparingly used in glacier surface change detection and appears to be futuristic technique. Further, to the best of our knowledge, no study has been carried out in the Indian Himalaya using OBCD to detect changes on glacier surface. In this study, a post-classification object-based change detection approach has been followed. As a case study, the changes in Gangotri glacier's (Uttarakhand Himalayas) surface have been detected using high spatial resolution WorldView-2 image and Linear Imaging Self-Scanning System (LISS) IV image for a three year period.

2. STUDY AREA

The Gangotri glacier has been considered as the study area. It is a major source of freshwater to Ganga, plays a vital role in the agriculture and hydroelectric power sectors. It is a north-westerly flowing valley glacier situated in the Uttarkashi district of Uttarakhand State, India. It extends between latitudes 30°43'20"N to 31°01'07"N and longitudes 78°59'42"E to 79°17'10"E [2]. The location map and extent of the study area is shown in Figure 1. This is one of the longest glaciers (~30 km) in the Indian Himalaya. The snout is known as Gaumukh from which the melt water, giving rise to the Bhagirathi River gushes out. Melting occurs throughout the year from Gangotri snout; however, its amount varies seasonally, with more melt waters in summer and less in winter seasons.

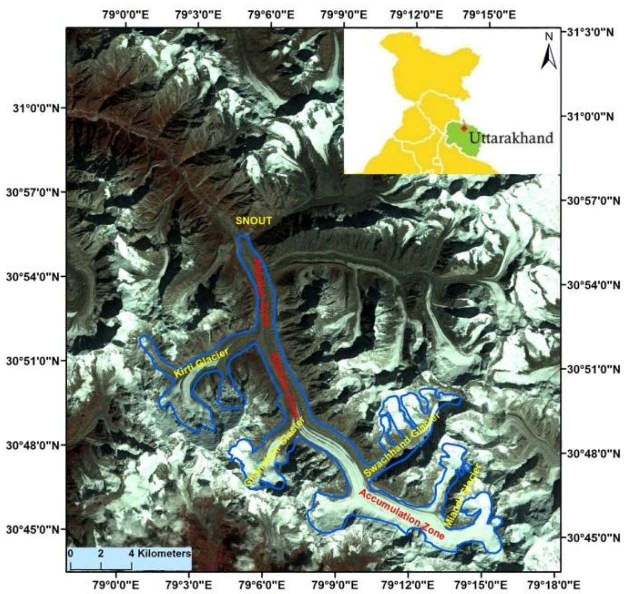

Figure 1: Standard FCC (R: Band 4, G: Band 3, B: Band 2) of Landsat TM image showing Gangotri glacier (Blue), its major tributaries (Yellow) and zones (Red).

3. METHOD

3.1. Data Processing

The datasets used in this study for performing OBCD include WorldView-2 (spatial resolution: 1.84 m, cell size: 2 m) image dated 09.11.2011 and LISS-IV (spatial resolution: 5.8 m, cell size: 5 m) image dated 15.09.2014. Due to the high cost of the WorldView-2 data, the image comprising only the ablation zone of main glacier trunk has been procured for experimental purpose. However, the ablation zone in the image covers almost all the glacier cover classes such as snow/ice, ice-mixed debris (IMD), supra-glacial debris (SGD), peri-glacial debris (PGD), valley rock, supra-glacial lakes (SGLs), debris cones, etc. Further, due to this very reason, that is, the high cost of WorldView-2 data, LISS IV image, which is available at nominal cost, was procured to obtain preliminary change results on glacier environment using OBCD. Both the WorldView-2 and LISS-IV images have been pre-processed for radiometric and atmospheric corrections. Both the scenes have been co-registered to ensure that the bi-temporal image objects in the same location are compared.

To compensate for spectral similarities between SGD, PGD and valley rock, ancillary data in the form of brightness temperature and slope were integrated with spectral data to enhance their discrimination. The slope information has been derived from ASTER Global DEM v2 of 30m and brightness temperature information has been derived from Landsat TM thermal band 6. The LISS-IV, slope and brightness temperature images have been re-sampled to 2 m and then subsetted to match with the spatial resolution and area of the WorldView-2 image respectively.

3.2. Post-classification OBCD

The workflow adopted in this study for detecting changes in glacier surface using OBCD is shown in Figure 2. A post-classification object-based change detection approach has been followed in this study in which the independently classified objects from multi-temporal images using OBIA are compared to detect the land use land cover changes. The object-based approach which has been adopted here for glacier change detection comprises of several sequential steps such as pre-processing of the multi-temporal high spatial resolution remote sensing images, image segmentation, defining glacier cover classes, selection of attributes, object-based image classification i.e. OBIA, and change detection using image differencing. All these steps are followed separately for each dataset i.e. WorldView-2 + ancillary data and LISS-IV + ancillary data. The image segmentation and OBIA steps are performed in most commonly used software for OBIA i.e. eCognition© whereas the change detection step has been done in ERDAS Imagine software.

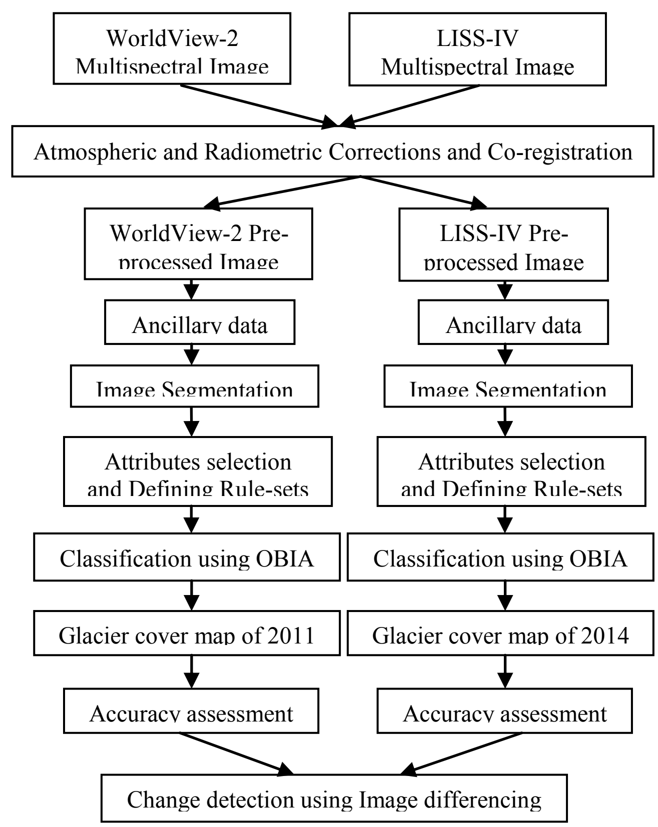

Figure 2: OBCD workflow for glacier change detection

The first step in post-classification OBCD is image segmentation which has been performed using multi-resolution segmentation. Selection of optimal segmentation parameters forms the pivotal step in OBIA. Iterative testing of segmentation parameters for WorldView-2 + ancillary has been done which resulted in the final selection of scale = 200 for large size features (level 1 segmentation) and 60 for small size features (level 2 segmentation), shape = 0.2, and compactness = 0.4, which has provided the best visual compliance of image objects with the identified glacier classes. Similarly, for LISS-IV + ancillary data, the values of optimal segmentation parameters have been found to be scale=180 for large size features (level 1 segmentation) and scale=35 for small size features (level 2 segmentation) have been found to be optimum whereas shape and compactness values are same i.e. 0.2 and 0.4 respectively. At level 1 segmentation, classes such as SGD, PGD, valley rock and shadows have been mapped and at level 2 segmentation, snow/ice, IMD, SGLs and debris cones have been mapped. Segments that were over segmented or under segmented were ruled-out using visual inspection.

The attribute selection process involves selection of spectral and spatial attributes depending upon the characteristics of glacier cover classes. In this study, the object attributes such as mean value, standard deviation, brightness temperature, slope, spectral ratios etc have been used to map different glacier cover classes. After attributes selection, OBIA has been performed. The following classification procedure has been applied by defining rule-sets:

a. Mapping of SGD, PGD, valley rock and shadows:

SGD, PGD, valley rock, and shadows have been delineated first as they form the basis for classification of other classes. SGD and PGD have been classified using the brightness temperature and slope whereas valley rock has been classified using the slope. Mapping of shadows has been carried out by using brightness temperature.

b. Mapping of snow/ice, IMD, SGLs and debris cones:

A second segmentation level has been used to classify snow/ice, IMD, SGLs and debris cones. Snow/Ice has been mapped using brightness temperature. IMD has been classified using NIR2/Yellow band ratio in case of WorldView-2 + ancillary dataset whereas in case of LISS-IV + ancillary data, NIR band has been used. SGLs have been mapped using NDSGLI index proposed by Mitkari et al. [3]. The spectral values of NIR band have been used to delineate debris cones.

Further to account for the differences in radiometric resolution between the WorldView-2 (11 bit) and LISS IV images (10 bit), the thresholds for classification had to be altered slightly. The accuracy assessment of the classified maps thus obtained for two time periods i.e. 2011 and 2014 revealed overall accuracies of 87.9% and 89.9% respectively. The independently classified maps were then imported in ERDAS Imagine software. The change detection was performed using image differencing tool. An example of the changing glacier cover from 2011 to 2014 is given in Figure 3. The areal changes obtained as a result are as shown in Table I. The accuracy assessment of the change detection map has been done using stratified random sampling scheme. The change from 2011 to 2014 has been assessed using the image of 2011 as reference. The accuracy evaluation of the OBCD approach presented in this study revealed an overall change detection accuracy of 91.41%.

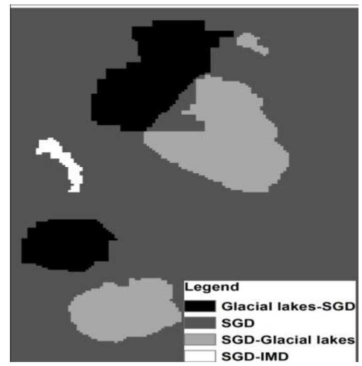

Figure 3: An example map of glacier cover change on a portion of Gangotri glacier from 2011 to 2014.

TABLE I
AREA CHANGE (SQ. KM. AND %) IN DIFFERENT GLACIER COVER CLASSES FOR THREE YEAR PERIOD FROM 2011 TO 2014

Class name	2011		2014		Area change (sq.km.)	Area change (%)
	Area (sq.km.)	Count	Area (sq.km.)	Count		
Snow/Ice	0.42	--	0.20	--	-0.22	-52.09
IMD	1.28	--	1.42	--	0.14	11.14
Valley rock	8.06	--	10.84	--	2.78	34.51
PGD	9.15	--	11.13	--	1.97	21.57
Debris cones	1.78	15	1.94	19	0.16	9.01
SGLs	0.09	97	0.16	69	0.07	70.30
SGD	19.06	--	18.98	--	-0.08	-0.42

4. RESULTS AND DISCUSSION

It has been reported that various features of the Gangotri Glacier especially the crevasses, SGLs, etc. are important in enhancing the rate of retreat. This supports the view that apart from global warming, rate of retreat is also influenced by characteristics of the glacier. Table I shows the change in areas of different glacier cover classes during the time period 2011-2014. From this table, it is clear that there has been a total area change of 12.11% in the Gangotri glacier cover during the three year period.

It is found that the snow/ice cover has decreased from 0.42 sq. km. in 2011 to 0.20 sq. km. in 2014. This indicates general decrease in snow fall and/or degradation of glacier health. The decrease in snow/ice is generally accompanied with increase in IMD. This has been observed in this study as well that the area of IMD has increased. It has increased by 11.14%. However, the percent cover of SGD appears to have decreased during 2011-2014.

The glacier surface is nothing but SGD and the change in SGD in the Himalaya affects the ablation rate of the glaciers and their response to climatic change. Further, the spatial and temporal variation in SGD (glacier surface) needs be considered when determining mass balance for glaciers through time. The glacier surface (SGD) has decreased in area by 0.42% between 2011 (19.06 sq. km.) and 2014 (18.98 sq. km.). This suggests that the Gangotri glacier retreated between 2011 and 2014.

The ablation zone of Gangotri glacier is full of SGLs. The area of SGLs is also important for determining the state of a debris-covered glacier. Over a period of time, increasing SGLs can suggest build-up of debris cover, resulting in a reduction of glacier stability. The change results of Gangotri glacier in this study obtained for the period 2011-2014 suggest that though the area of SGLs increased from 0.09 sq. km. in 2011 to 0.16 sq. km. in 2014, the number of SGLs has decreased from 97 in 2011 to 69 in 2014. An increase of 70.30% in the area of SGLs suggests that the Gangotri glacier retreated during 2011-2014; however, the decrease in the number of SGLs suggests that the rate of retreat of Gangotri glacier has declined. This has also been reported by Singh et al. [5] that though the Gangotri glacier is retreating but the rate of retreat has declined.

A number of debris cones are present all along the valley which comprises debris flow and fluvial sediments, the source of which is erosion of the adjacent moraines. The older phase of the glacier retreat defines the formation of older moraines which in turn defines the older generation of debris cones. In this study, an increase in the number and area of debris cones has been observed for the period 2011-2014. The number of debris cones increased from 15 in 2011 to 19 in 2014. The area of debris cones increased from 1.78 sq. km. in 2011 to 1.94 sq. km. in 2014. This shows that the Gangotri glacier receded in 2014 but by just 9.01%.

Previous studies [4] have also reported decreasing rate of retreat of the Gangotri Glacier in 2004 and 2008. It is a fact that glaciers are retreating globally and some glaciers appear to be declining at globally extreme rates. However, upcoming evidences suggest that such reports were, at best, exaggerated and the analysis is also contrary to the global warming [5]. Further, studies such as by Bhambri et al. [6] studied the areal changes in glacier using Cartosat-1 (2.5 m) and Corona KH-4A images (footprint ~17 km x 233 km) data. This showed that the high spatial resolution satellite data such as WorldView-2, Cartosat, etc possibly provide more valid results than coarse spatial resolution satellite data such as Landsat and topographic maps, and thus constitutes a valuable resource for glacier monitoring. In this study, an attempt has been made to study the glacier surface changes from high spatial resolution images of WorldView-2 and LISS-IV using OBCD approach. The results obtained also suggest that Gangotri glacier retreated during 2011-2014, but the rate of retreat is very less.

5. CONCLUSION

To study the pattern of rate of retreat of Gangotri glacier using OBCD approach, a number of high spatial resolution historical images are required. Further, the decrease in the number of SGLs in 2014 may be attributed to the spatial resolution of the LISS-IV data. As the spatial resolution of an image increases, it is possible to map small scale SGLs such as supra-glacial ponds. This is true in case of the WorldView-2 data because of its 1.84 m spatial resolution (2 m cell size). However, due to the 5.8 m spatial resolution (5 m cell size) of LISS-IV data, the supra-glacial ponds might not have been mapped. Further, the small scale features such as crevasses, rills, etc. could not be mapped with 5.8 m spatial resolution of LISS-IV data. Solution to this is to use the multi-temporal images WorldView-2 having revisit period of 1.1 days. However, WorldView-2 data is too costly. Therefore, another solution could be to use multi-temporal images pan-sharpened to 2.5 m using LISS-IV and Cartosat (2.5 m) which are too cheap compared to WorldView-2 data.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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