MODELLING SEMI-AUTOMATED DELINEATION OF SUPRA-GLACIAL DEBRIS AND CLEAN ICE GLACIAL CHANGES OF SHIGAR BASIN

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ABSTRACT:: Glaciers importance to the worldwide community turn out to be even further obvious when one studies their significance as water. Glaciers mapping is the first step to study the glaciers behavior. The specific objectives of the study were to (1) develop a computer model for semi-automatic delineation of supra-glacial debris and clean ice covered glaciers (2) analyze the change in areal extent of the clean ice and debris covered glaciers during the last decade 2000-2010. Medium resolution Landsat imageries with the ETM+ sensor were used with the temporal resolution of five years. For automatic delineation of clean ice and debris covered glaciers a model was developed based on different band rationing techniques NDVI, LWM, NDSI and geomorphological characteristics like slope and elevation. The total area of the glaciers was found to be decreased with the decrease in clean ice area. The glaciers debris cover analysis showed that overall on average there was a 20 % increase in the glacier debris cover from 2000 to 2011.

INTRODUCTION

Glaciers are world's water towers [1-3] delivering water for consumption and food generation all over the year. Intrinsically, they individually act to buffer small periodical variations by given that a stable, dependable source of provisions, even in periods of condensed precipitation [3,4]. This prominence is mostly vital in Asia, wherever greater than fifty percent of the inhabitants catches its water from the glaciers and snowfields of the Himalaya [5] interpreting the societies of that landform intensely vulnerable to even slight variations in glaciers' masses.

The Himalayas and the Tibetan Plateau form the extreme glaciated areas in the world, apart from the Polar Regions [6-10]. Geologists of the Geological Survey of India (GSI) lately calculated 5,218 glaciers in the Himalayas3 covering approximately 33,050 sq. km [11] or almost 17 percent of the Himalaya [9].

Himalayan glaciers are classified as clean-ice Type (C-type) And debris-covered Ice type (D-type) [12,13]. Debris or moraine covered glaciers are a significant sediment transport agent in cold mountainous environments [14]. Debris Cover the ablation zone generally originates from rock fall from the adjacent valley mountain, erosion from elevated lateral moraines, avalanches, and debris entrainment through glacial channels [15-18]. There are some obstacles to observing glaciers in Shigar Basin, along with any other place in the Himalaya. Mainly, thick sheets of rubbles in the glaciers' depletion regions make recognition and mapping of glacier boundaries very challenging [10,19,20].

An Understanding of debris cover is important for mass balance and glacier dynamics as debris thickness determines the ice- melt rate with the purpose of provision for and alleviate water source problems in advances of their existence [3,9]. However, if glaciers are to be examined, they necessarily first be delineate. Although, it is possible to efficiently map clear ice glaciers by means of satellite imagery with multispectral bands, it is essential to introduce new mapping techniques that depends on not only on spectral differences of satellite imagery to map the glaciers in Shigar basin [21-24]. A new morphometric method which incorporates topographical considerations, field data, and supervised processes, has been utilized to map debris roofed glaciers on Nanga Parbat [19], the Khumbu Himal [23] the Tien Shan [24] and the Alps [20]. The new method has already been recognized to be proficient for efficiently mapping huge debris protected glaciers in the Himalaya.

Using the morphometric parameters and different indices were computed using the Medium resolution Landsat imagery to delineate the clean ice and debris covered glaciers. The specific objectives of the study were to (1) develop a computer model for automatically delineation of clean ice and debris covered glaciers (2) analyse the change in areal extent of the clean ice and debris covered glaciers during the last decade 2000-2010. To fulfil these objectives DEM was used to compute geomorphic factors like slope and height together with some indices for the recording of clean ice and debris covered glaciers. The threshold rate distinct for each index NDVI (Normalized Difference Vegetation Index), NDSI (Normalized Difference Snow Index), LWM (Land Water Mask) index, was different for supra-glacial debris and clean ice glaciers that were extracted from the Landsat Imagery.

MATERIALS AND METHODS

Study Area

Shigar basin was selected as the study area (Figure 1). The latitude and longitude ranges from 35º 19' to 36º 07' and 74º 53' to 76º 45', respectively. It is one of the sub basins of Upper Indus Basin, situated in northern Pakistan.

Among all sub basins of Upper Indus basin, Shigar has the third highest numbers of glaciers after Shyok and Hunza. Shigar basin has 21% glaciers of Upper Indus basin and contains total 194 small and large glaciers and covers an area of about 30.34% of the entire basin area. Among these 30% are mountain, 25% niche, 24% valley and 18% cirque glaciers whereas the ice apron and ice cap glaciers are 2% each. The Shigar basin has glaciers in all direction however

primarily on North and North Eastern aspects while North Western aspects are also have higher numbers of glaciers.

The maximum (38) and minimum (16) numbers of glaciers present on the NE and on the western sides of the basin, respectively. Amongst all the glaciers of Shigar basin the main one is the Baltoro, with are more than 700 km^2. Baltoro is one of the longest glaciers (68km) outside the Polar Regions.

The total ice reserves of this basin are 581 km^2. There is 98.5% contribution of valley glaciers, 1% is by the mountain glaciers and below half percent is contributed by niche, cirque, ice cap and ice apron type glaciers.

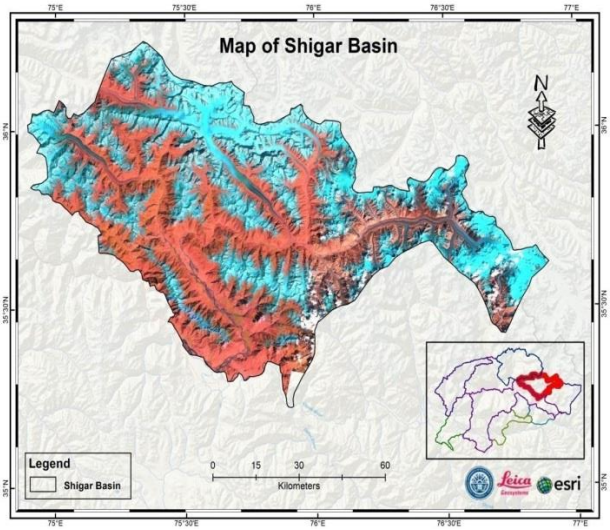

Figure 1. Location Map, Shigar Basin, Upper Indus Basin, Pakistan.

Administrative Boundaries

The administrative boundaries of Upper Indus basin and the outline of Shigar basin was acquired from Survey of Pakistan (SOP) in the form of shape files.

Remotely Sensed Satellite Data

Satellite images are considered as one of the best means of data in the glacier studies because of its easily availability, coverage of large and inaccessible areas and high spatial, spectral and temporal resolution. In this research study Landsat satellite images were used. The research study was conducted for a decade from i.e. from 2000 to 2011 for the mapping of glaciers boundary. Shigar basin was covered in two Landsat TM and ETM Plus sensor tiles.

Digital Elevation Model

Shuttle Radar Topographic Mission Global DEM (SRTM GDEM) with the spatial resolution of 30m was utilized to calculate the slope and elevation information of the study area for the delineation of glaciers boundary. Total six SRTM tiles were downloaded for the complete coverage of study area. . One SRTM tile has the spatial extent of 1° by 1°, and covers between the latitudes of 83°N and 83°S with expected accuracy of 20 m at 95% confidence for vertical data and 30m at 95% confidence for horizontal data.

Analytical Framework

The methodological flowchart for the research study is shown in figure 2. It comprises of three steps i.e. data pre-processing, ratio images and Model for the delineation of clean ice and supra glacial debris covered glaciers.

Morphometric Glacier Mapping

Morphometric glacier mapping (MGM) includes many constraints which, when joined, can occasionally demarcate glaciers efficiently, in spite of substantial debris concealments or other possible interferences [23,24]. Statistics of slope derived from the DEM information20 or more refined set of rules for classification of data based on geo-morphometric exploration19 and/or judgment schema classifiers [25] for appropriate approximation of possible debris covered glacier areas.

In this study MGM technique was used in which digital elevation model (DEM) greatly enhances the ability to characterize features in a mountainous environment. The basis in MGM is the use of topographic thresholds, derived from a DEM and the multispectral data along with ratio images for the automatic delineation of clean ice and debris covered glaciers.

Five major glaciers of Shigar Basin were selected for this study which includes the Baltoro, Biafo, Panmah, Chogo, Hisper because these are the glaciers with maximum area as they are the representative of whole basin but the Hisper glacier was then eliminated because of the terminus area was in other Basin

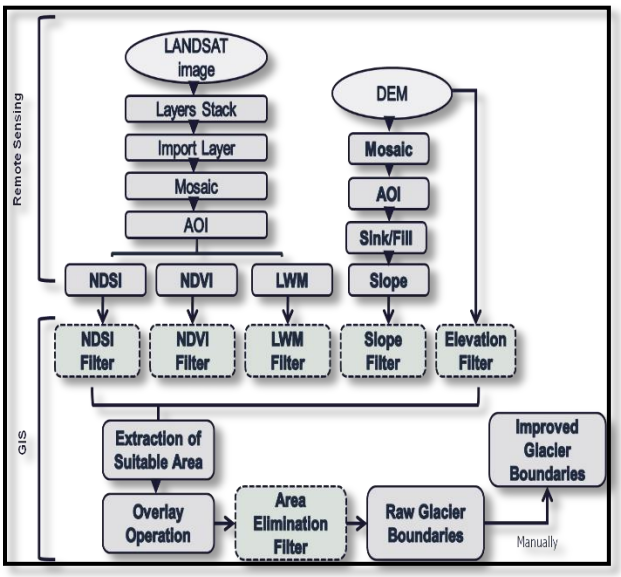

Figure 2. Automatic delineation of clean ice and debris covered glaciers.

Filter for Clean Ice Glaciers

The filters were generated on the basis of threshold values defined for the extraction of clean ice glaciers after the snow accumulation i.e. after March. Normalized difference snow index (NDSI) was used for the identification of the clean ice glaciers, threshold was given to NDSI ratio image but few tiny polygons of shadow, water bodies, vegetation, rocks, debris, and other misclassified polygons were also captured. Other filters were used to refine the clean ice including the NDVI for vegetation, LWM for water bodies, and mean hue for shadow. Slope and elevation criteria were also used to improve the glacier boundary. Small polygons with an area of ≤ 0.02 km^2 were removed. This process suitably delineates the boundary of clean ice glaciers. The glacier outlines were validated using Google Earth high resolution imagery.

All generated filters using the above indices were classified into two major classes i.e. one which were found suitable and other which were not found suitable for the delineation of clean ice. A raster layer of clean glaciers was obtained after applying the constraints listed in table 1 using Raster Calculator in Arcgis10 environment.

Table 1.Constraints for development of clean ice delineation filters.

Data	Constraints
NDSI	≥ 0.5
NDVI	≥ 0.34
LWM	≥ 31.5
Slope	> 60°
Elevation	< 4569 m.a.s.l

Filter for supra glacial debris covered Glaciers

The filters were generated for the delineation of debris covered (DC) glaciers, after the snow ablation i.e. in month of September, on the basis of specific defined constraints (table 2).

Capturing of DC glaciers is further complicated by errors due to same spectral signature of the debris covered glaciers and debris around it. Following delineation of CI glaciers using NDSI, the debris covered glaciers were captured from the remaining areas of the image using either NDVI or mean slope. This classification method also includes other features like vegetation, bedrock, and shadows. Using filters such as LWM, slope, and elevation the boundary of debris covered glaciers refined.

Polygons with an area ≤ 0.02 km^2 were removed. It was validated through Google earth. For the extraction of debris covered glaciers from the raster of the slope, elevation, LWM, and other indices i.e. NDSI, NDVI were classified into suitable and not suitable area using Raster Calculator, with defined constraints listed in table 2.

Table 2. Constraints for development of filters for debris cover glaciers delineation.

Data	Constraints
NDSI	≤ - 0.005
NDVI	< 0.3
LWM	50 – 115.8
Slope	< 24°
Elevation	3000 - 6000 m.a.s.l

The clean ice and debris cover glaciers boundaries were delineated automatically by using model developed for automatic delineation of clean ice and debris covered glaciers shown in figure 3.

After applying the overlay operation the raw boundary of all glaciers including the clean ice and debris covered glaciers were generated as shown in figure 4 & 5. Glaciers with combined layers of clean ice and debris covered glaciers shown in figure 6.

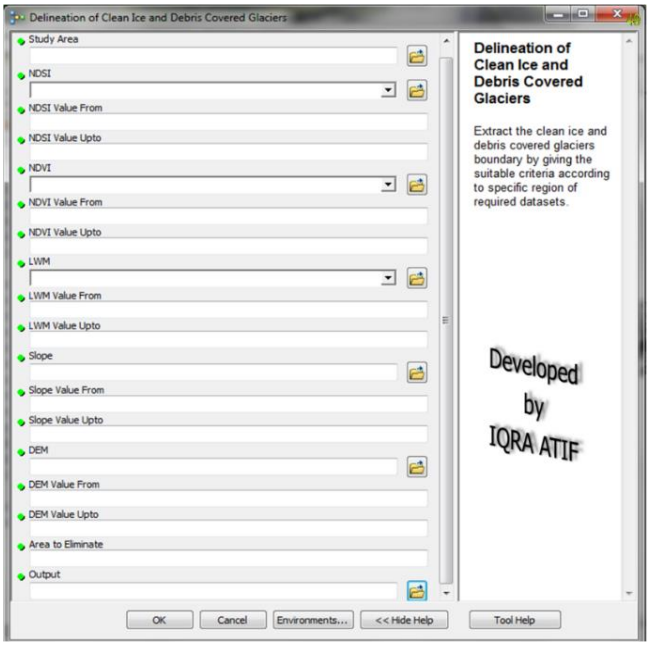

Figure 3. GIS based computer model for delineation of debris covered and clean ice glaciers.

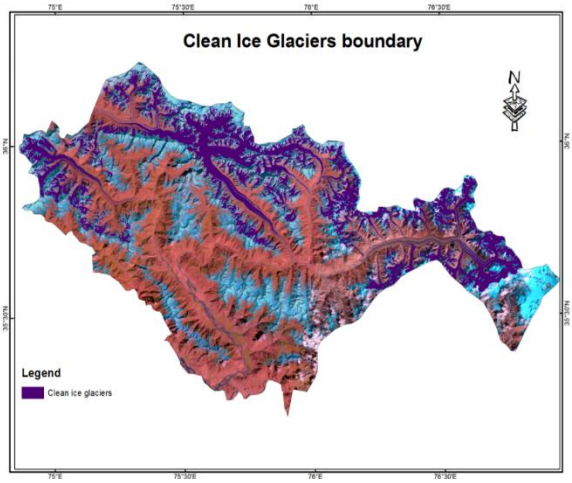

Figure 4. Raw boundaries of clean ice glaciers extracted from Shigar basin by applying filters.

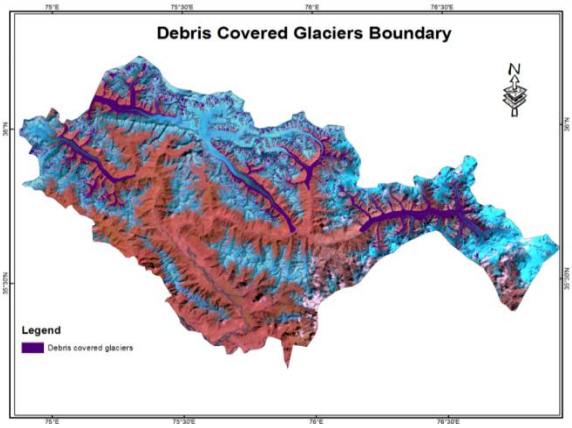

Figure 5. Raw boundaries of debris cover glaciers extracted from Shigar basin by applying filters.

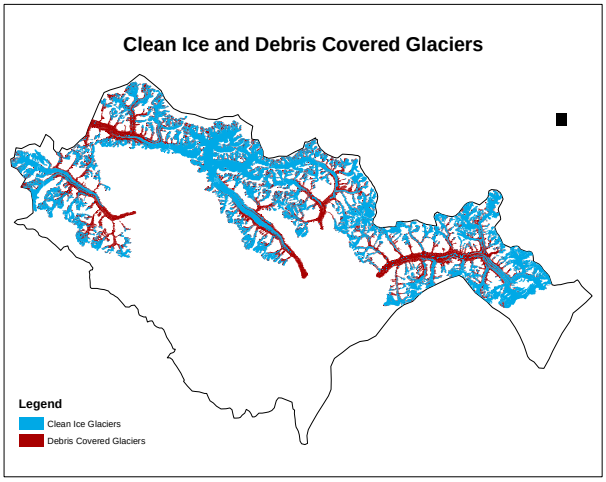

Figure 6. Raw boundaries of clean ice and debris cover glaciers overplayed to extract complete glaciers from Shigar basin by applying filters.

RESULTS AND DISCUSSION

Areal Change in Clean Ice Glaciers

The decreasing trend in clean ice glacial area was observed in Shigar Basin. Yamada et al.; stated that the retreating trend of clean ice glaciers is possibly speeded up in the 1980s [26]. Studies show that mass balance is negative from the time when measurements taken on clean ice glacier AX010 which is located in the Shorong Himal south-west of the Khumbu Himal in 1978, and the mass loss speeded up in the 1990's [27]. The glacier AX010 contracted from 0.57 to 0.42 km² (which is greater than 26%) during the years 1978 to 1999. The debris covered areas increase at many glaciers which is related with the glacier recession, e.g. at the Khumbu Glacier [28]. In 2005 the area was increased compared to the years 2000 and 2011 this could be attributed to the variability in climatic condition. Some studies have revealed the increases in the glaciers of the central Karakoram region [29,30]. During the 2005 winter season precipitation was at maximum and the temperature was too low as compared to decadal average30 reported that who reported a minor increase of glacial mass in the central Karakoram. The decreasing trend was observed in all glaciers i.e. Baltoro, Biafo and Chogo glaciers except for the Panmah glacier which shows an increasing trend over the same reported period. The figure 7 shows the clean ice area of four major glaciers in Shigar basin.

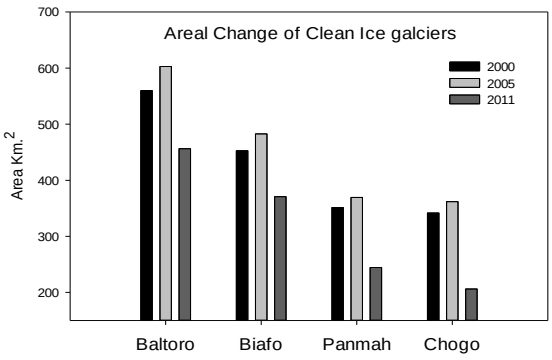

Figure 7. Areal change of clean ice Shigar basin glaciers during last decade 2000 - 2011.

Several studies [3,7-9,11,31-35] supported these findings that there is a general trend in retreat of glacial area in the Himalaya as well as its nearby mountain ranges.

Areal Change in supra glacial Debris Covered Glaciers

The debris covers of the Shigar Basin glaciers were showing increasing trends during the last decade i.e. from 2000 – 2011 as shown in figure 8. Few researchers [28,36] reported that that debris cover of Himalayas glaciers has been increased with the contraction glacier.

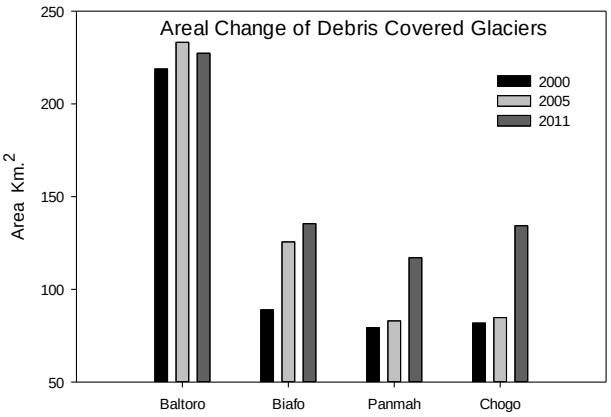

Figure 8. Areal change of debris covered Shigar basin glaciers during last decade 2000 - 2011.

The Remote sensing data shows an increase in debris cover of Biafo glacier only, there was a minor difference between the debris cover of Panmah and Chogo Glaciers as the Panmah glacier exist at higher altitude with the highest elevation of 7200 m.a.s.l and Chogo exist at lower altitude with the elevation of 6700-2700 m.a.s.l. Utilizing remote sensing techniques for the retreat in the area of glaciers numerous studies have been done in India, Kulkarni et al.; using remote sensing analyse the glacier retreat of Parbati in Himachal Pradesh [7]. They reported that the glacier area had decreased by 578 m from 1990 to 2001, almost 52 m annually.

The results reveal that the climatic effect on the whole Shigar Basin in the summer 2005 was similar. The whole Shigar basin was in influence of higher precipitation and lower temperature anomaly. Study was done by Nakawo et al.; showed that in almost 100 years, due to rate of high melting enormous portions of the glacier tongue will vanish [37].

Validation of glaciers outline

High resolution imagery of DigitalGlobe, GeoEye from Google Maps were used to estimate the accuracy of Shigar basin glaciers outline including the debris covered and clean ice region. Shapefiles of glacial boundaries were exported to KML format and overlaid on the Google Maps which consist of sub meter resolution of imagery, 60cm. Automatic delineation using the indices and morphometric complete glacier boundary including debris covered and clean ice portion produced accurate results and it precisely overcome the shadowed area. Shigar Basin glacial boundaries of Panmah, Chogo, Biafo and Baltoro is shown along with their terminus in figure 9. Root mean square was estimated for each glacier mapping. For Baltoro glacier the RMS error of 10.23 was calculated while for Biafo, Panmah and Chogo glacier the RMS error was approximately 11.28, 12.31 and

10.52. This proved the reliability of the morphometric approach used for the mapping of clean ice and debris covered glaciers using GIS and remote sensing techniques.

CONCLUSION

The morphometric technique for the delineation of clean ice and debris cover glacier was very effective because of its characteristics of incorporating slope, Elevation and the extraction of glacier from the shadowed regions and automatically differentiate the debris cover glacier from the surrounding rocks. For automatic delineation of clean ice and debris covered glaciers a model was developed based on different band rationing techniques and geomorphologic characteristics. The total area of the glaciers was found to be decreased with the decrease in clean ice area. The glaciers debris cover analysis showed that overall on average there was a 20 % increase in the glacier debris cover from 2000 to 2011.

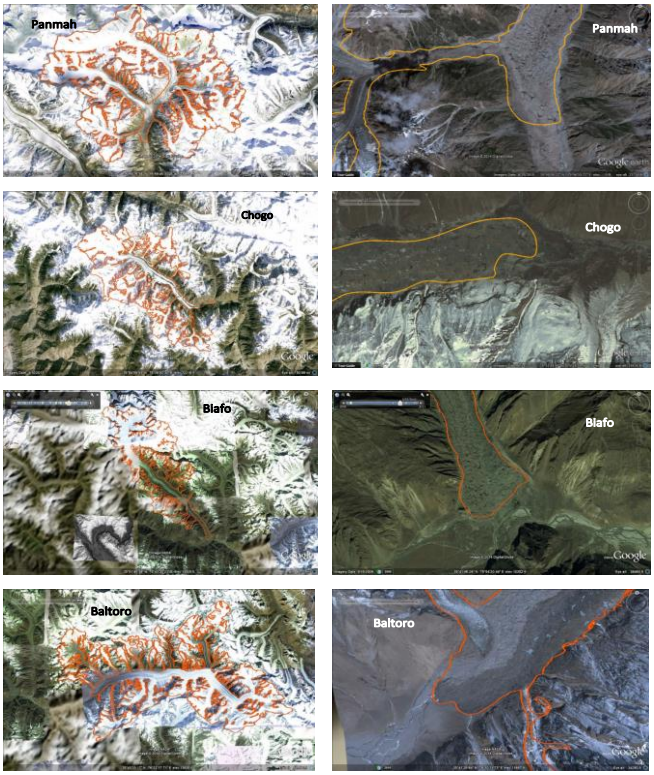

Figure 9- Showing the complete boundaries of Panmah, Chogo, Biafo and Baltoro glacier on left side while on right side the terminus of glaciers boundaries overlaid over high resolution imagery for positional validation.

The accuracy of the results could be increased with high spatial and temporal resolution of satellite imagery and digital elevation models like WorldView3 imagery and LIDAR data respectively. The model developed for the automatic delineation of clean ice and debris cover glacier was found very effective and could be applied on other basins of Himalayas.

Glaciers mass balance should be known to better understand the climatic effect and its effect the local hydrology and thus important for regional water supplies and accessing global sea level rise.

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