Application of Remote Sensing for Temporal Mapping of Glacier and Glacial Lake

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Abstract

In this study, we present spatiotemporal assessment of Glacier and Glacial Lake in the Hindukush and Karakoram ranges. Two sites, namely Yazghil Glacier and Darkut Glacier and Glacial Lake have been selected to map the impacts of climate change by Remote Sensing data and GIS. For each site, Glacier and Lake have been mapped with LANDSAT satellite images from 1977 to 2015, using a normalized snow & water index and digitization of lowest elevation of Glacier and Lake Area. The Yazghil has shown anomalous behavior i.e. the glacier remained almost stable during 2002 to 2011, but in 2015 the glacier retreated in length and breadth. On the other hand, during the same period Darkut Glacial Lake has been increasing continuously during 1988 to 2015 and the decreasing trend of the same Glacier about 0.43 Km was observed.The annual average air temperature data of Yazghil and Darkut depicts the increasing trend from 1916 to 2015, and the sharply rising trend was observed from 2000 to 2015 based on Climate Research Unit data. In the recent satellite data, the decline of Yazghil and Darkut Glacier and increasing Lake area of Darkut is a clear evidence of retreating of Glacier, which can be attributed to the rise in mean temperature of the region. The results indicate that the Yazghil and Darkut glaciers are in a state of retreat and have been gradually losing mass. It is necessary to monitor the area continuously and to save the downstream community from probable Glacial Lake Outburst Flood.

Key Words: Glaciers & Glacier Lake, NDWI, NDSI.

Introduction

Pakistan water resources largely depend on meltwater generated from Hindukush-Karakoram-Himalayan (HKH) mountain ranges. People living in the mountainous region rely on the agriculture activities. The glacier or snow melt water is used for agriculture, electricity generation and drinking purpose. Glacier melt water helps to maintain river system during the dry season. The run-off of Indus River is a mixture of glacier melt water and rainfall. Glacier melt water is of high importance for the run-off of the Indus River (Immerzeel et al., 2010).

Three different ranges i.e. Hindukush-Karakoram-Himalayan ranges are located in northern areas of Pakistan. Several studies on the HKH range suggest that the glaciers of the Karakoram are the stable and mostly surge type (Hewitt, 2005; Copland et al., 2011; Bolch et al., 2012; Kaab et al., 2012; Rankl et al., 2013; Herreid et al., 2015). Himalayan glaciers indicate the wide fluctuation rate of terminus (Dobhal et al., 2013). Ahmad, B., et al., 2015 used the statistical downscaled Global Circulation Models (GCM,s) of Representative Concentration Pathways RCP 4.5 and RCP 8.5 data from 2010 to 2099, the rising trend of temperature and precipitation regarding rain for Upper Indus Basin (UIB). Moreover, the fluctuation of the glacier terminus is directly and indirectly related to the increasing air temperature and decreasing trend of solid precipitation. The retreating glaciers a major source for meltwater (Lutz et al., 2014).

According to Intergovernmental Panel on Climate Change (IPCC) report of 2014, anthropogenic activities are the main cause of global warming and have likely affected the global water cycle. Worldwide Glaciers have continued to shrink due to climate change. Satellite remote sensing techniques is a practical approach generally used for assessment of Glacier mass balance. Remote sensing method is capable of detection of Glaciers mass changes. Gardelle et al., 2013, measure the mass changes of Karakoram glaciers by remote sensing data. The objective of the present study is to utilize the remote sensing application to map the long-term behavior of Yazghil Glacier and Darkut Glacial Lakefrom 1977 to 2015.

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Study Area

The study area includes Yazghil Glacier and Darkut Glacial Lake (Figure 1), located in the Hunza and Ghizer District respectively, Hindu-Kush Karakoram ranges of Gilgit-Baltistan, Pakistan. The climate of the area is humid receives solid and liquid precipitation as well, the westerlies weather system is dominated with maximum precipitation in winter (Herreid et al., 2015). The type of glaciers in this region is mostly winter-accumulation (Gardelle et al., 2013; Ragettli et al., 2013). Yazghil glacier flows from the peaks of the Hispar Muztagh to the valley of the Shimshal River. Its coordinates are 36°28'43.91" N and 75°13'48.92" E. Darkut Glacial Lake coordinates are 36°38'31.90" N and 73°24'25.22" E situated in Darkut village that is a sub-village of Yasin valley in Ghizer District. For this study, we selected the two sites because of the anomalous behavior of Yazghil Glacier and increasing area of Darkut lake. There is a high probability that in the future, flood risk may have grown and damaged the agriculture activities and local community which settled the downstream of the glaciers.

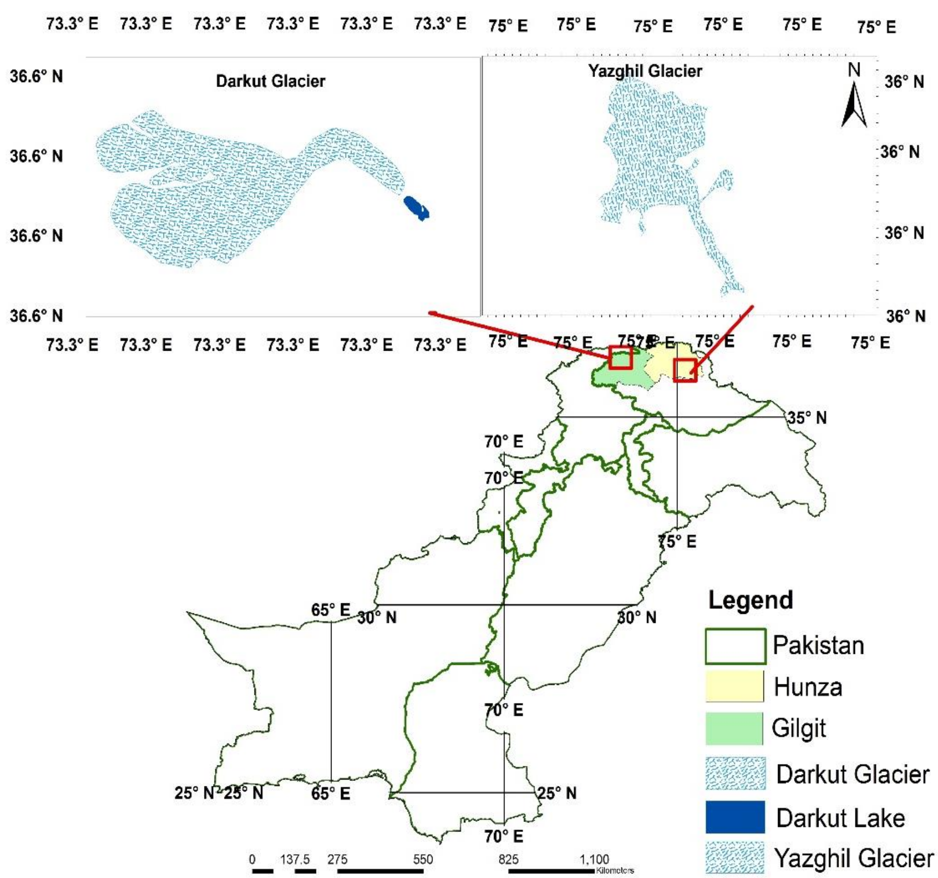

Figure 1: Geographic location of Yazghil Glacier & Darkut Glacier Lake, Hunza and Ghizer District Pakistan.

Data and Methodology

The primary data used in this study are LANDSAT 3,5,7,8 satellite images of multi spectral scanner (MSS), thematic mapper (TM), enhanced thematic mapper (ETM+) and operational land imager and thermal infrared sensor (OLI /TIRS). The data was acquired from the USGS Earth Explorer website for the duration from 1977 to 2015. Imagery provides essential information, the spatial and spectral resolution of LANDSAT 3 to 8 are different, most recent OLI/TIRS is available at 30*30 meter spatial resolution. The geographic location of the LANDSAT images for Yazghil glacier and Darkut Lake is used according to a worldwide reference system (WRS). For mapping, the least snow and cloud coverage images selected. The method to evaluate the mapping of Yazghil glacier terminus and Darkut Lake could be achieved through integrating remote sensing and GIS techniques. The data processing was carried out in ArcGIS and ERDAS Imagine software. As the images consist of different bands, those bands were layer stacked for further processing. The annual average mean temperature data set of Climate Research Unit (CRU) from 1916 to 2015 for last 100 years is used. For the spatial variability of annual area weighted temperature the domain latitude 36.15 to 36.54, longitude 75.08 to 75.55 for Yazghil and similarly latitude 36.50 to 36.70, longitude 73.30 to 73.50 for Darkut were selected.

At present, two methods are primarily used to map the Glacier terminus and the Lake area. The first is based on the Normalized difference Snow Index (NDSI) for glacier terminus and Normalized difference Water Index (NDWI) for the lake.

$$NDSI = Green - SWIR/Green + SWIR$$

$$NDWI = Blue - SWIR/Blue + SWIR$$

Normalized difference (Water/ Snow) Index is a satellite-derived index between visible (green & blue) and Shortwave Infrared (SWIR) bands. It is widely used to enhance the feature of Snow and Water. In order to distinguish snow from the cloud and reduce the impurities of water help to delineate Lake Boundary. The second method is digitization by visual interpretation of the terminus and lake based on indices map and geo-referenced google earth imagery for accuracy.

Result & Discussion

This study concentrates on the spatiotemporal behavior of Glacier and Glacier Lake. The Glacier extent was mapped by remotely sensed LANDSAT earth observation data acquired from 1979 to 2015. Glacier mass surplus or defect affect the hydrological cycle of the catchment. A negative mass yields an increased flow from accumulated ice and positive mass depicts the more accumulation of ice on glacier. Figure 2 shows the NDSI and digitization for terminus mapping of Yazghil. In the year 1979, the analysis performed on LANDSAT 3 the number of spectral bands and spatial resolution was very low. Glaciers are usually classified from the spectral band (Paul et al., 2016). Higher the number of bands easy to discriminate

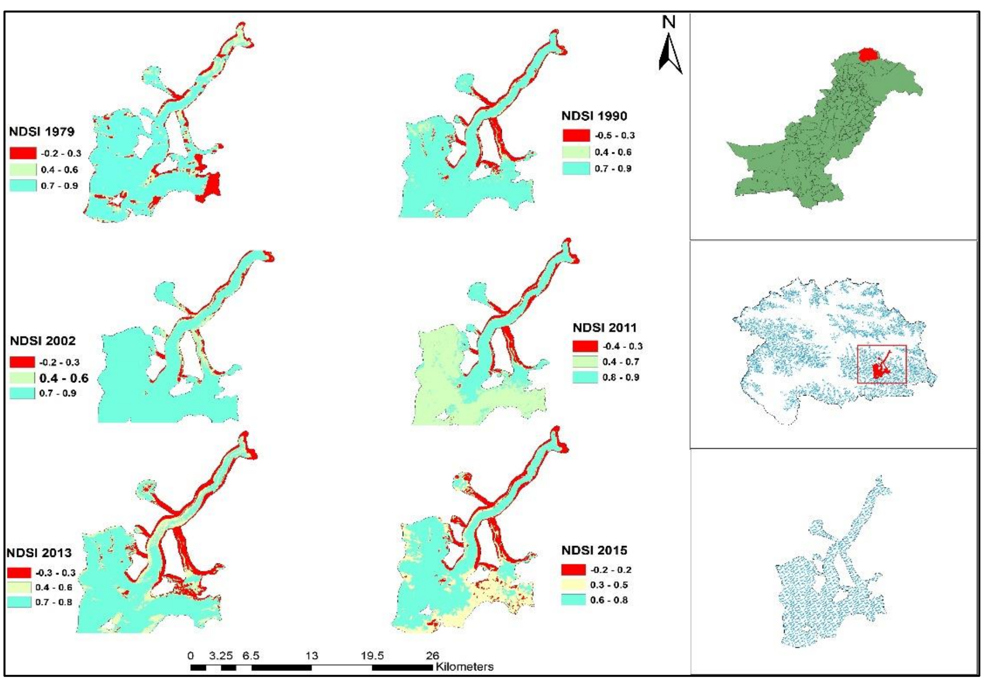

Figure 2: Terminus mapping of Yazghil terminus by Normalized Snow Index and digitization from 1979-2015

between Glacier, snow, debris and shadow. However, in case of a lesser number of bands it is challenging to extract the outline of the glacier. The NDSI results show the decline of Yazghil Glacier mass from 2011 to 2015. However, discharge data of Shimshal River is required for validation of reults.

The Karakoram is the most glacierized region. Its glaciers are the main water resource of Pakistan (Minora et al., 2013). Several studies on the Karakoram show that most of Karakoram glaciers are surging and display anomalous behavior (Hewitt, 2005; Gardelle, 2012). We performed temporal analysis on the LANDSAT imagery. The inaccuracies may occur in MSS and TM images due to least spectral bands, image resolution influences the accuracy of mapping. Figure 3 represents the terminus outline, Yazghil glacier is called two tongues glacier. Our result shows the anomalous behavior of Yazghil. In the earlier image 1979 to 1998, retreat/melt found in length and width. In the year 2002 to 2011, the stable situation of the glacier was found including length (lowest elevation) and size. Hewitt (2005), confirmed the recent advances of Yazghil by satellite imagery during 1999 to 2001. Moreover, in the year 2015 dramatically shrinking behavior in overall length and size was found. In short, Yazghil Glacier showed anomalous behaviour of surging and retreat over the year. In order to understand the anomalous behavior of Yazghil, high-resolution images and field experiments are required.

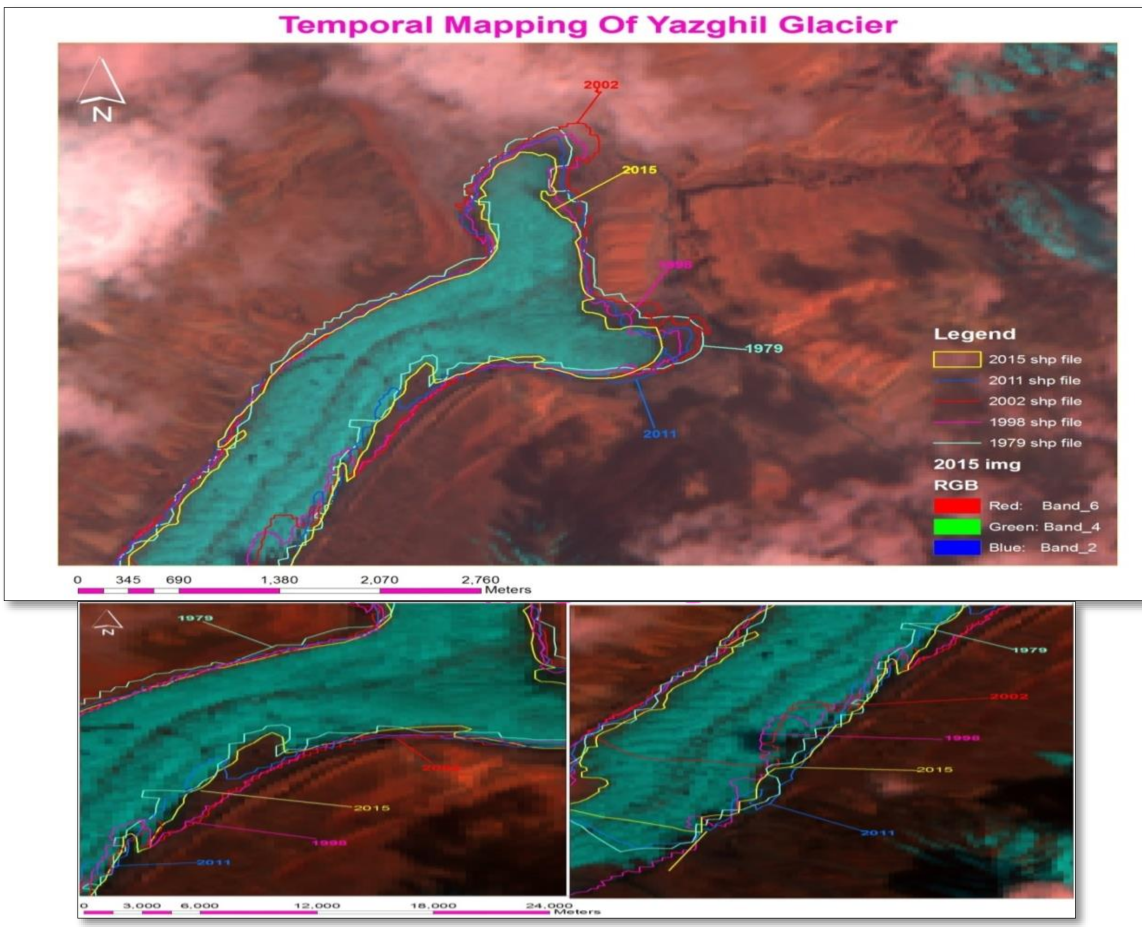

Figure 3: Terminus outlines (at lowest elevation) and size (breadth) of Yazghil 1979-2015.

A worldwide glacier studied shows an increase in debris-covered area or glacier declines. The Darkut glacier shows a slight loss mass resultant increase the lake area at the situated terminus of the glacier. The glacier shrinkage reports across high mountains Asia (Cogley, 2016). Temporal changes mapped from 1977 to 2015, in the earlier imagery Figure 4, of 1977. We cannot see the prominent lake in this image. Due to lack of complete bands, proper information cannot be retrieved from the image that either it is a debris covered lake or lake is not present at all in this satellite image.

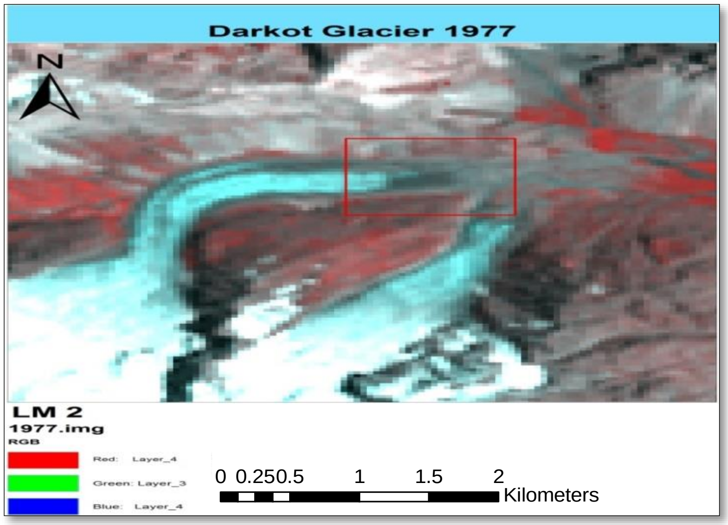

Figure 4: LANDSAT 3 MS sensor image of 1977

Normalized difference water index was applied on 1988 LANDSAT 5 TM image. Moreover, the extent of Lake was not clear, besides this, the band ratio of visible blue and SWIR was applied which showed the brighter water pixel on the image. Figure 5 shows the temporal changes of Lake Area from 1988 to 2015.

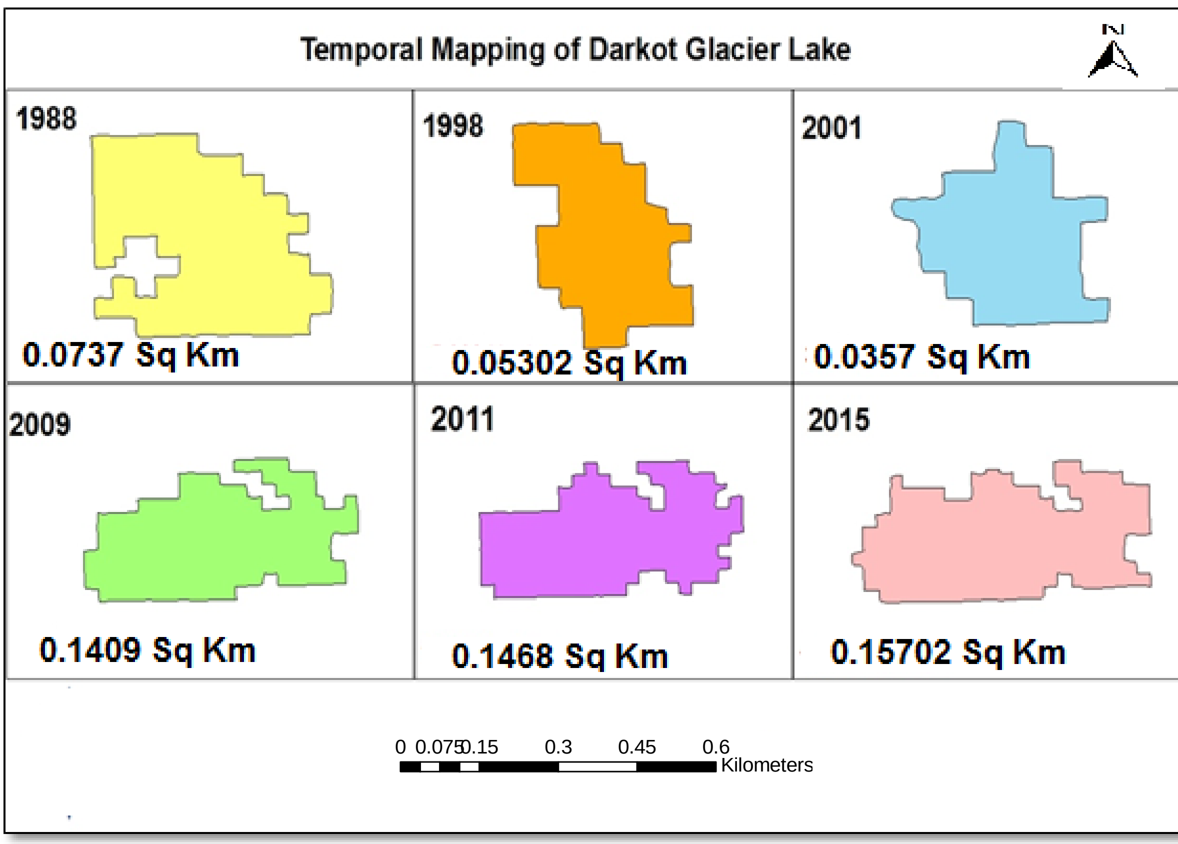

Figure 5: Temporal Lake area from 1988 to 2015.

In the year 1988, Lake Area is about 0.073 sq km. After ten years in 1998 lake area shrink up to 0.02 SqKM i.e. 0.053 Sq. km as compared to that in 1988. It further decreased in 2001 and the area was about 0.0357 Sq. km. From 1988 to 2001 gradual decrease in the area of the lake was observed while in 2009 area increased up to 0.149 Sq. km. The area is increase 0.59 for 2 years from 2009-2011, 1.11 for 4 years from

2011-2015. The area is increasing gradually from 2009-2015 with almost the same behavior. The area in 2015 is 0.157 sq. km. The main cause of the overall lake area increased is due to the retreating behaviour of the same glacier around 0.43 Km from 1998 to 2015. Figure 6, shows the terminus mapping of Darkut glacier by NDSI and NDVI. The terminus result shows that the gradual glacier retreat from 1998 to 2015 was observed. The increase in lake area the shrinkage of Darkut glacier and similarly the anomalous behaviour of Yazghil which may be a footprints of climatic changes over the region. Glaciers is easily understandable indicator of climate change. Moreover, the surging or shrinking of Glaciers can be caused by climate change (Arshad et al., 2016, Jansson et al., 2003). The spatial variability of mean annual area weighted temperature of Yazghil and Darkut based on CRU data are illustrated in Figure 7 a and b.

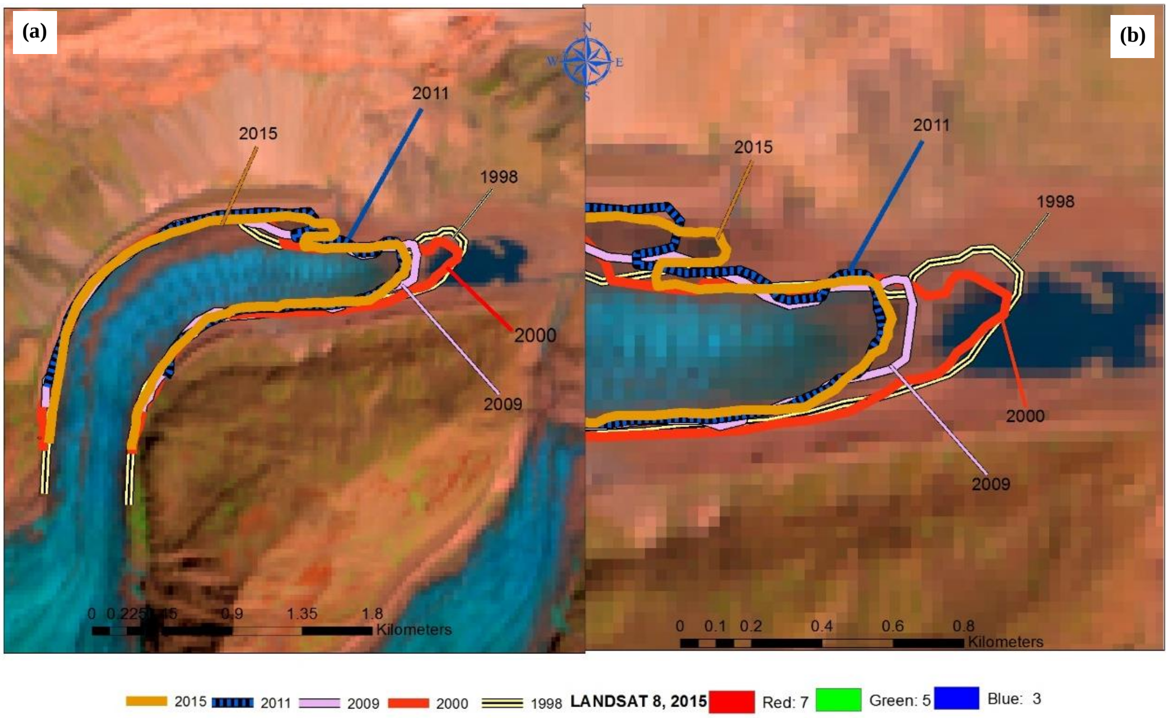

Figure 6: **(a)** Darkut Glacier, **(b)** Terminus mapping from 1998 to 2015

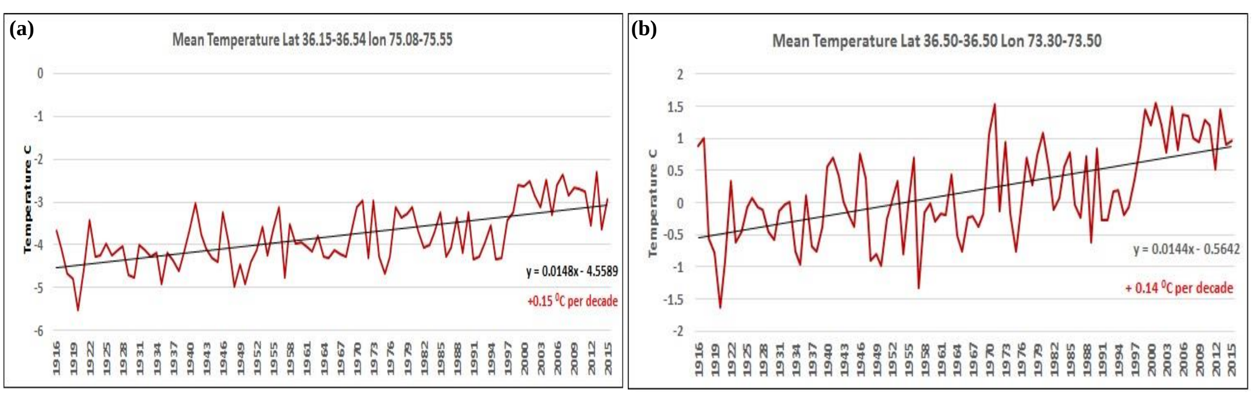

Figure 7: Trends of average annual temperature of Yazghil **(a)** and Darkut **(b)** during 1916 to 2015 from CRU data.

Air temperature indicates an increasing trend from 1916 to 2015, note that temperature at the rate +0.15 °C per decade for Yazghil and +0.14 °C per decade increased for Darkut. From Figure 7, we note the sharply rising trend of temperature from 2000 to 2015. The increasing air temperature can be related to rapid melting and shrinking of Glaciers over the basin. In response to increasing air temperature in future over the basin, mountains glaciers are expected to shrink in the coming decades.

Conclusion

We used an Earth Observation satellite data spanning four generation of LANDSAT sensors to analyse the temporal behaviour of Yazghil Glacier and Darkut Glacier and Lake. In accordance with the results, the total Yazghil Glacier surface increased or Glacier has increased from 1979 till 2002, but in 2011 Glacier decreased as compared to past and in 2015 the Glacier area and length further decreased. The retreating behaviour of Darkut Glacier has been observed and the lake at the terminus of Darkut Glacier shows the area increased during the same period. The air temperature for last 100 years shows increasing trend for Yazghil and Darkut. Moreover, the sharply rising trend of temperature from 2000 to 2015 can be linked to the Glacier melt due to the local climate change. An increase in Darkut lake area would be favourable for water resource management for cropping and others but simultaneously could be alarming in perspective of glacier lake outburst flood (GLOF). The results based on RS and GIS techniques reveals that the Glaciers of Himalayan and Hindukush are affected due to climate change. The expansion of lake area and anomalous behaviour Yazghil are hazards for the downstream community. The local people should be made aware of the consequences of climate change on Glacier and its possible outcomes.

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