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An Analysis of Glacial Retreat and Resultant Vegetation Expansion in the Karakorum: A case study of Passu Glacier in Hunza valley

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ABSTRACT

The glaciers are the life line of Pakistan's economy since they serve as fresh water and feed reservoirs which help in hydroelectric power production and provide water for agriculture. The changing climatic trends of the Hindu-Kush Himalayan (HKH) region have resulted in the decrease of its glacial volume such as Baltoro and Biafo. Passu, the glacier whose water feeds Hunza River, is also facing retreat due to climate change. Changes in the area under vegetation in Passu village due to Passu glacier retreat have also been estimated using normalized difference snow index (NDSI) and normalized difference vegetation index (NDVI) which were also derived from the satellite images. NDSI for snow cover mapping of Passu glacier indicates a decrease of 6.18% in snow covered area (3.0808 km^2) of Passu glacier from 1992-2016. This was identified as 12.8% as annual in the area of Passu glacier. In response to this glacial retreat, area under vegetation has increased @ 4 percent per annum since 1992 and it covers almost half of the area (0.981 sq. km area) of Passu village which is fed by the melted water of the Passu glacier.

Keywords: Climatic trends, Retreat, NDSI, NDVI, snow covered area and sparse vegetation.

INTRODUCTION

The rivers of Pakistan have their constant fresh water source in the glaciers that lie in its north. As per ICIMOD (2011), there are 18, 495 glaciers in the Indus basin of HKH. It is a huge glaciated region with total area of 21, 193 km^2. The average mass per glacier in the Indus basin's glaciated region is 1.2 km^2. 85% of the annual flow of Indus and its tributaries are contributed by the snow and ice melt (Hewitt *et al.,* 1989). Gilgit, Hunza, Shyok, Shigar and Astore are the sub basins of the UIB that are mostly galcierized. During a year, the snow shrouded zone in Upper Indus Basin ranges from 10 to 80%. According to Immerzeel *et al.,* 2012, during the snow accumulation period of Dec-Feb, the snow covered region covers almost 80% of the region, while it gets reduced to a mere 10% in the snow-melt period of June-Sep. The same can be proved with the example from upstream Tarbela reservoir, where maximum snow extent is recorded (during the study period) in February 2013, i.e. 191813 km^2 and the minimum was recorded in the snowmelt period of June 2013 i.e. 76196 km^2 (SUPARCO, 2013). The rapidly changing climatic trends in the higher altitude regions of the world are causing changes in the timing of the snowmelt (Zhou *et al.,* 2011). Jilani *et al. (*2007) have reported a retreating trend of two of the major glaciers of the HKH region, i.e. Batura and Biafo. Similar advancing and retreating trends of Liligo glacier have been reported by Pecci & Smiraglia (2000). Another glacier of great significance, in terms of its melt water contribution to the Hunza river, is the Passu glacier of the Karakorams. This glacier has 60% of its basin covered with ice, and is 28 km long (Woodward *et al.,* 2002).

Passu glacier went through a drastic retreat of 20m in the last 15 years (Riaz *et al.,* 2014). It has also undergone various episodes of advance and retreat and thus vegetation growth can be expected on the newly exposed terrain. Intense vegetation growth in front of retreating glaciers has also been observed in Alaska (Cooper, 1939; Boggs *et al.,* 2010), the Alps (Erschbamer *et al.,* 2008) and the

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Scandinavian Mountains (Matthews & Whittaker, 1987).

Attabad lake, located south of Passu glacier, was created due to a landslide on Jan 4, 2010, in the Gojal valley. This dam is facing dangers of bursting, due to constant changes in the glacierized region of Passu glacier. In the event of such a dam burst, there would be a catastrophic flooding downstream, thus making the present study more significant. As indicated by an extremely noteworthy research by Chaudhry *et al.* (2009), throughout the previous 40 years Pakistan faced a 0.76ºC ascent in temperature. On the other hand, there was a 1.5 °C rise in temperature recorded in the rugged north. For the period 2001-2010, the same rugged area of Pakistan endured a dangerous temperature ascent of 1.3°C. The quickly changing climate has brought about massive retreat and even depletion of significant glacial area of the region (Hasnain & Thayyen, 1999). Mazhar *et al.* (2015) mention similar temperature rising trend of 0.4°C in areas around Kakul and Astore that lie in the mountainous north of Pakistan. The authors also conclude that areas around Bunji, in the northern areas, for the period of three decades i.e. 1980-2010, suffered a temperature variance of -1.41°C to -0.30°C.

Glacial advances and retreats can be monitored trough mapping the snow cover of the region. NDSI is one of the widely used methods to map snow covered area by utilizing the satellite imagery. As indicated by Puri (2013), NDSI uses the reflectance values of snow, for snow covered area mapping. Snow and ice identification is done through NDSI, which utilizes the green and short wave infrared (SWIR) wavelength for snow/ice identification. The snow appears white, as its reflectance is high in the visible spectrum (Rummel, 2013). On the contrary, snow appears black in the SWIR region because of it low reflectivity. As high reflectivity is shown by clouds in the SWIR region, thus NDSI is believed to be most reliable in distinguishing snow from clouds (Puri, 2013). Kulkarni *et al.* (2006) presented yet another great advantage of using NDSI for snow cover detection. He mentions in his study that “NDSI is independent of illumination condition”. NDSI is capable of identifying the snow and non-snow pixels in the shadow of a mountain and also under any kind of orientation.

The present study analyzes the changes in the vegetation extent of the Passu village, during 2000-2016. A most frequently used normalized difference vegetation index (NDVI) (Dennison & Roberts, 2003; Sesnie *et al.,* 2008; Karaburun, 2010; Eichel *et al.,* 2016) were used to identify green cover of an area. Thus it monitors spatio-temporal variations in vegetation thickness, health and viability of plant cover. Passu village, in Hunza valley has rich and diverse plant life. Eberhardt *et al.* (2007) has also mentioned in their study that as this region enjoys an arid type of climate due to its subtropical location and thus steppe vegetation prevail in the study area. The authors report approximately 380 species of vascular plants found in this region, among which dwarf-shrub kind of vegetation was found to predominate. Besides the dwarf-shrub vegetation, patches of forest, dense scrub and turf were also found. According to Awan *et al.* (2013) Hunza valley is home to trees and shrubs of Russian olive (*Elaeagnus angustifolia* Linn.) which is used as a remedy for cough and flu and is a main ingredient of an herbal drink Joshanda. Eberhardt *et al.* (2007) reported the predominance of isolated trees (*Populus pamirica*, *Betula jacquemontii*) on the steep slopes in the Batura valley (north of Passu glacier). *Ephedra* sp. is a dwarf-shrub found commonly in Hunza valley which barely reaches the maximum height of 30 cm, as it is intensely grazed to ground level by the local herds. In Hunza main valley the most commonly and widely found species are very open dwarf-scrub of *Artemisia fragrans*, *Ephedra intermedia* and a few other species. Another dwarf scrub which is commonly spotted along the Hunza River is *Artemisia brevifolia-Haloxylonthomson*ii. There has been massive change in land use of the region as people cleared huge tracts of former *Artemisia fragrans-Ephedra intermedia* dwarf-scrub and converted it into irrigated farmland and fruit gardens (Eberhardt *et al.,* 2007).

MATERIALS AND METHODS

Study Area

Passu glacier lies in adjacent basins within the Hunza basin of the Karakoram Himalaya in northeast Pakistan as shown in **Fig.1**. As compared to Batura glacier, Passu Glacier is much smaller, almost 28 km long with a reasonably clean and highly crevassed surface.

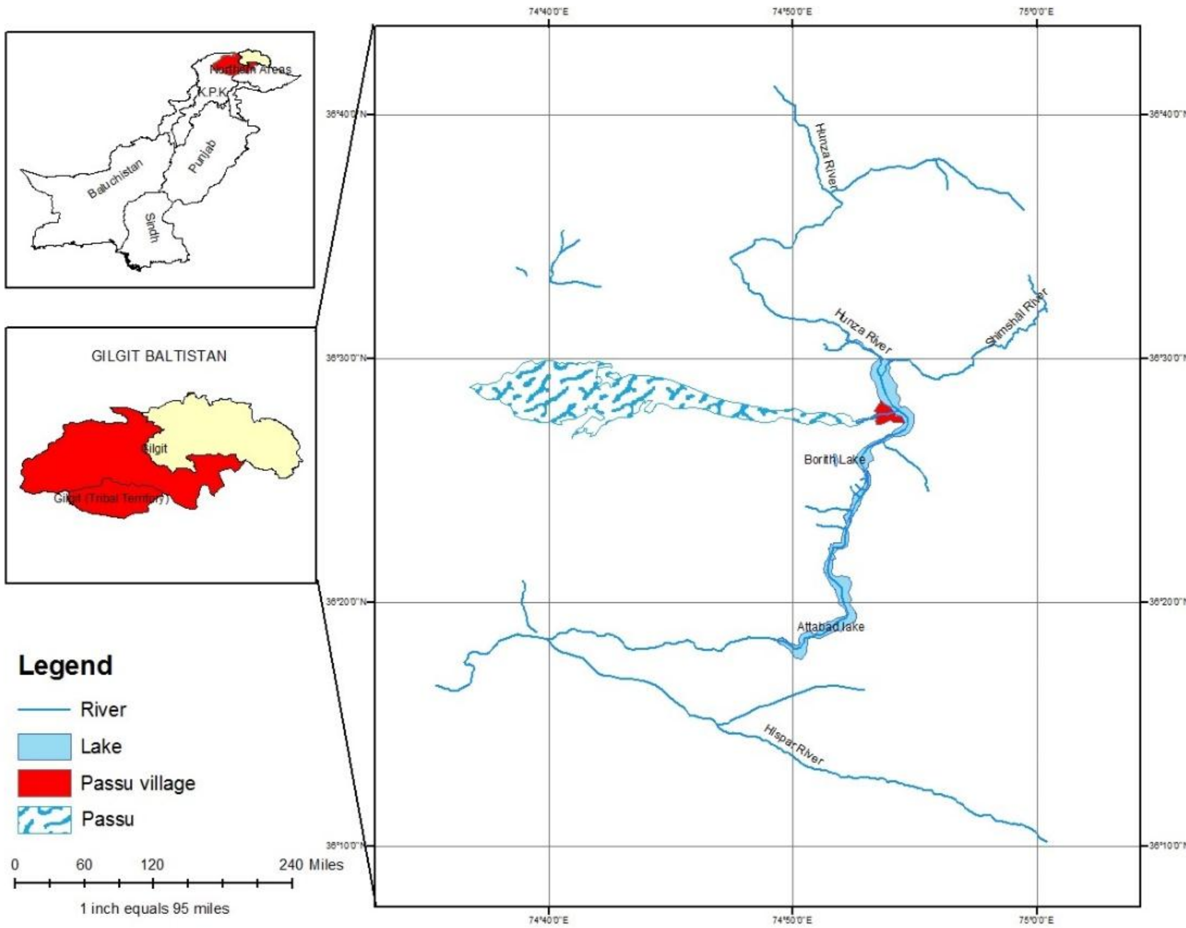

Fig. 1: Study Area map

The terminus lies at 2700 m above sea level. The Passu village lies beside the Hunza River at terminus of Passu glacier**.**

The major objective of this research was to produce maps showing the fluctuations in snow covered area of the Passu glacier, which feeds the Hunza River, for the time period 1992-2016 and its impact on vegetation change in Passu village, which lies to the east of this glacier (2000-2016). Thus, Passu village was chosen for vegetation cover change detection. The main analysis performed in this research included calculating NDSI of Passu glacier and NDVI of Passu village.

NDSI Calculation

Fig. 2 presents the methodology of snow cover mapping adopted in the present study. In this study, the images of Passu glacier, of three years for the month of October were selected for snow cover difference analysis. According to Rummel (2013) and Veettil (2012) it is recommended to use the images of October to study the snow cover as it marks the end of ablation season.

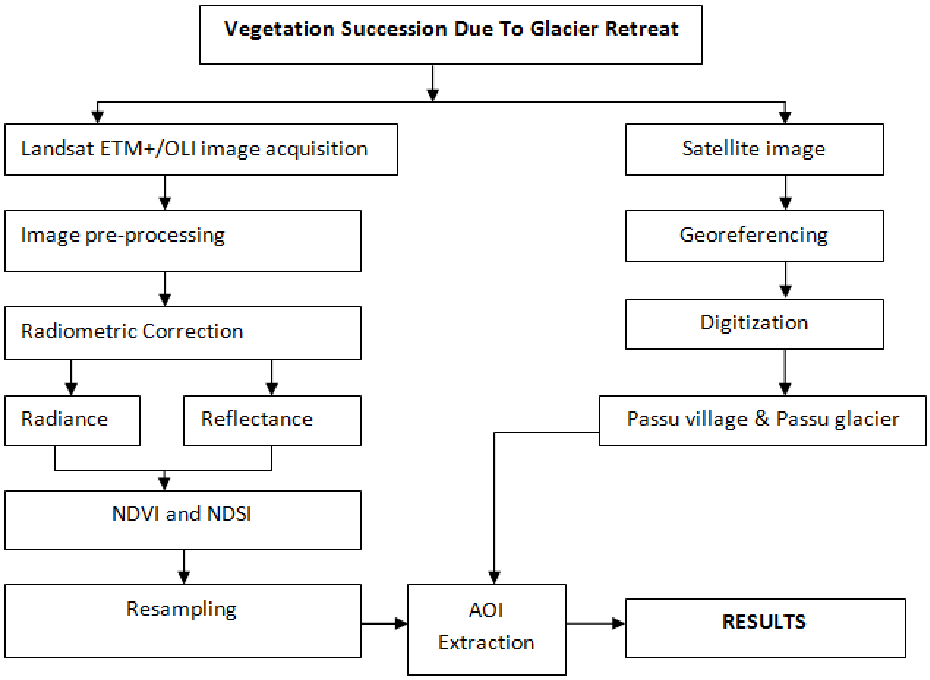

Fig. 2: Methodology of snow cover and vegetation mapping

Data Pre-processing

At first conversion of digital number to radiance values was done. This process is called radiometric correction. In the second step radiance values were converted to reflectance values (Chander *et al.,* 2009).

Following is the equation used to calculate the radiance of Oct 2000 image. This is the equation which is used in most of the papers (Puri, 2013, Bruce & Hilbert, 2006, Chander *et al.,* 2009).

Equation 1

The equation used for calculating radiance for 1992 Lands at TM image is:

$$L_{sensor} = \frac{L_{max} - L_{min}}{Q_{calmax} - Q_{calmin}} * (Q_{cal} - Q_{calmin}) + L_{min}$$

Equation 2

The equation used for calculating radiance for the year 2000 Lands at ETM+ image is:

$$L = Gain \times DN + Bias$$

Once the radiance has been calculated the reflectance was calculated for each band. Following formula was used for calculating reflectance:

Equation 3

$$\rho_\lambda = \frac{\pi d^2 L_\lambda}{E_{0\lambda} * \cos\theta s}$$

Equation 4

The following equation is used to convert DN values to TOA reflectance for OLI image:

$$\rho\lambda' = M\,\rho Qcal + A\,\rho$$

where,

ρλ' = TOA planetary reflectance, without correction for solar angle

Mρ = Band-specific multiplicative rescaling factor from the metadata

Q cal = Quantized and calibrated standard product pixel values (DN)

A ρ = Band-specific additive rescaling factor from the metadata

Data Processing/Analysis

NDSI was applied once the radiance had been calculated using the following equation:

Equation 5

$$\text{NDSI} = \frac{\text{Green Band Reflectance} - \text{SWIR Band Reflectance}}{\text{Green Band Reflectance} + \text{SWIR Band Reflectance}}$$

The result of NDSI application was layer of NDSI that had values which range between -1 to 1 (highest value showing maximum snow cover). A threshold value of 0.4 was applied to differentiate snow. The same threshold has been used by various researchers like Veettil (2012), Negi *et al.*(2009) and Dozier (1989). By applying this threshold value, pixels with values less than 0.4 were re-classified as snow-free area, while the pixels having values greater than 0.4 were re-classified as snow covered area.

NDVI Extraction

The NDVI is an indicator that can be used to analyze object being observed contains live green vegetation or not. Data processing for radiometric correction to extract NDVI is same as for NDSI in which conversion of digital number into radiance values followed by converting the radiance values to reflectance values (Chander *et al.,* 2009; Rouse *et al.,* 1973). NDVI is calculated by equation 6:

$$\text{NDVI} = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})}$$

Where RED is visible red reflectance, and NIR is near infrared reflectance. The wavelength range of NIR band is (750-1300 nm), Red band is (600-700 nm).NDVI values vary with the absorption of red light by plant chlorophyll and the reflection of infrared radiation by water-filled leaf cells. The NDVI value ranges from –1 to +1, where +1 denotes a thick and healthy vegetation cover, while –1 signifies non-vegetation areas. In order to find vegetation a threshold value of 0.1 was applied to identify sparse vegetation (Purevdorj *et al.,* 1998).

RESULTS AND DISCUSSION

The study concludes that the sifting climatic trends in the mountainous north are causing glacial area to decrease. The snow covered area of the Passu glacier which lies in the Karakoram mountain range, for the year 1992, 2000 and 2016, is presented in figure 3, 4and 5.The calculations of the glacial area prove that Passu glacier went through a massive decrease of 6.18% in snow covered area (3.0808 km^2) for twenty four years' time period (1992-2016), with an annual decrease of 12.8%. The maps of Passu glacier 1992, 2000 and 2016 prove that the snow free area has expanded at a small scale, mainly along the tip of the glacier, (figure 3, 4 and 5). Snow free area extends like a thin film along the northern boundary of the glacier. A gradual increase can be seen in the year 2016 map where the previous patches of snow free area have increased in size. In the middle of the eastern section of Passu glacier are found some small scattered patches of the snow free area. The results of NDSI can be seen in Table1.

Table 1: Results of NDSI

Date of Image Acquisition	Snow Covered area in %	Snow Free Area in %	Snow Covered area in km^2	Snow Free area in km^2
15/10/92	98.77	1.22	49.8483	0.6192
29/10/2000	97.18	2.81	49.0464	1.4202
17/10/2016	93.44	7.40	46.72	3.7

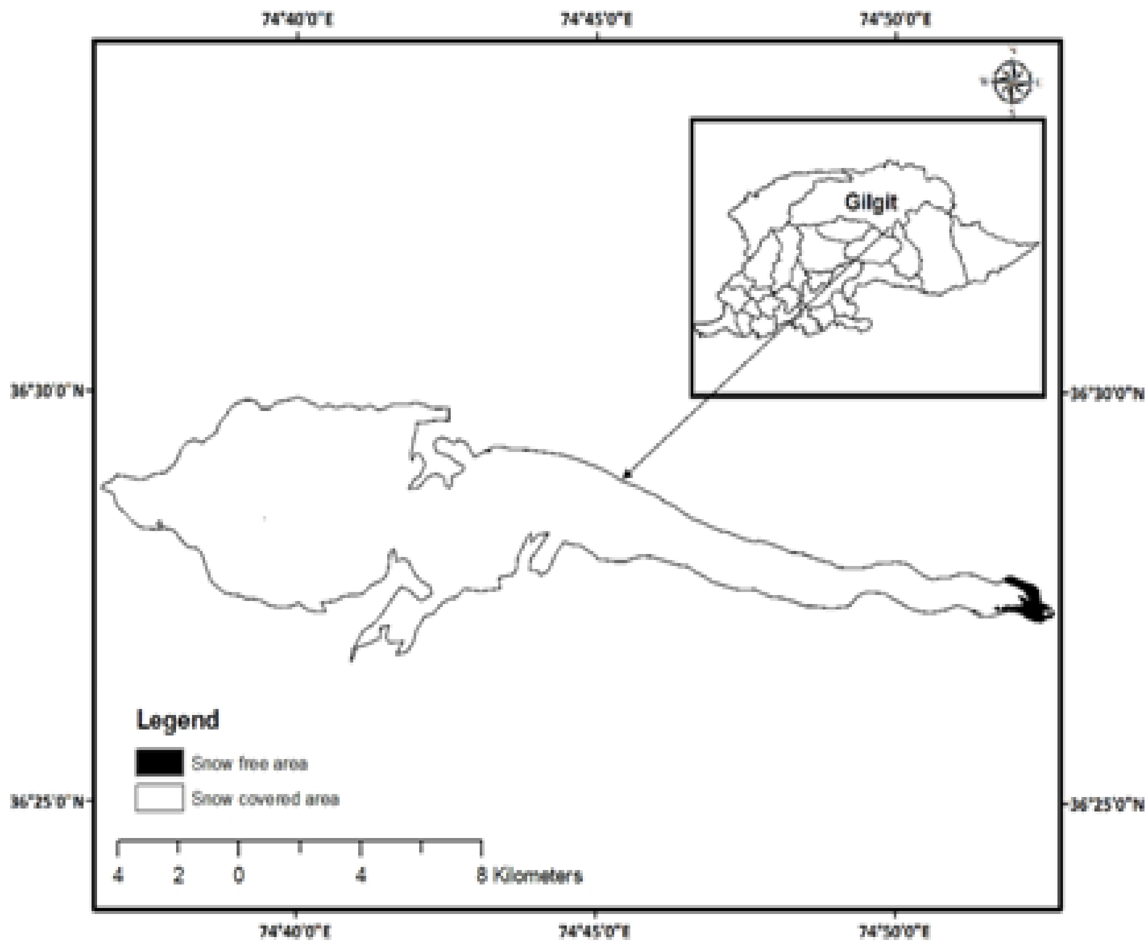

Fig. 3: Passu glacier, the snow covered area, Oct 1992

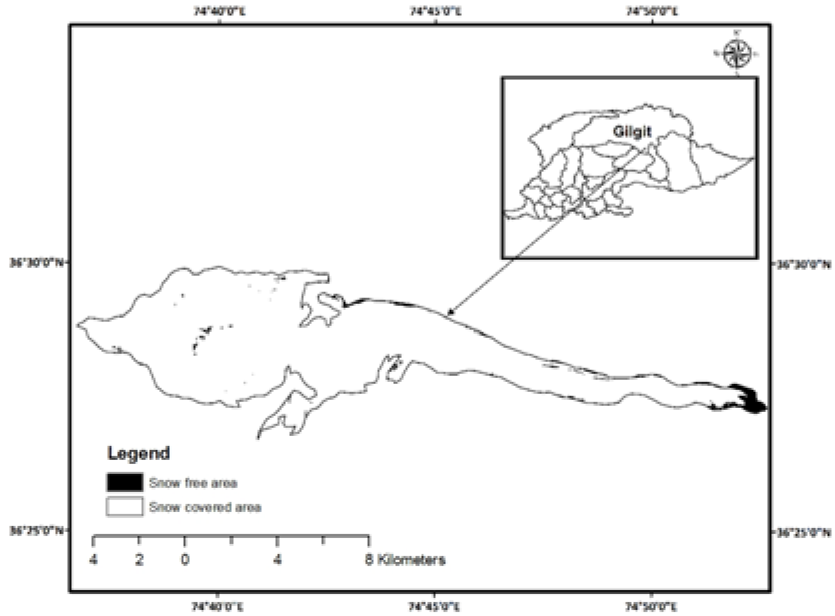

Fig. 4: Passu glacier, the snow covered area, Oct 2000

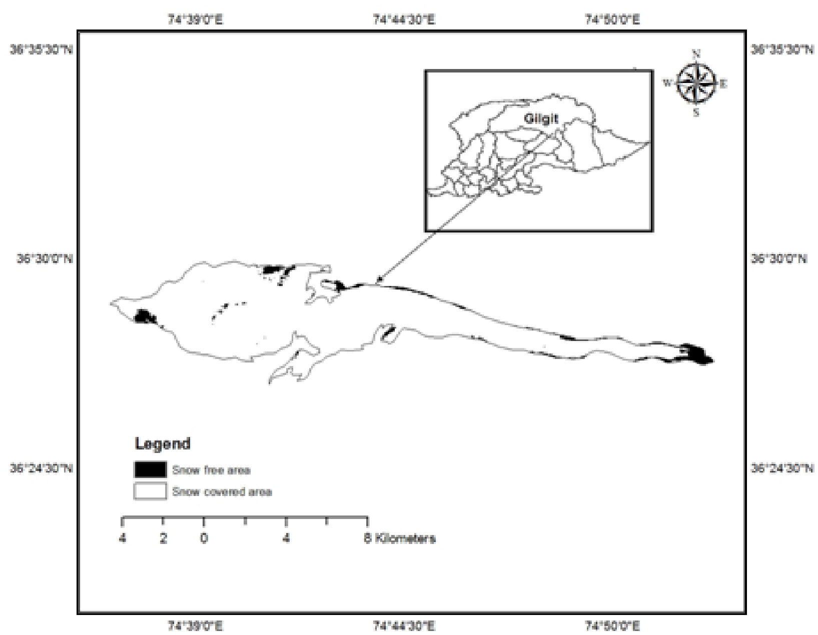

Fig. 5: Passu glacier, the snow covered area, Oct 2016

In response to glacial retreat, sparse vegetation of Passu village, located in the foreland region of Passu glacier, increased about 50 percent in 2016 as compared to its 2000 status. Figure 6depictsthe NDVI calculated for Passu village which shows that the vegetation cover has drastically increased from 0.6471 sq. km in 2000 to 1.6281 sq. k min 2016. Temporal variation of NDVI can be seen by visual interpretation in figure 6. Results have been presented in Table 2.

Table 2: NDVI results

Years	Barren rock area (sq.km)	Vegetation cover (sq.km)	Barren rock area %	Vegetation cover %
2000	1.1934	0.6471	59.67	32.35
2016	0.2043 sq.km	1.6281	10.25	81.40

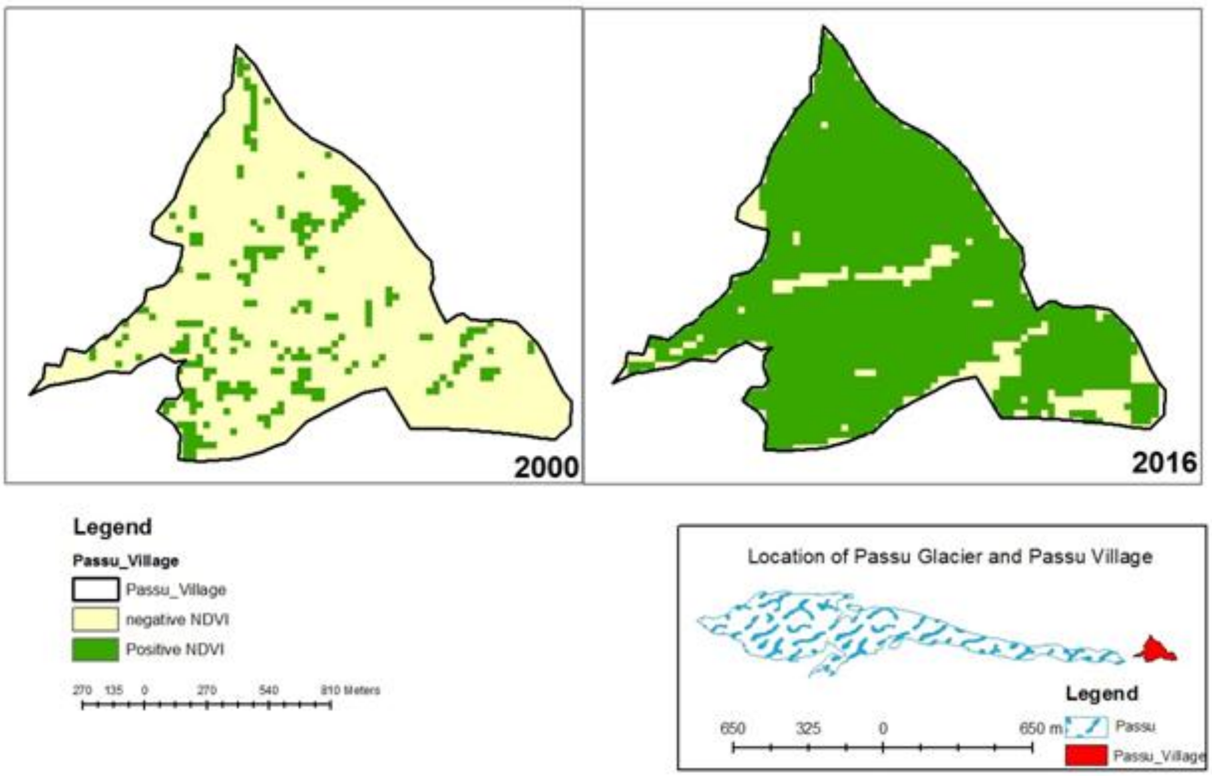

Fig. 6: Comparison of NDVI in Passu Village, 2000 and 2016

DISCUSSION

NDSI was used to calculate the snow covered area of Passu glacier, and the results proved a decrease of 6.18% of snow covered area for twenty four years' time period (1992-2016). Research has proved similar decrease of other significant glaciers of this region e.g. A similar retreat of 17 $km^2$was experienced by Batura and Biafo suffered a retreat of 6 km^2 for the time period of 1992-2000 (Jilani *et al.,* 2007). The findings of this research are also supported by another study conducted by Jilani *et al.* (2009). Another study supporting this research's findings was of Fowler & Archer (2004), where an increase of 16% in the flow of Hunza River was observed, due to an increase in 1°C in mean summer temperature of the region. This increase in 1°C in mean summer temperature of the region supports the fact that Batura and Biafo, besides Passu, are also suffering a retreat. Glacial retreat has given a boost to the vegetation of the region. Vegetation of Passu village increased almost 50% from 2000 to 2016. Vegetation increased at the rate of 4 percent per annum (1992-2016) and covered almost half of the area (0.981 sq.km area) of Passu village. This finding of the present study can be supported by a similar finding by Eberhardt *et al.,* 2007, where reported a massive clearing of local Artemisia fragrans-Ephedra intermedia dwarf-scrub and intense practice of irrigated farming and fruit gardening in the region. The study of Rasul *et al.* (2010) is also on the Himalayas, Karakoram and Hindukush lofty mountain ranges. They concluded that in Pakistan, we are hosting more than 5000 glaciers in Pakistani geographical limits which feed snow/ice melt water to the Indus River System together with summer monsoon. Due to global warming, frozen water resources have been losing their reserves at an unprecedented rate, not only, reducing the ice mass but increasing the number and extent of glacial lakes. Glacial Lake Outburst Floods (GLOFs) are the devastating mountain hazards which have started occurring with increased frequency during the recent years. An alarming by increasing temperature trend in northern parts of Pakistan during the last decade which surpassed all the past records has enhanced the snow/ice melt rate and given rise to lake formation process some of which are potentially dangerous for outburst. Due to increase in temperature, the snowline has shifted upward causing migration of biodiversity and lower elevation glaciers have started melting faster. Snow used to occur now in late winter and disappears in early summer, hence, reducing the residency period to complete metamorphic processes for conversion into ice. The issue of melting water underneath and around the terminal moraine needs continuous monitoring to understand their supraglacial behavior and to assess the potential danger of outburst on scientific basis for development of an early warning mechanism. An initiative of The Mountain Institute (TMI) in collaboration of ICIMOD toward Global Glacial Lake Partnership is a step forward to manage such lakes to mitigate the potential losses due to their outburst. Similar studies were reported from Arshad *et al.* (2011) who worked on Thirty-five destructive outburst floods have been recorded for the Karakoram Range in the past 200 years. Systematic application of remote sensing and geographic information systems (GIS) has revealed the formation of about 2420 glacial lakes in the Hindukush-Karakoram-Himalaya (HKH) Region of Pakistan, among which 52 lakes are characterized as potentially dangerous GLOF hazards. About 62% of the GLOF lakes belong to End Moraine Dammed type and 25%to Cirque type. Due to poor livelihood conditions, lack of resources and proper management within the system the local communities have a problem intaking effective response measures for risk reduction or mitigation. There is a need to create awareness of flood hazard, coordination and capacity buildings for preparedness and risk reduction among target communities. High resolution satellite data integrated with ground information can be utilized effectively for regular monitoring of these lakes in order to mitigate flood risk hazard in future.

CONCLUSION

This study reported a 12.8% annual decrease of Passu glacier during 1992-2016. It can be concluded that glacial retreat can be linked to increased runoff in Passu village which ultimately proved good for turning barren soil to vegetation. It has been observed that vegetation increased at the rate of 4 percent per annum from 1992 to 2016which covered almost half of the area (0.981 sq.km area) of Passu village.

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