GEOSPATIAL ANALYSIS OF GLACIAL DYNAMICS IN SHIGAR AND SHAYOK BASINS

By

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ABSTRACT

The glaciers of the Hindukush-Karakoram-Himalayan (HKH) region consist of a huge amount of perpetual snow and ice. These glaciers are retreating in the face of accelerating global warming. Assessment of glacial hazard is carried out in this research using Satellite and Topographic data.

About 5,218 large and small glaciers cover a glaciated area of 15,040 km^2 and ice reserves of 2,738 km^3. The Shayok, Hunza and Shigar basins contain the major part (83%) of ice reserves.

This research presents the glacial hazard computations of largest glaciers of Pakistan. The correlation of glacial hazard of these glaciers with average temperature rise of northern areas is confirmed.

The location of a site, snow cover/ melting behavior of the glacier, slope/ aspect of glacier, geo-morphology of the rocks and glacier dynamics are taken as indicators of disasters in the form of avalanches, snow/ land slide and glacier breakdown in the form of debris along with rock material.

The percentage degree of risk of glacial hazard is computed, which indicates that the world's largest glaciers have experienced degradation / volume loss over the years subjected to host of factors including anthropogenic activities.

For analysis, various methods of image classification in visible and thermal bands are used. The DEM is incorporated to detect the indicators of hazard as slope, orientation and glacier mass balance of the glaciers overlooking the settlements. The results show that settlements are found more threatened in Shayok basin in comparison with Shigar basin by disastrous events of glacial activity which is further reconfirmed during the field visits.

KEYWORDS: Global Warming, Glacial Hazard, Settlements, Anthropogenic, Geo-morphology.

INTRODUCTION

The glaciers are nature's renewable storehouse of fresh water that benefits hundreds of millions of people downstream. The glaciers of the Hindukush - Karakorum - Himalaya (HKH) region, however, are retreating in the face of accelerated global warming since the second half of the 20th century and have contributed to the formation of many glacial lakes on the recent glacier terminus (Mool et al., 2001). Rapid accumulation of water in these lakes can lead to sudden breaching of the unstable moraine dams discharging huge amounts of water and debris causing loss of life, property and the destruction of valuable forest and pasture resources, farmlands, and costly mountain infrastructures downstream. Some glaciers are reported to have created long-term secondary environmental degradation physically and socio-economically, both locally and in neighboring downstream countries (Nurkadilov et al., 1986). Glaciers retreat is recognized to be a common phenomenon in the Hindukush - Himalayan countries such as Bhutan, China, India, Nepal and Pakistan.

A major part of the snow and ice mass of the Pakistan’s HKH region is concentrated in the watershed of the Indus basin. This watershed can be divided into distinct river basins. This study is carried out in two river basins of HKH region of the country. The volumetric decrease of Siachen and Baltoro glaciers was estimated owing to host of factors out of which anthropogenic activities made a major contribution in degradation of Siachen glacier.

The northern Pakistan has some of the longest glaciers outside polar region like Siachen (76 km), Hispar (61 km), Biafo (62 km), Baltoro (59 km), Batura (64 km), Yenguta (35 km), Chiantar (34 km), Trich (29 km) and Atrak (28 km). Three out of seven world’s largest glaciers are present in the northern areas of Pakistan making its geographic location prime in the region.

The hydro meteorological cycle forms a link between two great natural reservoirs, the snow and glaciers in the mountains and the groundwater contained in the aquifers in the plains of Pakistan. The swelling of Indus and its tributaries is subjected to volumetric decrease of glaciers and once coupled with heavy monsoonal rains, can cause floods during summer.

Shyok River Basin

The Shyok River network drains large parts of glacier and snow covered mountains of the Karakoram Range in the northeast of the country. The river basin consists of some of the high mountain peaks of the Karakoram. This river crosses through parts of Laddak and the Karakoram ranges.

Shyok River is an important tributary of the Indus River in Ladakh. The main stream rises from the snowy wastes on the Despang plains in northern Ladakh, north of the Karakoram Range. The river flows westwards its initial stages, then turns southeast and makes a U-turn near Shyok to flow towards the northwest. It flows into the Indus about 40 km upstream of Skardu. Many tributaries join the Shyok River like Chang Celmo, Chipshap, Galiwan, Chus, Nubra and Saltoro River. Deposits of moraines brought down by ancient glaciers are found all along the river right from its origin to the mouth. The discharge of this river increases in late summer when the snow on the high mountains melts at a very fast rate.

Shigar River Basin

An important tributary of the Shigar River rises from the Baltoro glacier at the base of the Masherbrum peak and flows westwards to join the main channel of the Shigar in its middle course. Thus the Shigar system drains the melt-waters of two of the most important glaciers (Baltoro and Biafo) of the Karakoram Range. This river descends along a very steep gradient. Its entire catchment has been influenced by the action of glaciers. The valley is deep in its upper reaches but widens near its mouth. The Shigar River drains parts of Haramosh range and Masherbrum range in the northeast of the country. The river fed by melting water of large glaciers, joins the main Indus River near Skardu. It forms the gateway to the great mountain peaks of the Karakoram, including K-2.

Objective

The prime objective of this study is to assess the glacial hazard of glaciers of Shayok and Shigar basins in comparison. The secondary objective is the identification of hazard prone areas in Shigar and Shayok basins pertaining to glacial activity for declaration of high risk areas by formulation of Risk Index (%).

Study Area

Indeed, attempt has been made to document the glaciers depletion of northern Pakistan in the past but with traditional survey methods. In recent times, the dynamics of land cover and particularly climatic change in the area requires a more powerful and sophisticated system such as GIS and remote sensing data which provides a general extensive synoptic coverage of large areas than the traditional survey methods. Remote sensing is helpful in providing up-to-date information and GIS assists in marking spatial distributions and its management. Spatial distribution of glaciers depletion is now possible with high spatial, spectral and temporal resolution image giving fairly accurate results. This study deals with the major glaciers of Shigar and Shayok basins i.e Siachen and Baltoro in northern Pakistan.

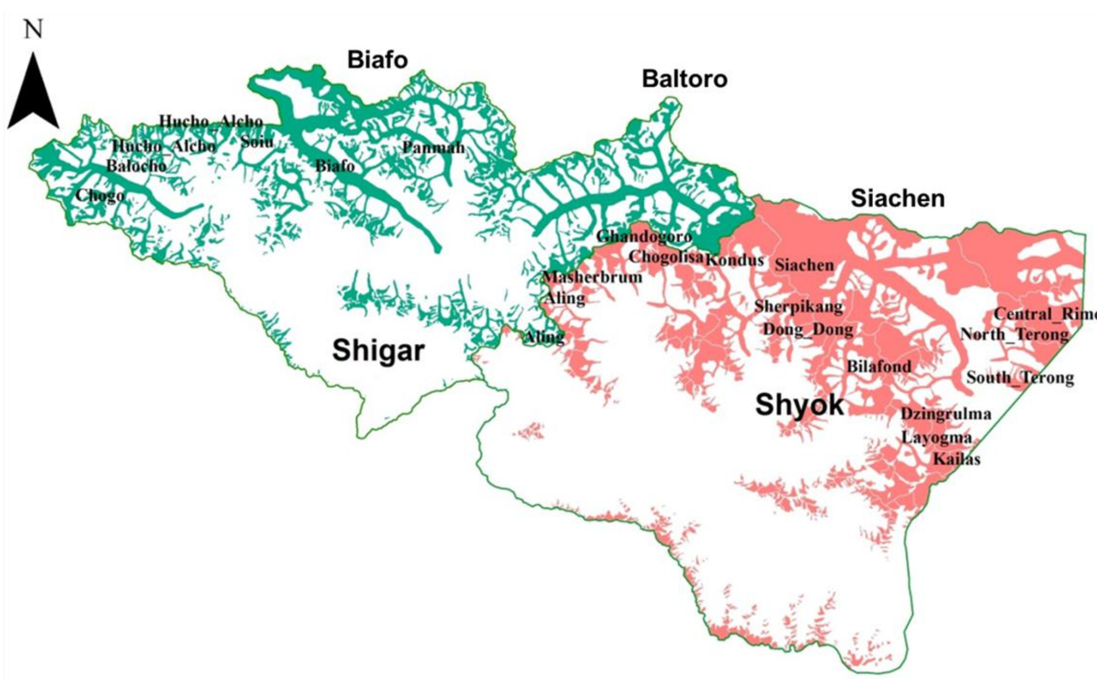

Figure 1: Major glaciers of Shigar and Shayok Basins of northern Pakistan.

LITERATURE REVIEW

Earth surface is unique in characteristics it possesses in the form of land cover. Generally, the northern hemisphere has warmed to a greater extent than the southern hemisphere, and mid to high latitudes have generally warmed more than the tropics. Alpine glaciers are subjected to heat flux thus causing them to melt.

The warming of the atmosphere caused by increases in greenhouse gases is melting glaciers. Crests of the high ranges in the Karakoram–Himalayan region are largely snow bound. The Karakoram has greater ice and snow cover (27 to 37%) than any other mountain system outside the polar region (Wissman, 1959).

Glaciological Complex

The Karakoram-Himalayan region lies in an environment that is glaciological complex with high altitude source areas (above 4,500 m) having permafrost and annual precipitation in excess of 2,000 mm (Khan, 1994). The Karakoram alpine glaciers are amongst the steepest in the world and they extend through a wide range of climatic environments. Most of the precipitation is not derived from the Indian monsoon but from depressions moving in from the west during the spring and summer. However, occasional monsoon disturbances do succeed in extending sufficiently far north so as to enter the area. Under such circumstances the precipitation levels increases substantially.

Glacier's Velocity and Fluctuations

Due to great thickness of ice, the deeper parts of the glaciers are at or close to 0 °C and they behave like temperate glaciers (Hewitt, 1998). Owing to relatively high activity indices, these glaciers have relatively high flow rates ranging from 100 to 1,000 m/yr (Goudie et al., 1984). Velocities of some of the selected glaciers of Karakoram are shown in Table 1. Historical record of glacier fluctuations in the Himalayas and the Karakoram indicate that in the late nineteenth century the glaciers were generally advancing followed by predominant retreat (Goudie et al., 1984).

Glaciers	Length (km)	Velocity (m/yr)
Baltoro	59	300
Siachen	76	1,000
Biafo	62	19

Table 1: Published estimated lengths and velocities of Baltoro, Biafo and Siachen glaciers. The length data is of year 1998 and the velocities are yearly average (Hewitt, 1998).

Glacial Surges and Climate Change

Five confirmed and three other possible glacial surges in Karakoram have occurred in the past decade (Hewitt, 1998), possibly indicating sensitive response to climate change. Winter storms dominate glacier nourishment at present. However, nearly one third of the high-elevation snow accumulation which has been measured occurs in summer (Hewitt, 1990). Moreover the general patterns of advance and retreat in the region relate to changing vigor of the summer monsoon. This seems to be a further reason to give more attention to surging glaciers as the glaciers fluctuation is subjected to terrestrial heat flux.

Siachen Glacier

The Siachen is the biggest valley glacier of this basin having an area of 1,056 sq. km followed by glacier having an area of more than 323 sq. km. The total length covered by the Valley glaciers is more than 500 km. The maximum length recorded for the Siachen glacier is 76.6 km. Since the inception of anthropogenic activities the Siachen glacier is showing abnormal behaviour. The Siachen glacier is subjected to 2 km retreat during the last two decades which is the max retreat in the vicinity.

The Siachen glacier is having dynamic characteristics shown in Table 2.

Parameters	Value
LENGTH	76641 m
ASPECT	SE
AREA	1056.42 $(Km)^2$
THICKNESS	418.35 m
RESERVE	441.96 $(Km)^3$
LAT	35°33'27.83" N
LONG	76°54'29.49" E

Table 2: Parameters of Siachen glacier situated in Shayok river basin.

Hydrology

The Karakoram and Himalayan mountains form the main source of snow and ice melt runoff to the Indus River System. The precipitation enhancing and shadowing effects of the main mountain ranges provide dramatic contrasts that greatly complicate the hydrological picture. Snowmelt predominates the south of the Himalayan crest. The Indus and its tributaries form the main drainage in the Karakoram-high Himalayan region. East to west, its main tributaries are Shayok, Shigar, Hunza, Astor, Gilgit, Ishkuman, Yasin, Ghizer, Yarkhun, Rich Gol, Arkari, Kunar, Panjkora, and Swat rivers which are fed from these glaciated basins.

MATERIALS AND METHODS

The basic materials required for the compilation of volumetric estimation of glaciers are high quality topographic maps and temporal high resolution satellite data. The remote sensing data of land observation satellite Landsat-7 Thematic Mapper (TM) are used for the temporal analysis of glaciers and the identification of potentially dangerous depletion. A combination of digital satellite data and the Digital Elevation Model (DEM) of the area are used for better and more accurate results for the computation of volumetric calculations of glaciers. Ice is melting at a dramatic pace. Pakistan too is confronted with this problem. Glaciers will experience a substantial retreat during the 21st century and the duration of snow cover is expected to decrease substantially for each °C of temperature increase at mid elevations (Bundesministrium, 2003). Three of the world's seven longest glaciers outside the Polar Regions are located in Pakistan (Figure 2) namely Siachen Glacier, Baltoro Glacier and Biafo Glacier which are subjected to global warming.

This study work is restricted to Siachen glacier out of Shyok river basin and Baltoro glacier out of Shigar river basin of northern areas of Pakistan. The area is bounded by:-

- Shyok river basin 75º 56' to 77º 27' E Long and
  34º 39' to 35º 42' N Lat
- Shigar river basin 74º 53' to 76º 45' E Long and
  35º 19' to 36º 07' N Lat

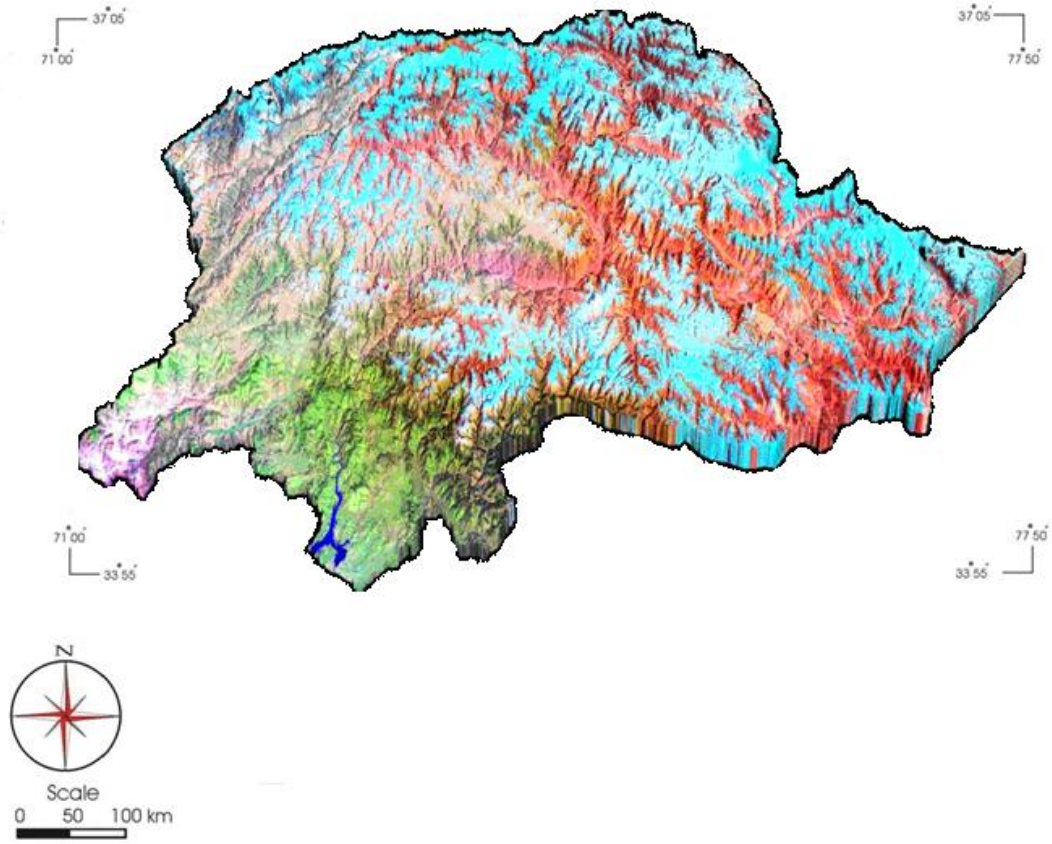

Figure 2: 3D views of glaciated areas of northern Pakistan generated with SRTM data of year 2000 of 90 m resolution.

Data Sets

Following data set is used for the purpose of this research:-

- SPOT Images of Baltoro and Siachen glaciers of northern Pakistan within the time span of last decades obtained from SUPARCO.
- ASTER multispectral Images of Shayok and Shigar basins of northern Pakistan within the time span of last decades.
- Digital elevation models of Baltoro and Siachen glaciers from SRTM data of year 2000, latest release of ASTER GDEM and topographic maps of Survey of Pakistan.

- Meteorological data including average annual temperature record of northern areas of Pakistan during the last decades obtained from Pakistan meteorological department.
- Geomorphologic data of northern areas of Pakistan obtained from geological Survey of Pakistan.

The glaciers are mostly concentrated in the north. The river basin boundary and spatial distribution of glaciers were identified from the satellite images and supplemented with the digitize map from Survey of Pakistan topographic sheets at scale of **1:250,000**. The topographic maps (43M, 52A and 52E) are the map series of the 1990 published by the Survey of Pakistan. These topographic maps are based on aerial photographs, field surveys at various times and the error ranges in digitization of SoP topographic sheets are verified through large-scale topographic sheets.

Digital Elevation models (DEMs) of study area having 30m resolution were generated from both the contours of topographic sheets of Survey of Pakistan and the SRTM data down loaded after having done the registration/ over-lapping of two DEMs. The requisite information of slope, aspect and elevation were obtained to perform the analysis.

Image Processing

The LandSat, SPOT and ASTER images are acquired from SUPARCO, after georeferencing the desired Area of Interest (AOI) is extracted. Moreover the topographic maps are scanned and after georefrencing, all are digitized to get GIS layers for analysis.

- The Sat images are processed and georeferenced.
- Aspect and Slope maps are generated using height information extracted through DEMs.
- Identification of Glaciers, GLOFs and Glacial hazard areas are carried out through geospatial analysis.

Methodology

The study and acquisition of literature, topographic maps and satellite images for capturing the digital data of glaciers are carried out in first phase. Thereafter from maps and SRTM data the digital elevation models are generated for analysis of volumetric decrease / depletion of Baltoro and Siachen glaciers in order to assess the glacial hazard in Shiger and Shayok basins. Finally the correlation with anthropogenic activities in this vicinity of northern areas for computation of glacial hazard to the settlements arecarried out. The methodology adopted in this research is shown in a flow chart.

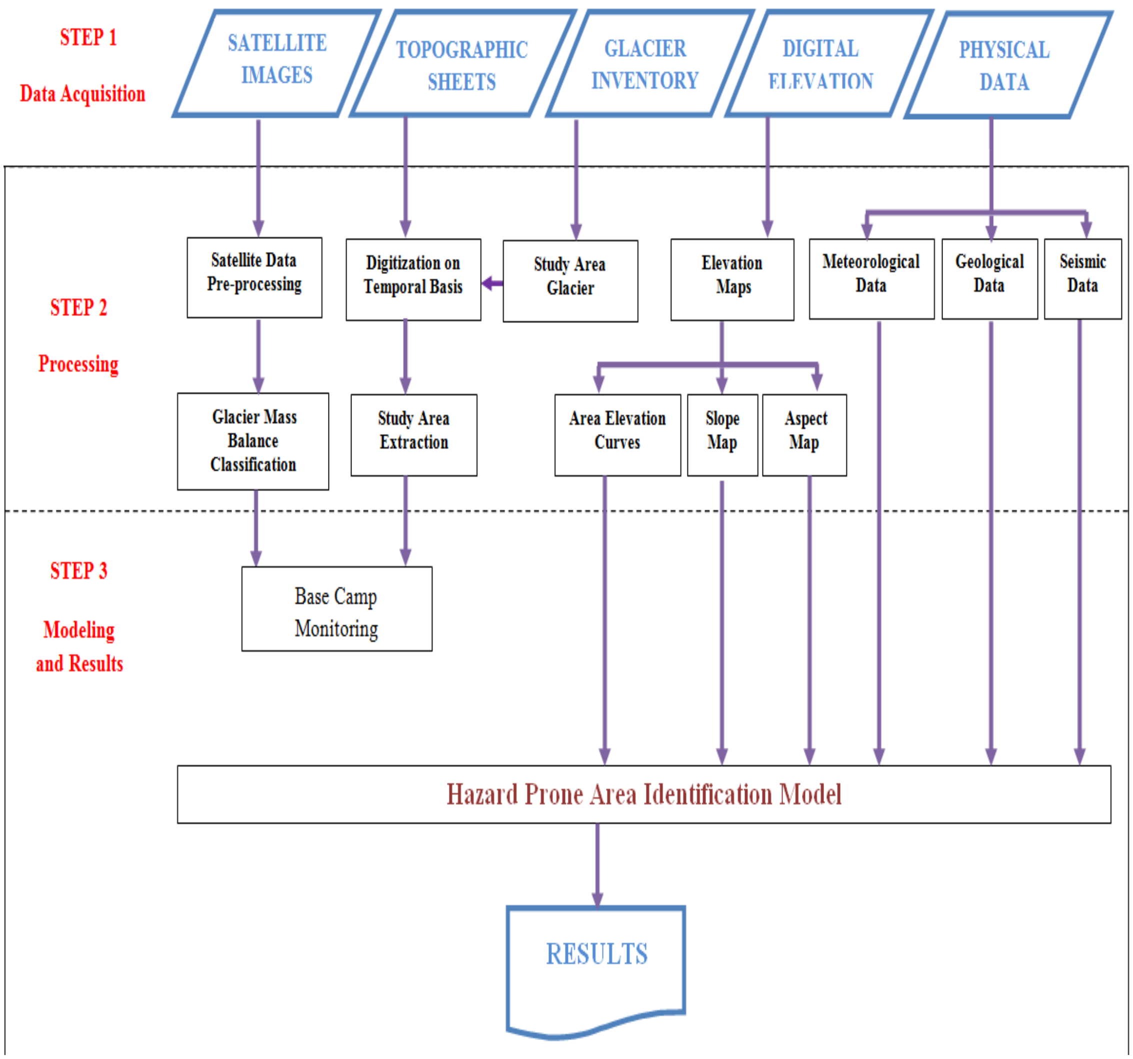

Figure 3: Methodological flow chart of geospatial analysis of glacial hazard.

RESULTS AND DISCUSSION

The objective of the study form the basis of all the analysis carried out in this report. The results are presented in the form of maps, charts, statistical tables and discussed appropriately. These include volumetric decrease of the important glaciers of northern Pakistan during a decade, spatial distribution of the glaciated areas of Pakistan.

The occurrence of glaciers has always been linked to climatic conditions. Climate is of fundamental importance to the inception and growth of glaciers. Salerno et al. (2008) studied variations in the surface area of glaciers in Sagarmatha National Park (Mount Everest region) for the second half of the 20th century. They found an overall decrease in glacier area by 4.9% (from 403.9 to 384.6 km2) in four decades and they ascribed the decrease in area to a decrease in precipitation and hence a glacial retreat. The form of the landscape dictates the threshold conditions for glacier occurrence and determines glacier morphology. Under certain climatic conditions for glaciation, glaciers of different shapes and sizes are formed depending on the landscape. Mountain glaciated regions are associated with climatic fronts and zones of maximum precipitation.

Alpine glaciers are generally situated at middle latitude regions of the globe. During most of the summer season, high flows in the Indus River system are due to snow and ice melt of alpine glaciers in the Himalayas. Hewitt (1990) states that evidences over the past 150 years indicate that the snow and ice cover of the upper Indus River basin undergoes large spatial as well as temporal variations.

The glacier area of northern Pakistan forms the single most concentrated source of runoff for the whole Indus basin. Since this frozen precipitation contributes more than 50% of the total flow of the Indus River System and a larger part of the future supplies upon which Pakistan can depend, knowledge of this resource seems a prime requirement for water resource and flood hazard monitoring on the Indus basin. The glaciers in Karakoram region are high activity glaciers and have some of the steepest gradients in the world. According to their movement patterns, Karakoram and Himalayan glaciers are grouped into the following three categories:

- Glaciers with steady movement (these are also the longer ones)
- Glaciers having cyclic advances (these have short steep crevasses)
- Surging glaciers characterized by catastrophic advances

Hazard Prone Areas Identification

High risk areas are identified in Shigar and Shayok basins where settlements are exposed to:-

- Land slides
- Avalanches
- Flash flooding (Glacial Lake Outburst Floods)
- Climatic conditions
- Snow storms

These risks are being faced by the spatial locations of settlements, various installations as well as the surrounding areas. Slope and Aspect of various glaciers as well as the surrounding areas (both snow and ice covered peaks and valleys) owing to their exposure to solar radiations, snow accumulation, ice accumulation and formation of crevices in ice, conversion of ice into debris especially in lower peaks of the mountains, formation of glacial lakes and water bodies in glaciated areas due to changing climatic conditions together with anthropogenic activities and lastly the geomorphologic features are the host of factors contributing towards glacial hazard.

Glacial Hazard Analysis

Glaciers experience a substantial retreat and the duration of snow cover is expected to decrease substantially for each °C of temperature increase at mid elevations (Bundesministrium, 2003).

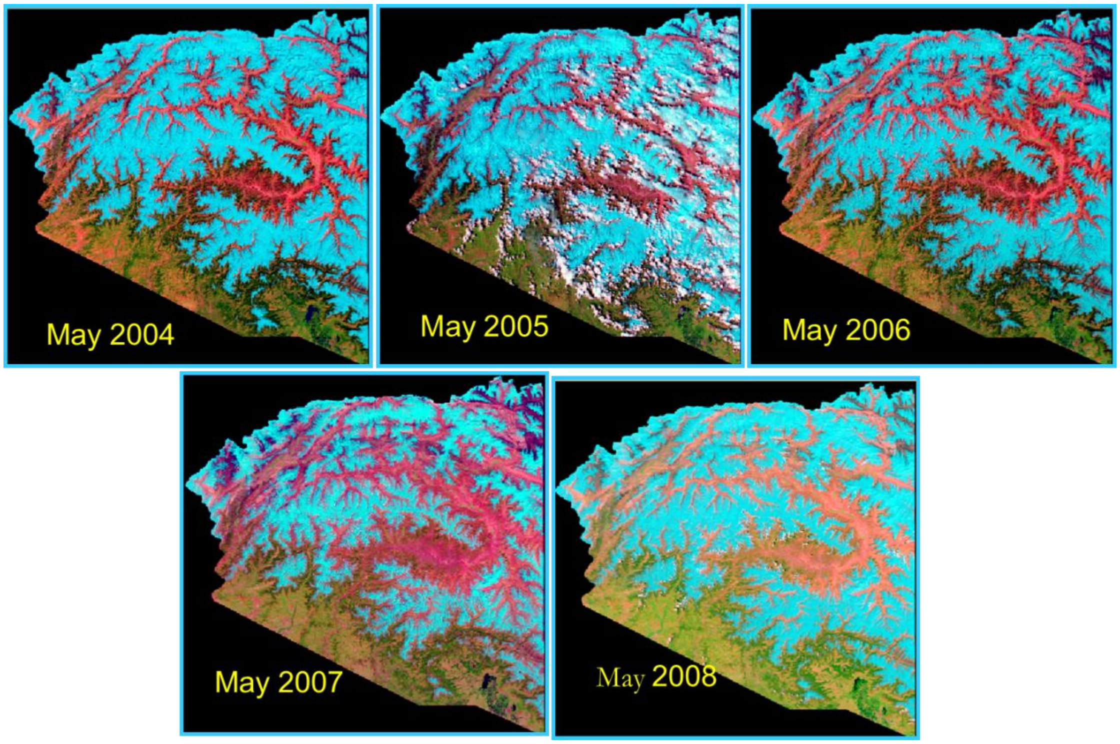

Figure 4: Depletion of glaciers in Pakistan from 2004 – 2008.

Glaciers suffer a further volume reduction. Glacier retreat is expected to enhance summer flow of the alpine rivers. As they retreat, glaciers leave important masses of unstable rock material, which may contribute to debris flows. Glacial hazard prone areas in the vicinity are at high risk.

<u>Glacial Hazard Risk Indicators</u>

The glacial hazard risk indicators e.g, Location, Elevation, Slope, Aspect, Retreat and Geomorphology of a particular site determine the description of risk.

Indicators	**Description of Risk**
Location	Location of a settlement (**Glaciers** with abrupt changes in melting rates are dangerous)
Elevation	Direct relation with the **probability of occurrence** and its magnitude

Aspect	The **SE is more prone** to disasters as it endures more solar radiation causing depletion
Slope	Literature shows a slope between **30 – 45 %** are prone to glacial hazards such as avalanches and slides
Geomorphology	Type of **underneath surface** and parent material
Geo Cover	Heavily forested areas are much safer than **open spaces**
Crevasses	Deeper crevasses help snow/ice accumulation which may **burst out in response to a slight change** in parameters
Snow / Ice melting of Glacier	Glacial hazards such as **GLOF** (Glacial Lake Outburst Flood), avalanches, or landslides are triggered by abrupt glacial melt

Table 3: Glacial hazard risk indicators.

<u>Risk Index</u>

The risk Index factor is assigned based on parameters like Location, Elevation, Slope, Aspect, Retreat and Geomorphology of a particular site. The degree of threat is assigned based on these parameters. Further on the basis of calculated indicators of glacial hazard, the % degree of risk are calculated by using the following equation:-

$$\% \text{ Degree of Risk} = \frac{\boldsymbol{No.of\ disaster\ indicator\ falling\ in\ danger\ criterion}}{\boldsymbol{Total\ number\ of\ studied\ indicators}} \times 100$$

Qualitative Degree of Risk	Degree of Risk (%)	Parameters	Remarks	Probability

Dangerous	80-100	Location, Elevation, Slope, Aspect, Retreat, Geomorphology	Re Location	High
Very High	60-80	---- do ----	Re Adjustment	High
High	40-60	---- do ----	Continuation at High Risk	Medium
Moderate	20-40	---- do ----	Continuation at Moderate Risk	Medium
Low	0-20	---- do ----	May Continue	Low

Table 4: Probable outcome based on risk index.

Shyok River Basin

The Shyok River basin stretches over a latitudinal and longitudinal range of 34º 39' to 35º 42' and 75º 56' to 77º 27' respectively. This river basin is bounded with Jammu and Kashmir disputed Territory in south, China in northeast and Shigar and Indus River basins in the west.

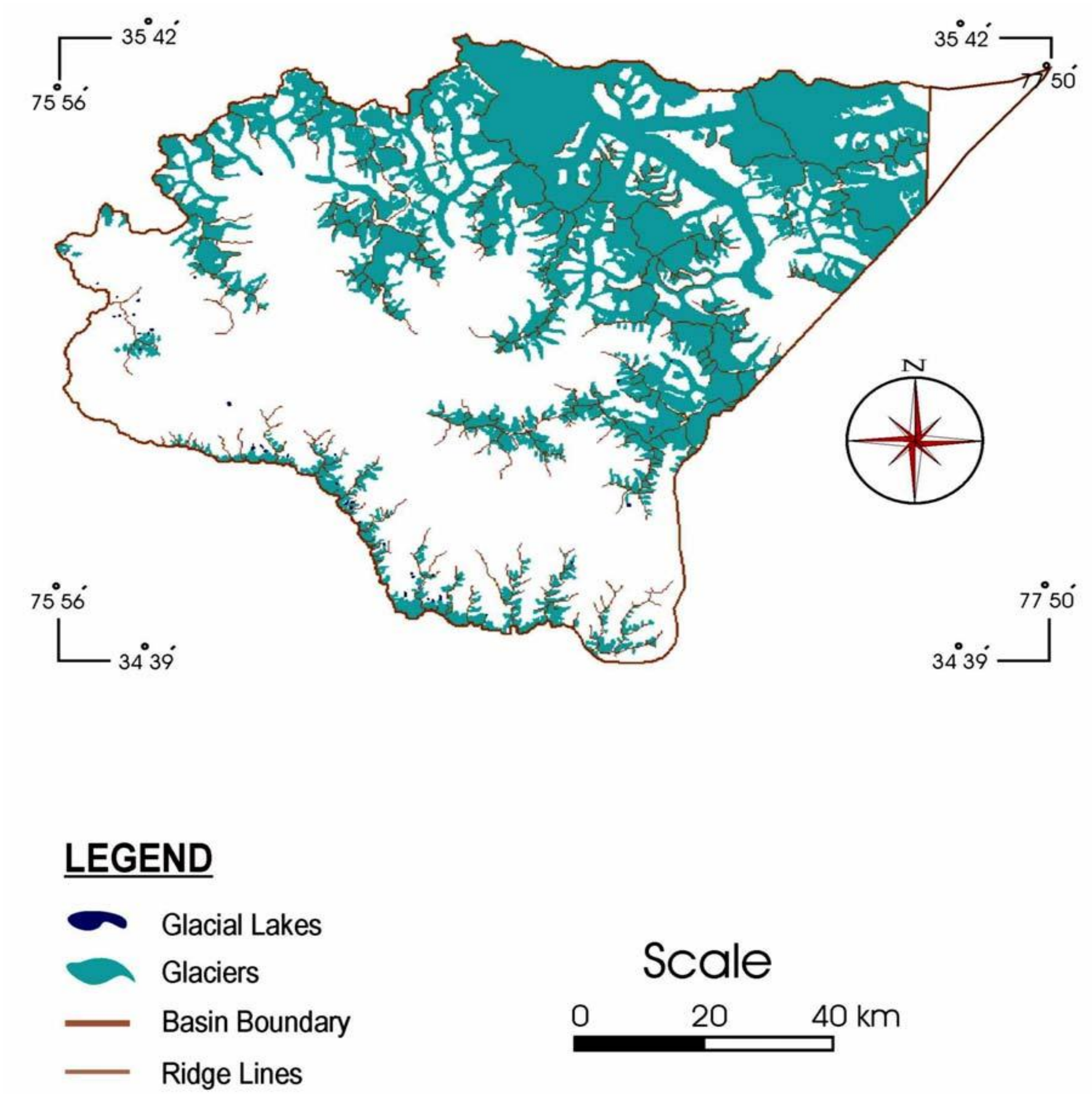

Figure 5: The glacier distribution in Shyok river basin showing Siachen glacier's significance in the region being the largest.

The total area of the basin is about 10,235 sq. km out of which 34.67% is under the glacier cover. There are 372 glaciers in the basin out of which 86% can be classified as mountain type glacier while only 14% are the Valley glaciers. The Siachen is the biggest valley glacier of this basin having an area of 1,112 sq. km (Bhambri et al., 2013). The Bilafond glacier is a large size Valley glacier having several supra glacial lakes.

a. **Seasonal Snow Coverage of Shyok Basin.** The figure 6 shows that in the months of June, July and August are lowest that depicts high rate of melting during these months in this area. Whereas, comparison of the seasonal snow cover behavior of Shigar and Shyok basins shows that Shyok has high snow melting activities during the months of June, July and August.

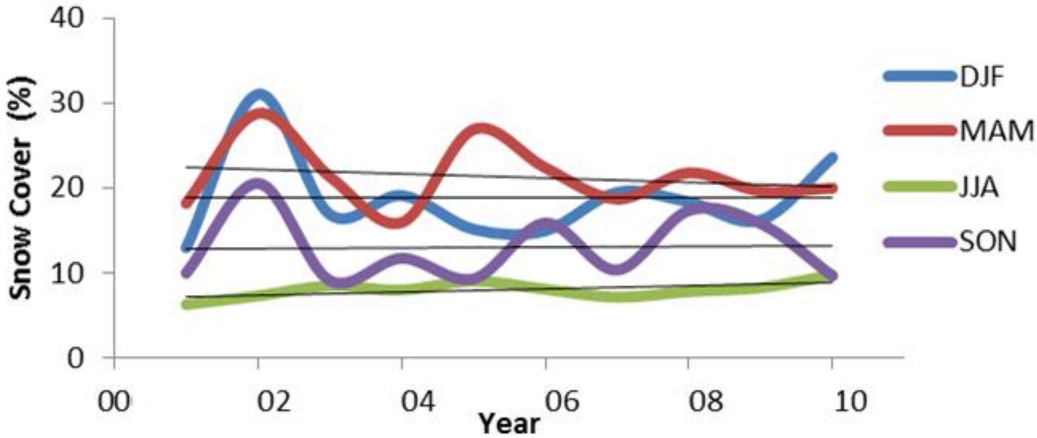

Figure 6: Snow Coverage of Shyok Basin in Km in a Decade

This result leads us to the conclusion that the anthropogenic activities in the region of Shyok are causing comparatively higher melting and thus more risks of glacial mass movement to occur. This may be verified by using high resolution satellite data and ancillary records.

b. **Aspect Wise Snow Coverage of Shyok Basin**. The huge size glaciers are concentrated on NE and SE aspect of the basin. The SE and S aspects have the maximum glacier area of about 1,657 and 501 sq. km respectively owing to the fact that the larger glaciers like Siachen, Kondus, Bilafond, Ghandogoro, Masherbrum, etc. are facing to these aspects.

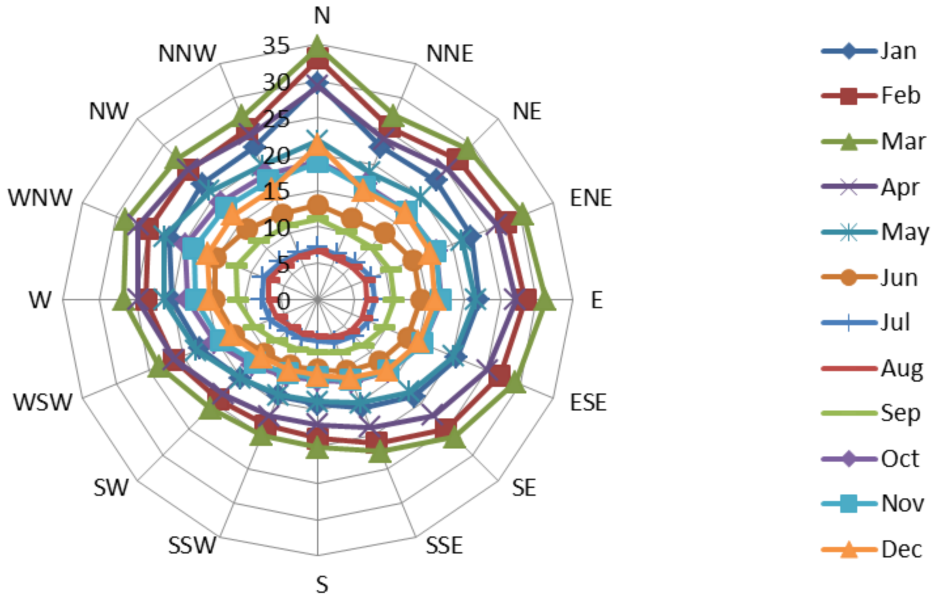

Figure 7: Aspect Wise Snow Coverage in Km in a Decade of Shyok Basin

The figure 7 shows aspects zone of N has maximum snow coverage whereas zones of W to ESE have minimum snow coverage over the year. Five different seasons and the aspect-wise snow distribution in these seasons can be seen easily from figure 7. Here it is clear that the aspect zones N to NE and S to SW hold greater area of the basin than other aspect zones and the other aspect zones have maximum melting activities which may cause triggering of some catastrophic event in combination with factors such as seismic activity, high temperature and anthropogenic activity.

Siachen Glacier

The Siachen is the biggest valley glacier of this basin having an area of 1,056 sq. km followed by glacier having an area of more than 323 sq. km. The total length covered by the Valley glaciers is more than 500 km. The maximum length recorded for the Siachen glacier is 76.6 km. Since the inception of anthropogenic activities the Siachen glacier is showing abnormal behaviour. The Siachen glacier is subj to 2 km retreat during the two decades which is the max retreat in the vicinity. This retreat is mainly subjected to global warming coupled with anthropogenic activities in the vicinity. Siachen Glacier is also known as the highest battle ground between two countries Pakistan and India. This is the reason that siachen glacier is subject to anthropogenic effect along with global warming which includes:-

a. Active military bases
b. Large carbon deposits from military activity causing Increased solar radiation
c. Poor waste collection mechanisms, drums being thrown in crevasses
d. Induced pollution
e. Glacial ice being cut and melted with chemicals
f. Arms and ammunition depots
g. Dumping of non-biodegradable waste in large quantities
h. Construction of camps and posts
i. Explosive Blasting for track construction
j. Oil pipelines laid inside the glacier to supply kerosene and aviation fuel to the outposts from base camps
k. Helicopter flight thrust and sound
l. Heavy Machine Guns backblast

After acquiring the images from SUPARCO, different band combinations were used for glaciers classification. Band ratio 4/5 gave the Siachen glacier's bounds. The resultant of Siachen glacier's shape file was ascertained after the identification of the bounds of the glacier. For volumetric decrease calculations the digital elevation models of both time bounds were generated. The contours of topographic map sheets of 1:25000 scale of Survey of Pakistan of 1990 were digitized for generation of DEM as one dataset. The SRTM data of 2000 was downloaded and there after the voids were removed with the help of land serf software and DEM of Baltoro glacier was generated for another dataset. Extract by mask utility was incorporated for computation of 3D surface area and volume of glacier having established the plane height. The complete process is carried out for both the data sets involving change in DEMs which has resulted in volumetric decrease computations of 11.09% over a decade.

Settlement

Settlement situated near snout of glacier at a height near 14000 ft. The location is prone to disaster from a possible glacial mass movement / debris flow. The glacier containing debris and rock fragment may prove catastrophic cause of a cloud burst.

Figure 8: Glacial hazard to settlement.

Determination of Glacial Hazard Risk Index

a. The glacial hazard risk index are determined by aggregating the degree of risk for certain parameters like location, elevation, slope, aspect, retreat and geomorphology of a glaciated area.

b. **Location**. The location of glacier terminus / snout approaching settlement site. Although glacier seem motionless to the observer, in reality glacier is in endless **motion** and the glacier terminus is either advancing or retreating. The location of the terminus is directly related to **glacier mass balance**, which is based on the amount of snowfall which occurs in the **accumulation zone** of a glacier, in comparison to the amount that is melted in the **ablation zone**. The position of a glacier terminus is impacted by localized / regional temperature change over time posing threat to the settlement.

c. **Elevation.** The elevation of settlement nearest glacier makes it vulnerable. All the time it's cold at 18,000 feet and above. Globally, the prognosis for glaciers is dismal. At elevations below 14,000 feet the Himalayan Alps are melting, and that the same is true throughout the region. Antecedent, the low elevation of the glacier pose threat to the settlement site as depletion of glacier can cause catastrophic.

d. **Aspect**. The orientation of the glacier surface with respect to incoming solar radiation, or aspect, e.g, SE which is particularly important on account of depletion, in area of Shayok alpine glaciations, i.e, on the mid-latitudes. The smaller glaciers are particularly more impacted by the aspect. The sloping surface facing the sun receives much more solar radiation than if that same surface were flat. There is generally a melting of glaciers and lowered snowlines towards the southeast slopes, thus the glacier aspect being SE to S causes a major hazard to settlement as of being more pronounced aspect to solar radiation.

e. **Slope**. Alpine glaciers are found only where snow has room to accumulate to a large enough mass. Because of this, glaciers have a preference for peaks that have wide plateau areas. Steep, precipitous peaks tend to have less of a snow cover, because the snow is unable to pile up on the steep slopes. If a highland area is dissected into many steep slopes, avalanches redistribute snow to the valleys, and glaciers are confined to these gentler slopes. The glacier having more than 30 % slope encompasses hazard of avalanche triggering. The settlements nearest glacier having their slope more than 30 % make them more prone to avalanche trigger once coupled with geothermal gradient cause of global warming.

f. **Geomorphology**. Geomorphology of the glaciers dictates the underlying **bedrock topography**. **Valley glaciers**, which provide drainage for ice fields, are also constrained by underlying topography. Ice-free exposed bedrock and slopes often surround valley glaciers, providing snow and ice from above to accumulate on the glacier via **avalanches**. The area is tectonically active as the main karakoram thrust (MKT) passes nearby. The impact of regional geodynamics and local tectonics dictate generation of glacial hazard to the settlements if nearest glaciers is posing threat of alluvial fan.

Glacial Hazard Risk Index For Settlement

The degree of glacial hazard risk index of the settlement site are determined based on certain parameters as following:-

Parameters	Weight	Remarks
Location	20%	Dangerous
Elevation	20%	Dangerous
Aspect	20%	Dangerous
Slope	20%	Dangerous
Geomorphology	20%	Dangerous

Table 5: Glacial hazard risk index for settlement site.

On the basis of the above table it are concluded that all the studied indicators of disaster fall in the dangerous criteria or otherwise. Therefore according to equation of degree of risk, the max degree of risk is as follows:-

$$\% \text{ Degree of Risk} = 5/5*100$$
$$= 100\%$$

Shigar River Basin

The Shigar River basin is situated in the latitude and longitude range of 35º 19' to 36º 07' N and 74º 53' to 76º 45' E respectively (Figure 9). The elevation range varies from about 2,500 m to more than 8,600 m.

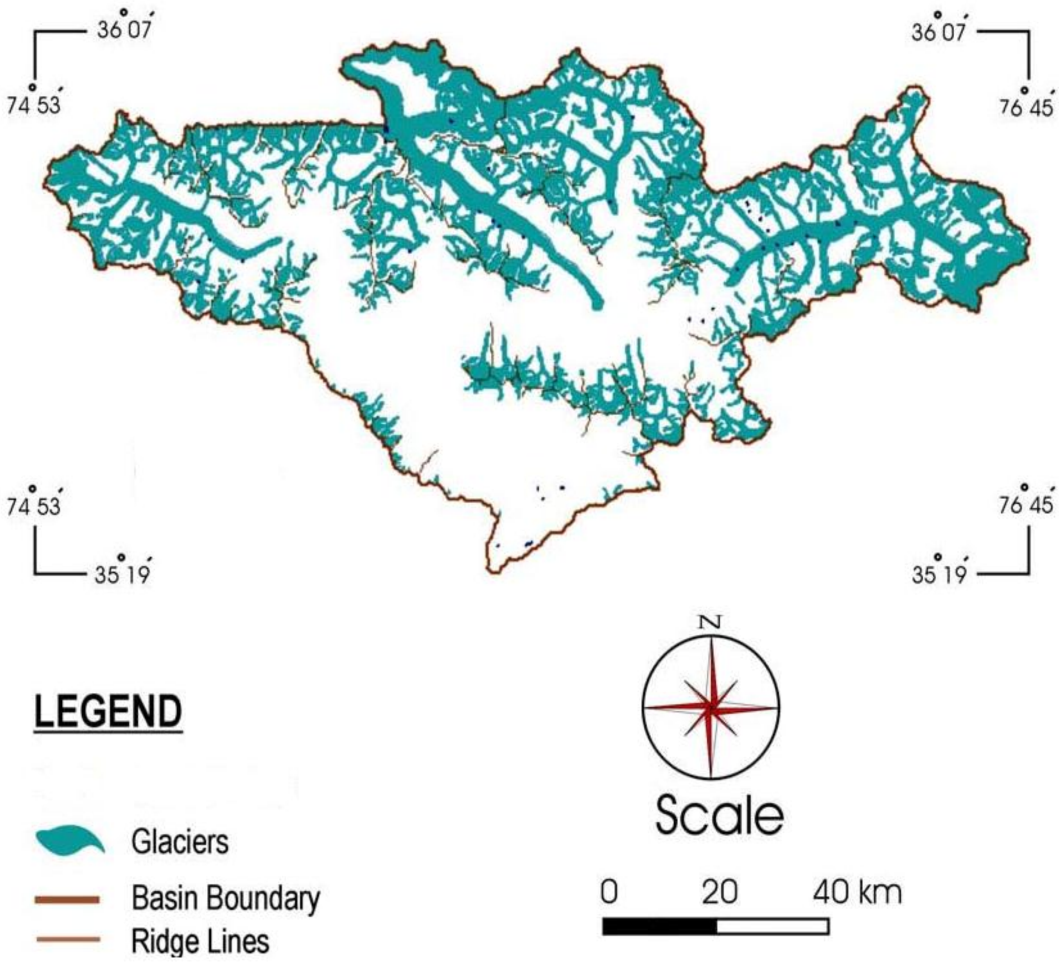

Figure 9: The glacier distribution in the Shigar river basin showing Baltoro glacier significance in the region being the largest.

The basin stretches over an area of 7,382 km^2 out of which, the glacier area is about 2,240 km^2. The distribution of different types of the glaciers is presented in figure 8. The large size glaciers are mainly concentrated on the N, NE and NW aspects. The total ice reserves of this basin are 581 km^3.

a. **Seasonal Snow Coverage of Shigar Basin**. The figure 11 shows that the months of June, July and August are lowest that depicts high rate of melting during these months in this area. Whereas, comparison of the seasonal snow cover behavior of Shigar and Shyok basins shows that Shyok has high snow melting activities during the months of June, July and August.

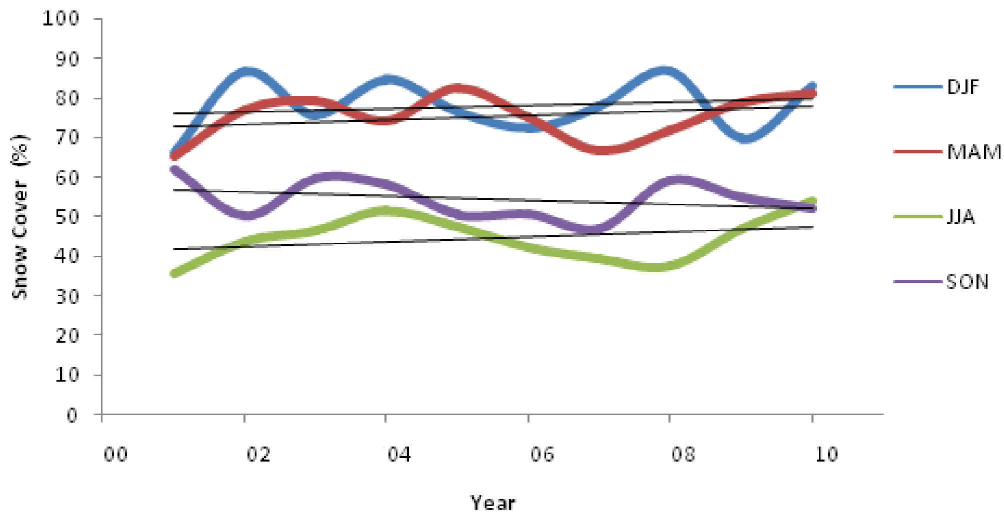

Figure 10: Snow Coverage of Shigar Basin in Km in a Decade

This result leads us to the conclusion that the anthropogenic activities in the region of Shyok are causing comparatively higher melting and thus more risks of glacial mass movement to occur. This may be verified by using high resolution satellite data and ancillary records.

b. **Aspect Wise Snow Coverage of Shigar Basin**. The huge size glaciers are concentrated on SW and SE aspect of the basin. The SE and W aspects have the maximum glacier area of about 1,111 and 693 sq. km respectively owing to the fact that the larger glaciers like Biafo and Baltoro etc. are facing to these aspects. The two out of world's seven largest glaciers lie in Shigar river basin. The Baltoro glacier with a length of 59 km has the maximum area of 633 km^2.

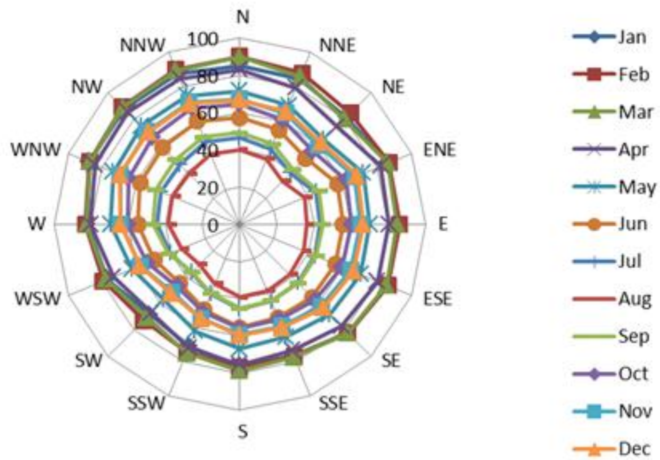

Figure 11: Aspect Wise Snow Coverage in Km of Shigar Basin

The figure 11 shows aspects zone of N has maximum snow coverage whereas zones of W to ESE have minimum snow coverage over the year. Five different seasons and the aspect-wise snow distribution in these seasons can be seen easily from figure 11. Here it is clear that the aspect zones N to NE and S to SW hold greater area of the basin than other aspect zones and the other aspect zones have maximum melting activities which may cause triggering of some catastrophic event in combination with factors such as seismic activity, high temperature and anthropogenic activity.

The two out of world's seven largest glaciers lie in Shigar river basin. The Baltoro glacier with a length of 59 km has the maximum area of 633 km^2.

Baltoro Glacier

After acquiring the image from SUPARCO, different band combinations were used for glaciers classification. Finally with band ratio 4/5 and the thermal band Baltoro glacier's bounds were identified. The resultant of Baltoro glacier's shape file was ascertained after the identification of the bounds of the glacier. For volumetric decrease calculations the digital elevation models of both time bounds were generated. The contours of topographic map sheets of 1:25000 scale of Survey of Pakistan of 1990 were digitized for generation of DEM as one dataset. The SRTM data of 2000 was downloaded and there after the voids were removed with the help of land serf software and DEM of Baltoro glacier was generated for another dataset. Extract by mask utility was incorporated for computation of 3D surface area and volume of glacier having established the plane height. The complete process is carried out for both the data sets involving change in DEMs which has resulted in volumetric decrease computations of 6.43% over a decade.

The difference in glaciers percentage volumetric decrease is because of the aspect, slope, geothermal gradient, density, glacier bed rock topography and anthropogenic activities.

CONCLUSION

The study of the important glaciers of northern areas of the Pakistan and their volume estimation is carried out. The study area comprised two river basins, the Shyok and Shigar. Using remote sensing data and the topographic maps available at a scale of 1:250,000 the study was completed. For volumetric decrease of glaciers, the methodology adopted is followed to achieve the subject results. The results of the study shows different behaviuor of the glaciers owing to their location/ placement, aspect, slope, elevation from mean sea level, underneath geomorphology and the most important the presence of anthropogenic activities. The significant volume loss of Siachen glacier (11.09%) in comparison with Baltoro glacier (6.43%) clearly indicates that the anthropogenic activities are having a major contribution in degradation of Siachen glacier.

Glaciers are major sources of water, studying the volumetric decrease with temporal analysis is vital for planning / development of water resource conservation, flood monitoring and mitigation activities. The major sub basins of Indus River in HKH region of Pakistan are Shyok and Shigar. Most of the snow and ice reserves are concentrated in the mountain ranges lying in these basins. These river basins contain the glaciated part in northern Pakistan, which forms the headwaters of the main Indus basin (Mukhopadhyay, 2015).

In this report the information obtained is about volumetric decrease of the largest glaciers, Siachen and Baltoro of HKH region of the country. The ice reserves of Shigar and Shayok basins are subjected to manifest of global warming which is causing their decay. Overall in these basins, maximum glaciers are subjected to anthropogenic activities because of active military presence in the vicinity. The military operational peripheral is one of the major factors for volumetric decrease of the glaciers. Siachen glacier behaves differently owing to the extensive military orientation in the Shayok basin.

One of the major impact of glaciers volumetric decrease is formation of glacial pockets which need monitoring and early warning systems. The most important mitigation measure for reducing the risk is to reduce the volume of water in the glacial pockets in order to reduce the peak surge discharge. Downstream in flood prone areas, measures should be taken to protect infrastructure against the destructive forces of outburst floods, as a resultant of volume decay of glaciers. Controlled breaching can be carried out to avoid possible peak surge discharge from glacial pockets. The volumetric decrease of these glaciers is due to global warming, which is a consequence of a host of factors, such as increase in greenhouse gases because of anthropogenic activities and decrease in ozone layer. Antecedent, anthropogenic activities particularly military specific operational activities be reduced in Shayok basin to ensure stability and safe guard the Siachen glacier.

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