

MAPPING AND ANALYSIS OF BALTORO GLACIER AND SHIGAR RIVER

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ABSTRACT

Glaciers and snow are the major components of compact water bodies constitute 68% of global fresh water that can control constancy of the local water resources in the mountainous areas. Water melt from glaciers and snow subsidize a prominent part of river or stream discharge. Advancing and retreating of glaciers influence the rate of stream flows. In this study, spatio-temporal mapping of Baltoro glacier is done in order to evaluate the rate of glacier retreating by using the method of normalized difference snow index (NDSI), linear regression analysis on the Landsat ETM+ and OLI images of years 2003, 2004, 2008, 2009, 2013, 2014, 2016, 2017 to find its effects on the discharge rate of Shigar River obtain from Pakistan Meteorological Department and Water and Power Development Authority (WAPDA) as the main tributary of Shigar River comes from the Baltoro glacier. Consequently, the results show that the retreating behavior of Baltoro glacier effects the discharge rate of Shigar River. This conclusion will help water resource managements to make strategies regarding runoff when glacier is retreating.

KEYWORDS: Baltoro glacier, Discharge rate, Glacier melt, NDSI, Retreating.

INTRODUCTION

Water resources of Pakistan mainly depend on the meltwater produced from Hindukush-Karakoram-Himalayan (HKH) highlands. The snow and glacier water-melt are priory used for drinking, power production and agriculture purpose. Glacier melt-water benefits and supports to uphold river system during the dehydrated conditions. The excess water of Indus River is a combination of rainfall and glacier melt water. But the run-off of the Indus river is the mainly the glacier melt water which is of high importance (Yasmeen & Afzaal, 2017). Climate change has greatly affected the availability of water resources which influences agriculture and power generation capacity. Therefore, it is essential to estimate the availability of water resources in future in order to do adequate planning accordingly and for better management of resources of water. Glaciers of northerly Pakistan are most of the extended and largest mid-latitude glaciers on ground. They are situated in the Karakoram, Himalayas and Hindu Kush highlands and envelope an extent of around 15,000 km². Glaciers in northerly Pakistan are significant for their character in supplying water reservoirs and their threat possibility (Bishop, Shroder Jr, Bonk, & Olsenholler, 2002). The change in climate has a strong impact on river flows of Pakistan. This will result in advanced proportion of snow-glacier melting for not many years with

foremost intensification in river flows leading to an eternal deprivation in water flows from Upper Indus Basin (UIB) glaciers. The Indus plains of Pakistan are most fertile sectors as these are watered by River Indus and its tributaries (Khan, Ashiq, & Gabriel, 2014). The melting glacier subsidizes more than fifty percent to the entire water flows of UIB (Snow, 1990). The changing climate disturbances is vibrantly depicted by the snow and glacier liquification as glaciers are receding because of global warming (Khan *et al.*, 2014).

MATERIAL AND METHODS

STUDY AREA

The study area includes Baltoro Glacier and Shigar River as shown in Figure 1. It is because; Baltoro Glacier gives rise to the Shigar River that is the main tributary of the Indus River. Baltoro Glacier and Shigar River, both are situated in the Shigar district of Gilgit-Baltistan region of Pakistan (Schmidt, 2000). Baltoro glacier runs through the mountain range of Karakoram in Northern Pakistan. It is 63km long and is the fifth longest non-polar glacier. Its coordinates are 35°44'11"N and 76°22'51"E. It has an area of more than 700 km². the highest mountain in the region (Gibson, Glasser, Quincey, Rowan, & Irvine-Fynn, 2017).

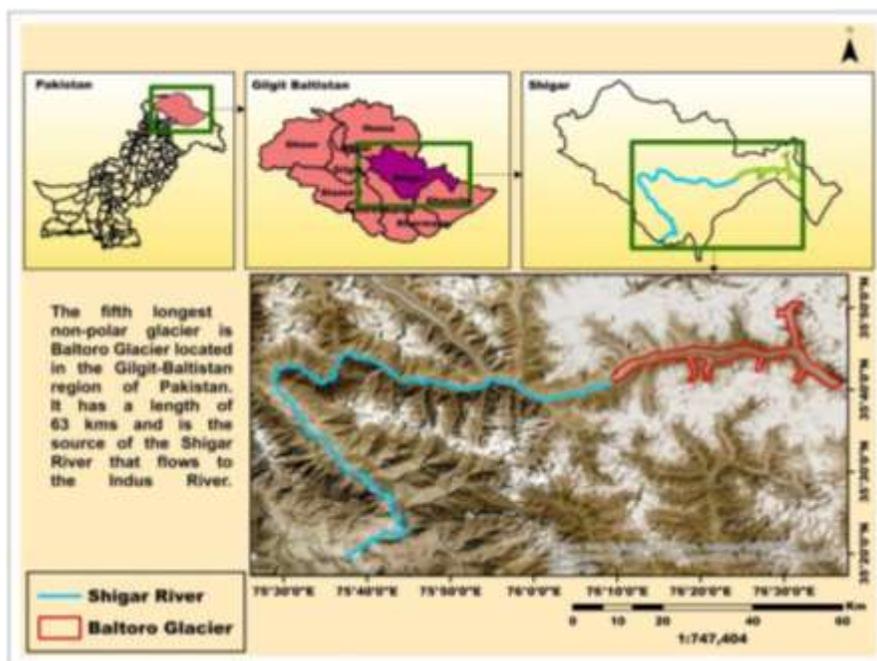


Figure 1: Location of Baltoro glacier and Shigar River

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Shigar River meets the Indus River from the right side at Skardu Valley. Its coordinates are 35.2°N to 37°N and 74.5°E to 76.5°E. It has border with The Masherbrum Mountains lie to south and Baltoro Muztagh lies to the east and south of the glacier. K2; the second highest mountain in the world, is located in this region with the height of 8,611m probably Shyok River Basin and China in the east, Indus River Basin in the west and south and Hunza River in the north. Its elevation is 2438 masl. Shigar River's flows are mostly the contribution from the glacier melt of Biafo, Chugolugma and Baltoro glaciers, the most important glaciers of Karakoram Range. Its catchment area is 6610 km². Its drainage area is 7382 km². Its total glacier area is 2240 km² (Khan et al., 2014).

According to Koppen-Geiger climate classification, climate of Shigar District is BWk i.e. Cold desert climate (Sarfaraz, Arsalan, & Fatima, 2014). The least amount of rainfall recorded in Shigar district is in the month of November with an average of 0.15 mm (Pakistan Meteorological Department).

Dataset Used

Satellite images of Landsat ETM+ and OLI are obtained from 2003-2017 as shown in table 1. As the discharge rate of Shigar River is not calculated after 1998 so discharge rate of Skardu River is obtained by Pakistan Meteorological Department as well as Water and Power Development Authority as Shigar River lies on the upstream of Skardu River. Temperature of Shigar District in °C is also collected from Pakistan Meteorological Department.

Table 1. Information about satellite images

Satellite	Images	Sensor/ Bands	Dates
Landsat-8	LC08_L1TP_148035_20140615_20170421_01_T1	OLI Band3-6	15-06-2014
Landsat-7	LE07_L1TP_148035_20031218_20170124_01_T1	+ETM Band2-5	18-12-2003
Landsat-7	LE07_L1TP_148035_20040611_20170120_01_T1	+ETM Band2-5	11-06-2004
Landsat-7	LE07_L1TP_148035_20081231_20161223_01_T2	+ETM Band2-5	31-12-2008
Landsat-7	LE07_L1TP_148035_20090727_20161218_01_T1	+ETM Band2-5	27-07-2009
Landsat-7	LE07_L1TP_148035_20131213_20161119_01_T1	+ETM Band2-5	13-12-2013
Landsat-7	LE07_L1TP_148035_20161205_20170124_01_T1	+ETM Band2-5	5-12-2016
Landsat-7	LE07_L1TP_148035_20170530_20170625_01_T1	+ETM Band2-5	30-05-2017

Data Analysis

NDSI (Normalized Difference snow Index) was then applied on the satellite images and then reclassify tool was used for the calculation of count of pixels of snow free and snow-covered areas over the time period of 2003-2017 in ArcGIS. After that area % is calculated from the pixel count in Excel. Formula of NDSI for Landsat-7 is:

$$\text{NDSI} = \frac{[\text{Band-2 (Green)}] - [\text{Band-5 (SWIR1)}]}{[\text{Band-2 (Green)}] + [\text{Band-5 (SWIR1)}]}$$

Formula of NDSI for Landsat-8 is:

$$\text{NDSI} = \frac{[\text{Band-3 (green)}] - [\text{Band-6 (SWIR1)}]}{[\text{Band-3 (green)}] + [\text{Band-6 (SWIR1)}]}$$

Secondary data of Temperature of Shigar district after converting into tabulated form, Regression analysis was then applied on both Discharge rate and Temperature separately for the estimation of trends whether it is increasing or decreasing with the passage of time.

Formula of Linear Regression Analysis is:

$$Y = a + bX$$

Where,

Y = Dependent variable

X = Explanatory variable

b = Slope of line

a = Intercept

The schematic flow structure is illustrated in Figure 2.

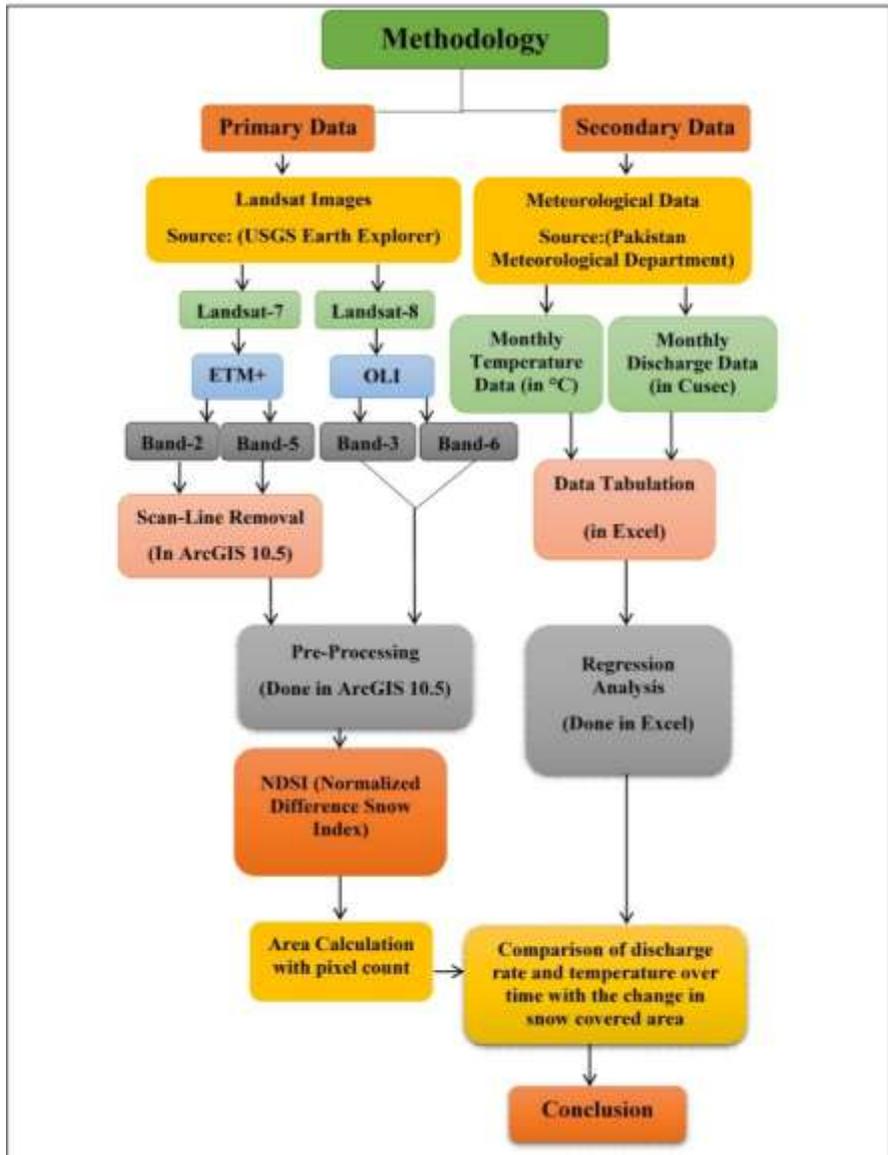


Figure 2: Research methodology

RESULTS AND DISCUSSION

Rate of Glacier Retreating

The Figure 3 shows the degradation of Baltoro Glacier mass from 2003-2017 i.e. with each passing year, snow covered area is decreasing by 0.9%. Total area of Baltoro Glacier is 134.6085 km². It is 63km long and is the fifth longest non-polar glacier located in the Gilgit-Baltistan region of Pakitsan. In the accumulation period, year 2003 and 2016, snow covered area is 99% and 92% respectively i.e. with each year passing accumulation period is

decreasing by 0.54%. In the melting period, year 2004 and 2017, snow covered area is 74% and 68% respectively i.e. with each year passing melting period is increasing by 0.46%.

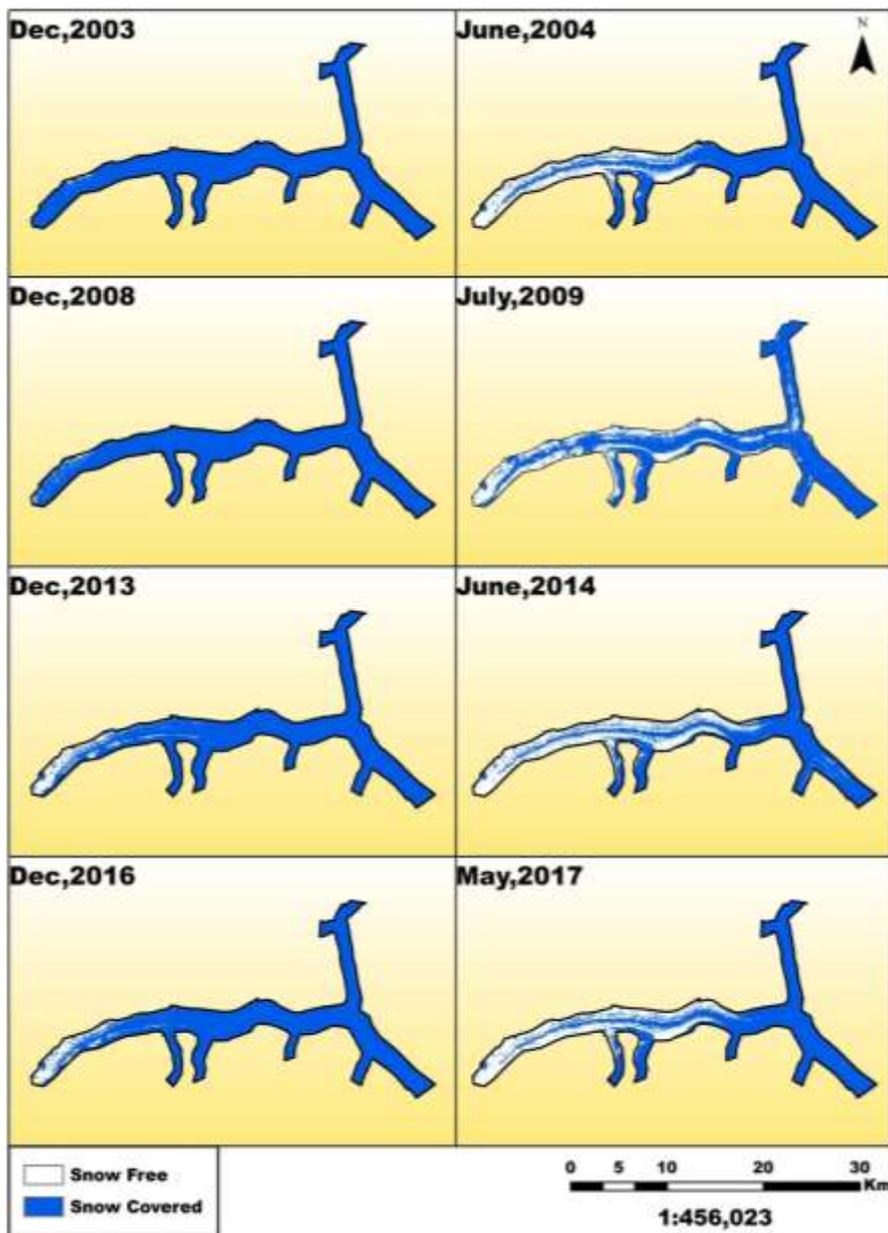


Figure 3: Terminus mapping of Baltoro terminus by normalized snow index from 2003-2017

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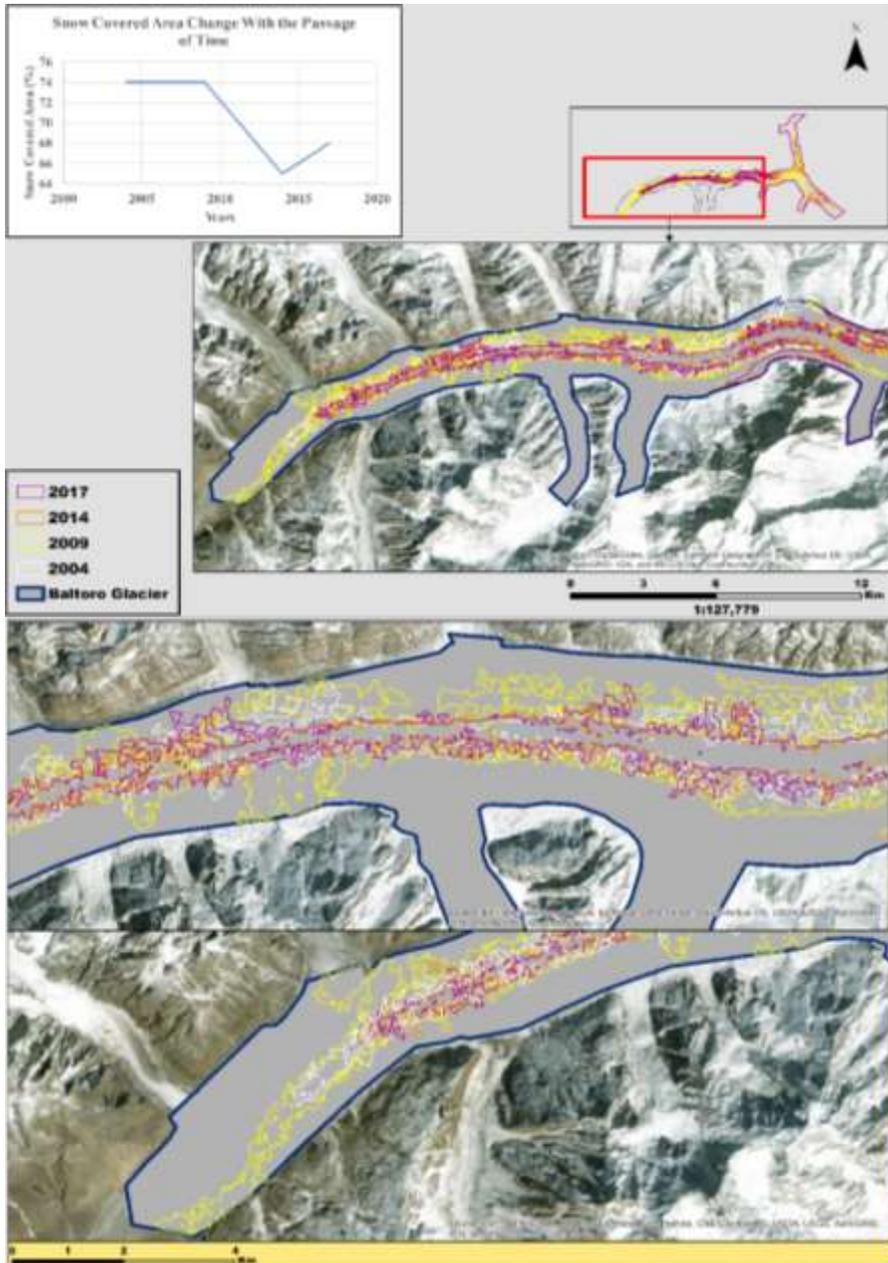


Figure 4: Terminus outlines and size of Baltoro glacier 2003-2017

Karakoram range is the glacierized region among all mountain ranges. The main water source of Pakistan is the melt water from glaciers of the Karakoram region. The Figure 3 shows that with each passing year snow covered area is decreasing by 0.9%. This means that terminus of Baltoro glacier is retreating in the years 2003-2017. Figure 4 shows the anomalous

behaviour of Baltoro. In the Figure 4 from year 2004-2009, advanced terminus is found i.e. increase in the length of Baltoro Glacier. However, in the later years 2009-2014, retreat situation is found in the length. Moreover, in the year 2014-2017 slight advancement of 1% is found in the length of Baltoro Glacier. However discharge data of Shigar River is required for the validation of results.

Correlation Of Change In Stream Flow And Retreat Of Glacier

After doing NDSI analysis, trend of discharge data of Shigar River from year 2000-2018 is seen. Snow covered area is then compared with discharge rate of Shigar River.

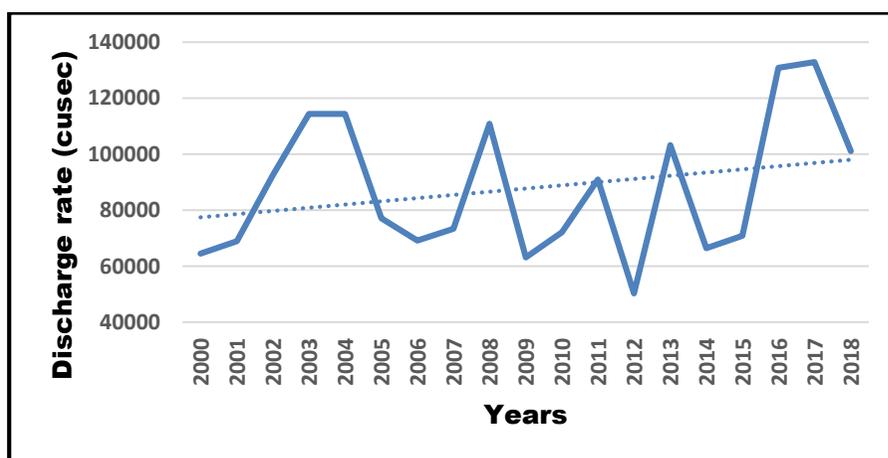


Figure 5: Discharge rate changing with the passage of time in the month of June from 2000-2018

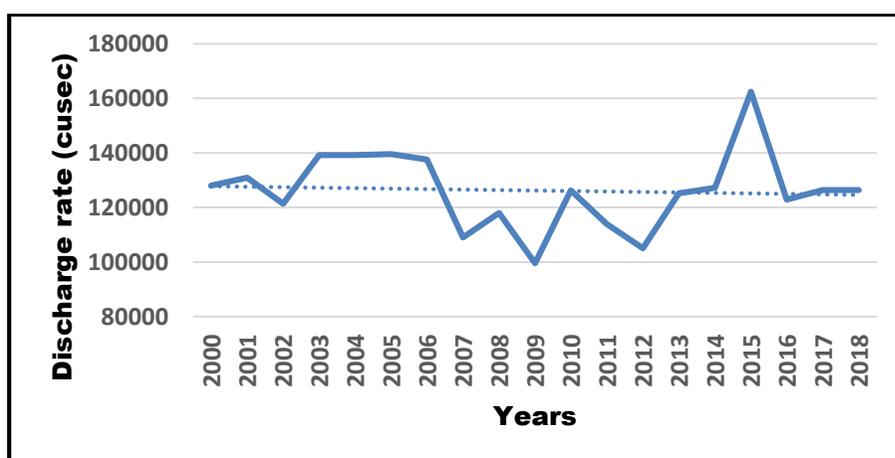


Figure 6: Discharge rate changing with the passage of time in the month of July from 2000-2018

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In the melting period from 2004-2017, with each year passing discharge rate of Shigar River is increasing by 1146 cusec in the month of June and is decreasing by 170.13 cusec in the month of July. In Figure 5 trendline shows that discharge rate is increasing with the passage of time in the month of June and in Figure 6 trendline shows that discharge rate is decreasing in the month of July because glacier length gets advanced in this month.

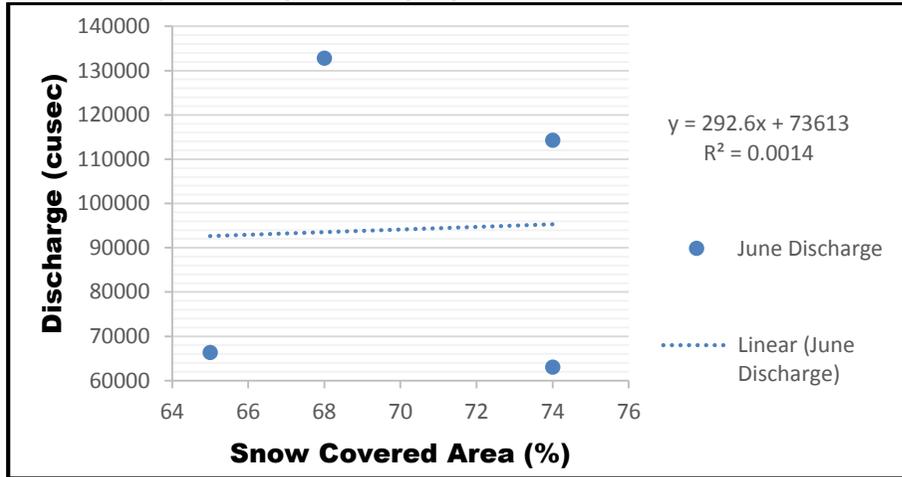


Figure 7: Discharge rate with respect to snow covered area in the month of June in the melting period from years 2004-2017

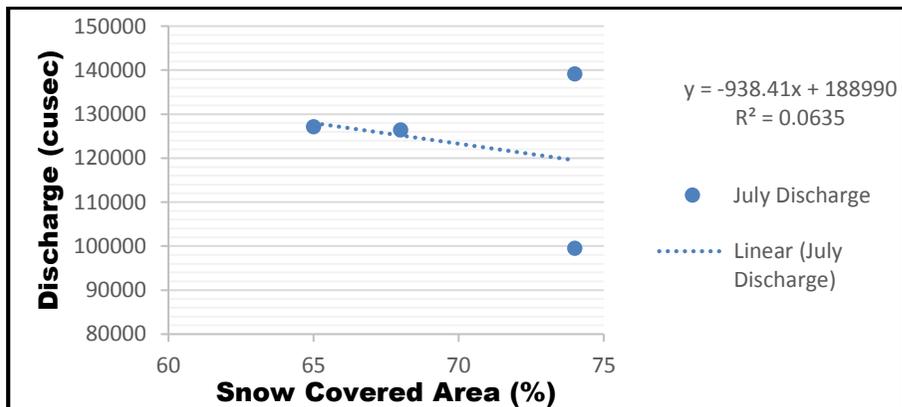


Figure 8: Discharge rate with respect to snow covered area in the month of July in the melting period from years 2004-2017

The Figure 3 shows that with each year passing melting period is increasing by 0.46%. Therefore, in the month of June, with every melting rate of 0.0014, discharge rate of Shigar River is increasing by 292.6 cusec. In the month July, with every melting rate of 0.0635, discharge rate of Shigar River is decreasing by 938.41 cusec. In Figure 7 trend line shows that with

decreasing snow-covered area, discharge rate is increasing in the month of June.

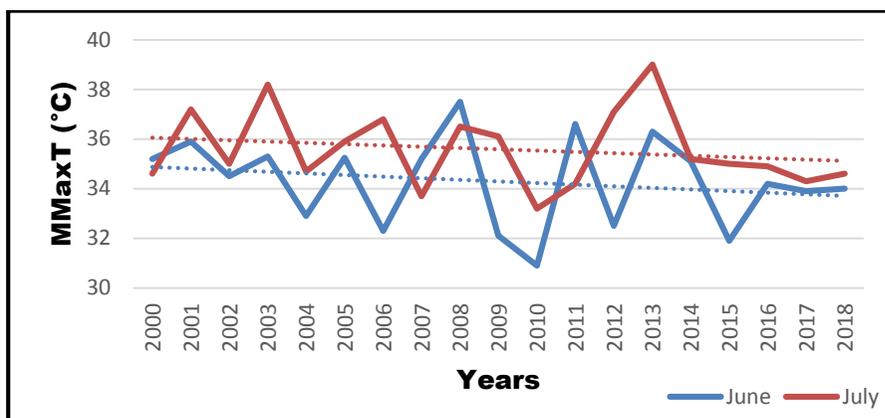


Figure 9: Change in maximum temperature in the month of June and July from 2000-2018

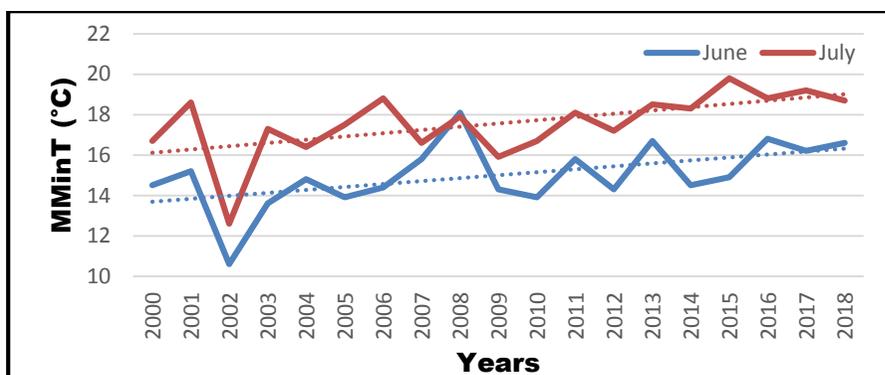


Figure 10: Change in minimum temperature in the month of June and July from 2000-2018

In Figure 9 and Figure 10, It is noted the slightly rising trend of temperature from 2000 to 2018. This increase in air temperature can be associated to gradual melting and retreating of Baltoro Glacier in Shigar basin. Temperature in the year 2009 is decreasing in the month July and hence the snow covered are gets increased in the July 2009. This is the reason why the discharge rate is increasing in the month of June and slightly decreasing in the month of July.

CONCLUSION

The present study was planned to find the relationship between Baltoro Glacier retreating or advancing and its effects on the stream flow of Shigar River. As glaciers are the most important source of fresh water globally.

Mapping And Analysis of Baltoro Glacier and Shigar River

Glacier melt water plays an important role in maintaining the things generated by local fresh water in the mountainous areas. People living in the hilly areas are mostly dependent on the glacier water moving down streams. World is experiencing global warming which is diminishing the traces of Little Ice Age (LIA). Relationship between glacier melting or advancing and stream flow rate is directly proportional to each other. Increasing trend of glacier melting will ultimately increase the river flow, likewise, decreasing trend will decrease the river flow.

In the present research, it is concluded that Baltoro glacier is retreating with the passage of time in the month of June and advancing in the month of July. On the other hand, discharge rate of Shigar River is increasing in the month of June and decreasing in the month of July. It is revealed that the relationship between Baltoro glacier retreating or advancing and the discharge rate of Shigar River is directly proportional to each other. This conclusion supported and justified by many previous researches done on glacier retreating or advancing with the change of atmospheric temperature or due to increased solid precipitation also on change in the stream flow in the respective river. Baltoro glacier has shown slight change in retreating or advancing otherwise rest of the glaciers in the Karakoram region shown advancing (Smiraglia et al., 2007). During the last 100 years, Baltoro Glacier tongue variations have shown stability i.e. balance in retreating and advancing, after the examinations of modern and ancient photographs and calculations (Mayer, Lambrecht, Belo, Smiraglia, & Diolaiuti, 2006). Glacier and snow melt fractions also constitutes in the river discharge with that of periodic rainfall (Mukhopadhyay & Khan, 2015). Increasing trend of Shigar River runoff due to increase in temperature by the changing climate has proven that with increasing temperature of Skardu, discharge rate of Shigar River is increasing. The temperature-runoff relationship proposes seasonal rise runoff in summer season because of glacier melt which is 40%. The amount of rainfall is smaller in Shigar Basin hence its outcome is not vibrant in UBCWM reproductions (Khan et al., 2014). Stream flow of Upper Indus Basin depends mostly on glacier and snow melt than on the overflow as result of rainfall in the southern area (Astore) and northern area (Hunza) (Tahir, Chevallier, Arnaud, Ashraf, & Bhatti, 2015). The melting of glacier contributed in Indus River flows during summer season, at the time when glacier melt is at its extreme or peak points (Lutz, Immerzeel, Shrestha, & Bierkens, 2014). The increasing and decreasing terminus of Yazghil Glacier has shown prominent effect on increasing area of Darkut Lake situated at the terminus of Yazghil Glacier (Yasmeen & Afzaal, 2017). There is significantly a close relationship among fluctuations in runoff features and snow variations in the basins. Runoff augmented in the three distinctive river basins from 1960-2010 in response to rise in glacial melt water (Deng, Chen, & Li, 2019). In the time period of 46-years, the glacier mass balance

has displayed a negative balance. In the Tarim River Basin, glacier overflow has a distinct influence on the inconsistency of stream flow. For four base rivers in the Tarim River basin, glacier overflow accounts for 41.5 percent of the stream flow in the period of 1961–1990, and from 1991–2006, the input of glacier overflow to stream flow augmented to 46.5 percent (Gao, Ye, Zhang, Qiao, & Zhang, 2010). Glaciers have shown a negative mass balance during the period of 1970-2009. Glacier melts subsidize 33.5 percent runoff to Tuotuo River and 15.8 percent runoff to Buqu River. With the increasing rate of retreating glaciers, stream flow rate of the two basins area increasing (Wu, Yao, Huang, Liu, & Chen, 2013).

ACKNOWLEDGMENT

This study was only possible by government organization, Pakistan Meteorological Department (PMD) and Water and Power Development Authority (WAPDA), which provided supportive information for Baltoro Glacier and Shigar River. I am grateful to my supervisor Ms. Sahar Zia (Lecturer, Lahore College for Women University, Lahore) for providing technical support and assistance in this work.

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