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Impact of Climate Change on Hinarchi Glacier and Bagrot River Runoff in Central Karakoram National Park of Gilgit-Baltistan, Pakistan

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Abstract: The effect of global warming and climate change on cryosphere in the mountainous region is quite evident as exhibited by reduction of snow cover and glacial receding. Regression analysis of Climate Research Unit (CRU) gridded data showed rising trend in average annual maximum temperature for the period 1901 to 2012.The annual mean minimum temperature for the same period indicated distinct rising rate 0.017 ˚C per year. The Annual mean temperature for the same period also increased at a rate of 0.013˚C per year. Similarly, Trend analysis performed on annual maximum temperature on Automatic Weather Station data set, where significant rising tendency observed i.e. 0.19˚C per year for the period 1993 to 2009 while the increasing trend of annual mean minimum temperature was not significant (0.06 ˚C) for the same period. Annual mean temperature for the same period is also rise at a rate of 0.13˚C per year. In order to smooth out short term variations and visualize the long term changes in temperature, five and ten year moving average of annual maximum, mean and minimum temperature were calculated. Generally, there is increasing trend in precipitation but the dry spells also prevailed in the whole region. Due to rising temperature, the ever fastest rate of glacial depletion is eventual on Hinarchi Glacier which retreated about 900m from its terminus during the last century. Bagrot river runoff trend was also determined based on hydrological data from the period 1966 to 2009 which shown decreasing trend.

Keywords: Climate change, Glacier, Snow and River runoff

1. INTRODUCTION

The three largest mountain chain Hindukush-Karakorum- Himalaya (HKH) some times called the 'Third Pole' (Dyhrenfurth, 1955) is one of the largest sources of ice and snow outside the Polar Regions. More than 1.3 billion people living in this region rely on the meltwater of snow and Glacier from HKH Mountains to sustain their livelihood, mainly for drinking, irrigation, hydropower and navigation. Mountain ranges are mostly sensitive to climate change and HKH region has no exemption. Changes in the Glaciers may have a significant impact on quantity and timing of water availability (Rabatel *et al.,* 2013).Seasonal melt water from these Glaciers is one of the main sources of freshwater that directly sustain people living in the region, especially in Arid and Semi-arid areas. The melting of Glaciers in the Himalayas region probably increase flooding and affect water resources within the next two to three decades followed by reduced River runoff as the Glaciers will be retreated (Draper *et al.,* 2007). The Indus River and its tributaries are highly depending on the HKH Glaciers and melting of these Glaciers will affect River flow (IPCC, 2007).

Climate change, growth in population, urbanization, land use change and inefficient water management are all drivers affecting the hydrological regime in the region. As the warming trend in this region is significantly higher than global average and the climate change is a great concern (Rasul *et al.,* 2008). Impact of climate change in this region may pose drastic effect with rapid Glacier melt resultantly serious implications for water availability in the major River basins of HKH. Under such circumstances lives and livelihoods of millions of people would be under threat.

The aim of this study is to assess climate variability in the region to understand its impact on Glacier fluctuation and associated River runoff.

1.1 STUDY AREA

Bagrot valley (central coordinates74˚, 43' E, 36˚, 50N,) with an elevation of 2400 masl at a distance of 35 km in North East of Gilgit City. It covers an area of 452 km^2 with 1100 households and approximate population of 10,000 people. The villages of Hamaran, Sinaker, Datuchi, Bulchi, Farfu, Hoppy and Chirah in the valley are interconnected by un-metalled roads. The Bagrot River with the length of 26.8km supplies water for irrigation to all the villages inside the Bagrot valley. The dense and agriculturally productive lands of adjoining villages of Gilgit (Jalalabad and Oshikhandass) also dependent on the River water. The main Glaciers in this valley re Hinarchi, Gargo/Burche, Yune and Gutumi.

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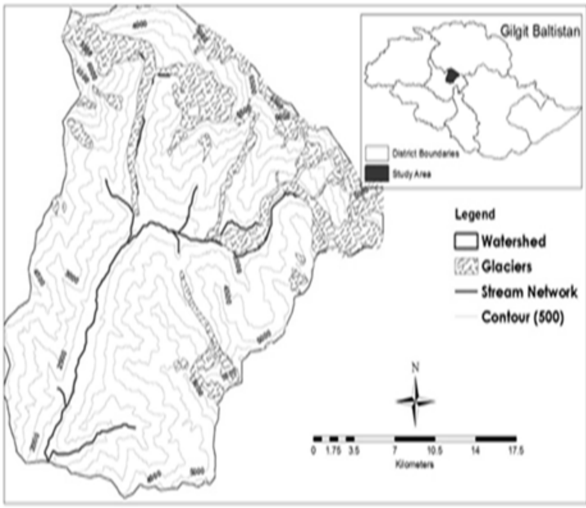

Fig. 1. Map of Bagrot Valley

2. MATERIALS AND METHODS

Due to complex mountain terrain of HKH, there is lack of regular data collection points in this Region. Various sources of data are employed to determine climate variability and its impact on Hinarchi Glaciers. Temperature and precipitation data generated by the Automatic Weather Station (AWS) with an elevation of 2310 m (36° 01' N 74° 33' E) installed by Matthias Winiger for CAK-Project was used and performed regression analysis to determine the temperature and precipitation trend in the valley. Along with the AWS data, CRUdata set for the period of 1901-2012were also used. The CRU gridded data covering the global land surface at 5 × 5 degree solution of global data set was converted in to regional data set by using GrADS (Grid Analysis and Display System) software.

Photographs taken during the expedition by H.H. Hayden on Hinarchi Glacier, in September, 1906 was incorporated to determine the change in Glacier by comparing it with the photograph taken in 2014 from the same position. Bagrot River runoff data from Water and Power Development Authority (WAPDA) was used to determine the runoff the River and its relationship with the climate variability in the valley.

3. RESULTS AND DISCUSSION

Glaciers at lower elevation of Gilgit-Baltistan are gradually thinning with the passage of time. There are several factors that may cause Glaciers depleting but climate change and global warming are the obvious ones. To access the climate variability, CRU gridded data for temperature and precipitation downscaled for Bagrot valley. The average maximum, minimum, and mean temperature in the valley is shown in **(Fig. 2).** The regression line shows a general increasing tendency in average annual maximum temperature (0.008°C) but the increasing rate is not significant, although the annual mean minimum temperature shows a distinct increasing rate i.e. 0.017 °C per year. Similarly, annual mean temperature also rose at a rate of 0.013°C per year. Time series analysis performed on observed data to determine the pattern of change in temperature over different time series as shown in **(Fig. 3).** The annual mean maximum temperature regression line shows higher tendency of temperature increase at a rate of 0.19°C as compared to annual mean minimum temperature (0.06 °C). The annual mean temperature also rose at the rate of 0.13 °C per year. The average monthly maximum temperature reaches almost 30 °C during the month of August and reaches 2 °C during the month of January as shown in **(Fig. 4)**. The average monthly minimum temperature remains zero during the winter season (Dec, Jan, and Feb) while remains above freezing in rest of months (March to November). The average monthly mean temperature reaches its maximum in July and August and remain below freezing during the month of January. Higher values of mean temperature are result of greater number of warmer days than comparatively less warmer days in July and August, since mean temperature values are highly affected by extreme temperature values (Zahid *et al.,* 2011).

In order to smooth out short term variations and visualize the long term temperature changes, five and ten year moving average of annual maximum, mean and minimum temperature were calculated are shown in **(Fig. 5).** The five year moving average showed a greater change in annual mean, minimum and maximum temperature than the ten year moving average. The five and ten year moving average of mean and maximum temperature showed nearly the same pattern while minimum temperature showed same moving average of five and ten years. The change in minimum temperature is lower than change in maximum and mean temperature.

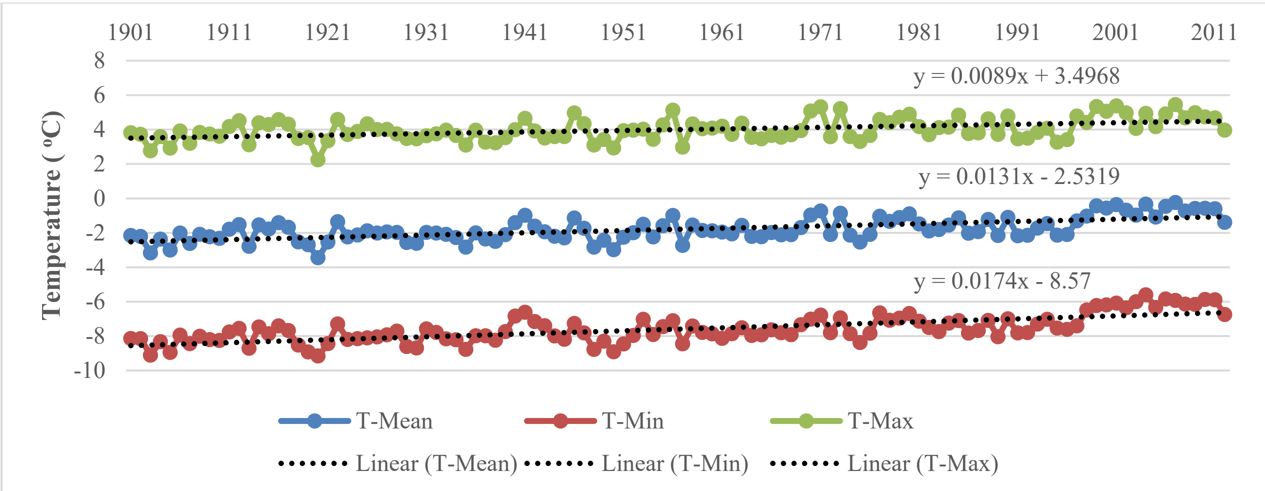

Fig. 2: Linear Trend Model for annual average maximum, minimum and mean temperature from 1901 to 2012 in Bagrot valley based on CRU Data

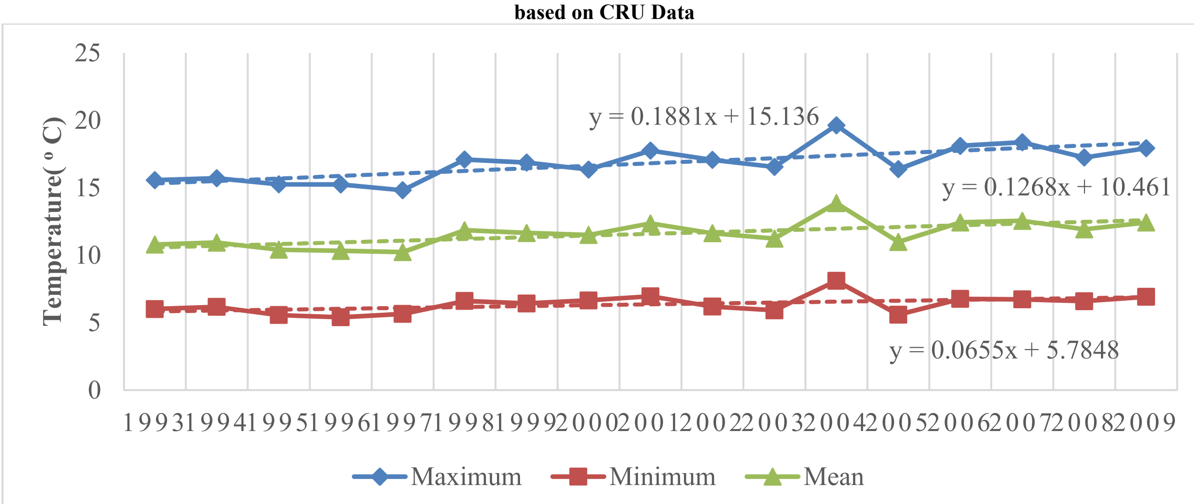

Fig. 3: Linear Trend Model for annual average maximum, minimum and mean temperature from 1993 to 2009 in Bagrot valley AWS Data

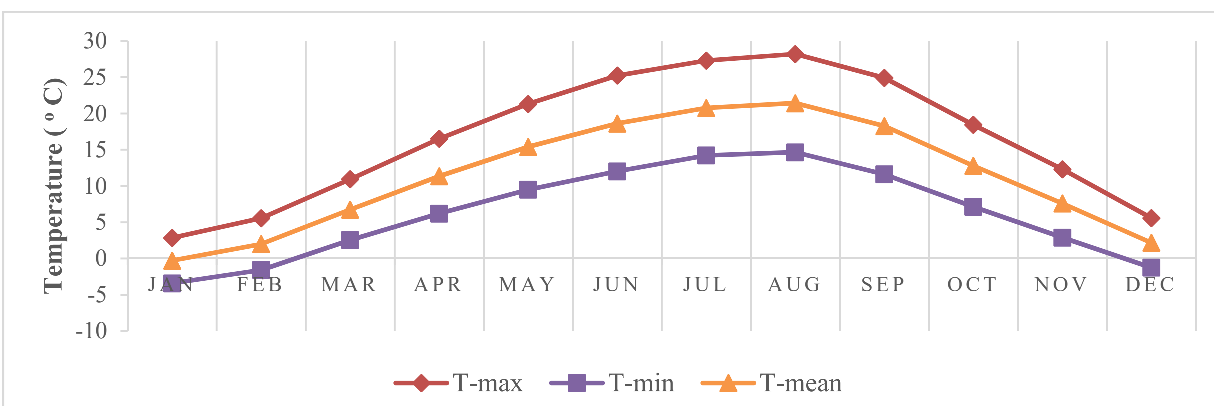

Fig. 4:Average monthly temperature in Bagrot valley (1993- 2009)

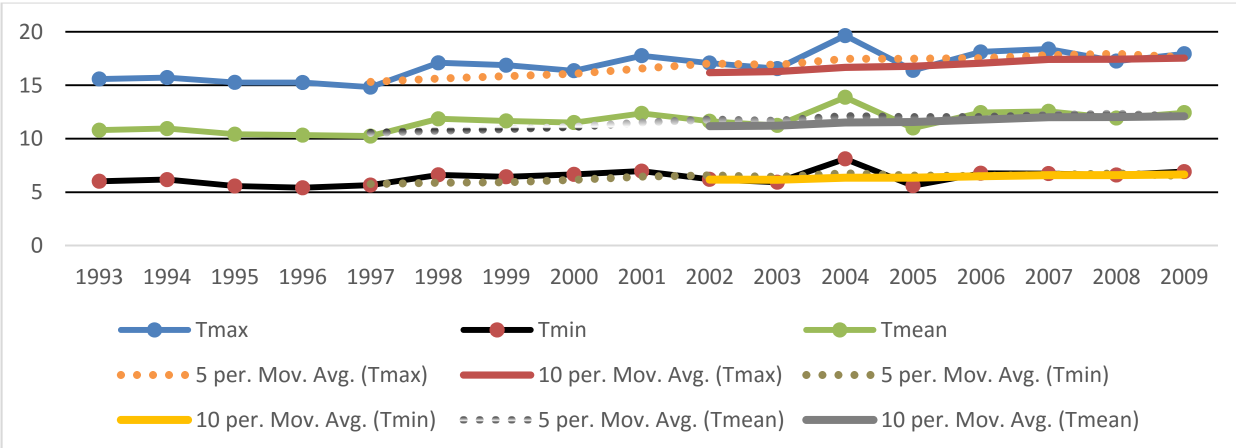

Fig. 5: Five and ten year moving average of maximum, minimum, and mean temperature in Bagrot valley

The precipitation variability in Bagrot valley was determined by using the real time precipitation record of meteorological station and CRU gridded data set. Both data sets shows great inter annual variability of precipitation in the valley. **(Fig.6A)** presents the temporal variation of precipitation from the period 1994 to 2009. Regression line shows an increasing trend in precipitation (5.49mm per year) but the dry spells also prevailed. Similarly **(Fig. 6B)** represent the CRU data set also shows an increasing trend in precipitation (0.89mm per year)but the increasing rate was not significant as compared to station data. The years below the trend line are considered as drought years while the years above the trend line are graded as flood peaks with sufficient amount of precipitation in both data sets. The analysis of temperature and precipitation by using two data set reveal that there is great variation in temperature and precipitation in the valley due to complex topography of the mountainous region. Research also showed that (Rasul *et al.,* 2008) the warming trend in northern mountain was double as compared to the lower elevation.

The visible changes of Glaciers in terms of retreat and extent cannot be hide from the stereo-photograph when present was compared with the past. A similar evidence of change is present in **(Fig. 7).** Hinarchi Glacier lies in the Central Karakorum National Park (CKNP) at about 36˚ 5' N and 74˚ 43' E. The change in snout position of Glacier was calculated by visiting the site and this Glacier has been retreated by almost 900m from the 1906 to 2014. Horizontal distance from past to present snout position is physically measured at the site by visualizing the past photograph. The longitudinal extent of this Glacier was also verified by using Google Earth showing 900 m.

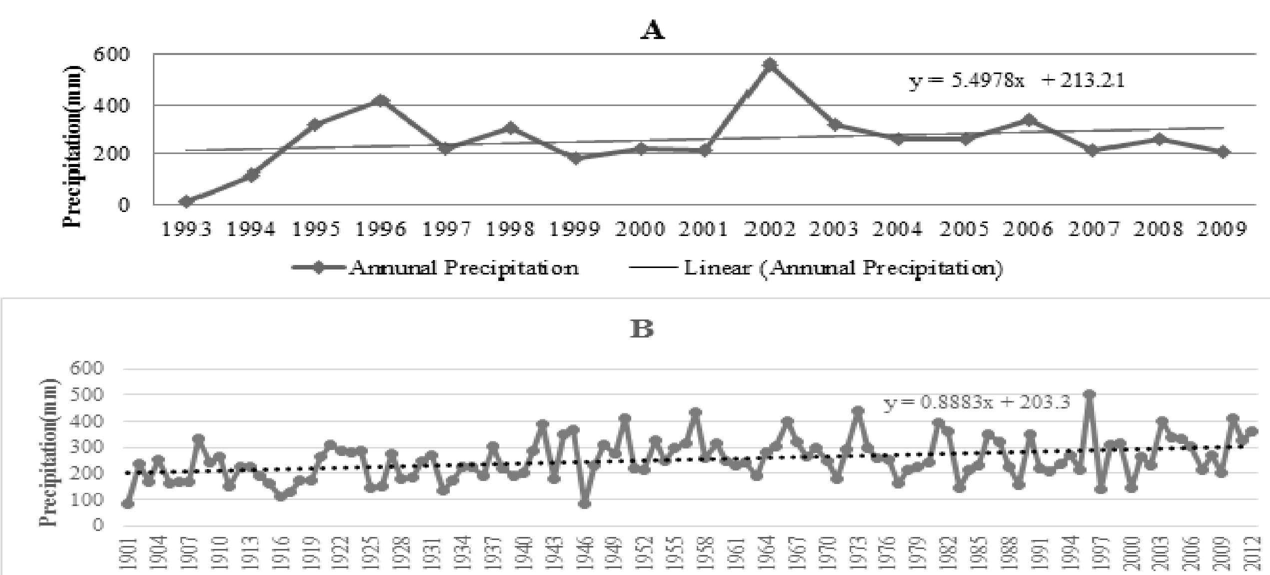

Fig. 6: Linear Trend Model for Annual Precipitation in Bagrot valley

Since the temperature maxima in this region has been increasing at a greater rate as a result the snow cover and Glacier extend has been retreating simultaneously (Rasul *et al.,* 2012). Apart from effect of rising temperature on Hinarchi Glacier another reason of melting might be the deposition of Carbon on the Glacier as the burning of woods in the villages. Due to low level inversion in the valley, the block carbon which emit from wood burning, deposit on the icy surface of the Glacier. Another reason of retreating Hinarchi Glacier might be Glacier mining. Every summer, the local people of the Bagrot valley selling the tons of crystal snow from the Hinarchi Glacier (Personnel communication with local community). As they are not professional miners due to that lot of crystal snow is wasted at the site too. Bagrot valley Glaciers fed Bagrot River runoff. Seasonal meltwater from Bagrot valley Glaciers is one of the main source of fresh water reserves which is lifeline for thousands of people living in this valley for drinking, irrigation and hydropower generation. Bagrot River runoffdata from 1966 to 2009 was analyzed to determine its runoff trend as shown in **(Fig. 8)**. The runoff reaches it maximum level in the month of July and August while it reaches its minimum level during the month of January and February. Similarly, the average monthly temperature researches its maximum level (-30 $^{\circ}$C) in the month of July and August while remains (2 $^{\circ}$C) during the month of January, February, and December (Fig. 4).Overall the results indicates that River runoff increased with the increasing of temperature and vice versa.

Regression analysis of decadal runoff in Bagrot River shows overall a decreasing trend as shown in the **(Fig. 9)**. The current decade (2001-2010) showed increasing runoff trend as compared to previous two decades. The increasing runoff trend in current decade is due the sharp increase in temperature (2001-2010) in the valley as can be seen in CRU temperature data set analysis in Fig. 2. However, to understand decreasing trend of runoff in the River we must understand the dynamic behavior of other Glaciers in the valley whose meltwater contributes to the Bagrot River runoff. Different scientists have different opinion about Karakoram Glaciers. Hewitt (1998) reported the wide spread expansion of large Glaciers in this region with few exception of Glaciers surging while (Rasul *et al.,* 2012) reported that in general, Glaciers at low elevation up to 4500m above sea level have been losing their mass significantly while above that elevation either Glaciers are stable or the melt rate is slow. The main reason of controversy among the scientist includes lack of data sharing, projection of small scale study over the entire region and insufficient in-situ measurements. However, all the scientists come to an understanding that Glaciers at high elevation are comparatively stable or melting at a slow rate while the Glaciers at low elevation are losing their ice mass at a faster rate. Same pattern has been observe in the study site, where Hinarchi Glacier base lies at lower elevation (2600 masl) where drastic change in snout position has been changed showing retreating behavior.

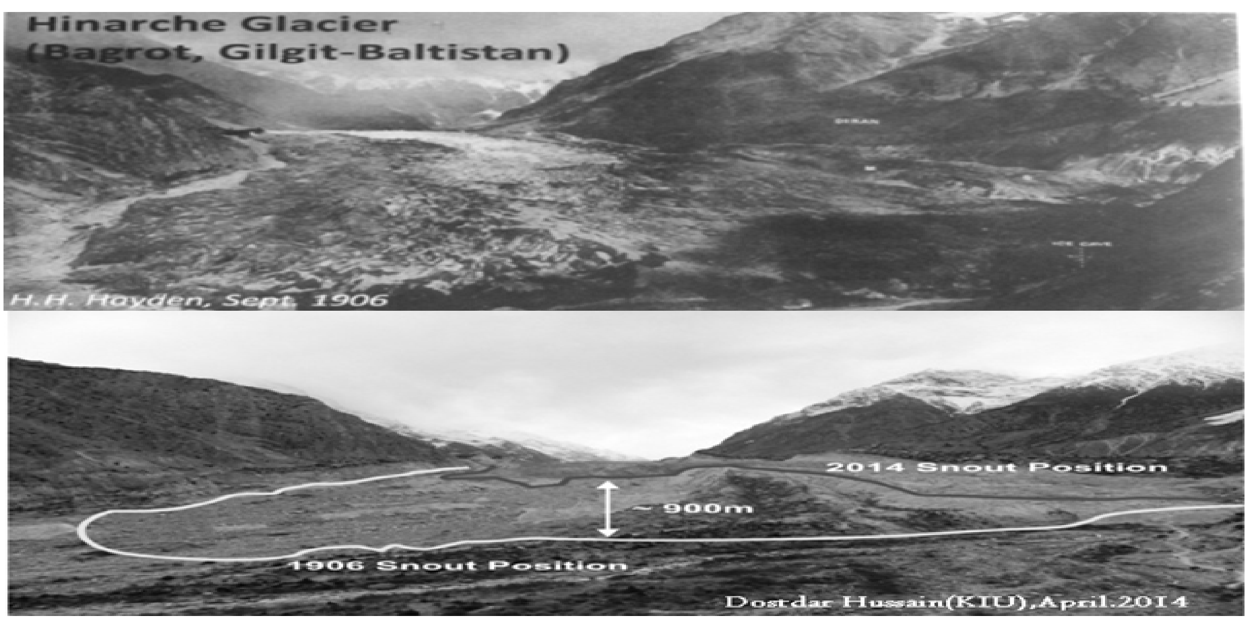

Fig. 7: Stereo Photographic of Hinarchi Glacier, Source: M. Winiger, GIUB, UIB-Excursion, April 2014

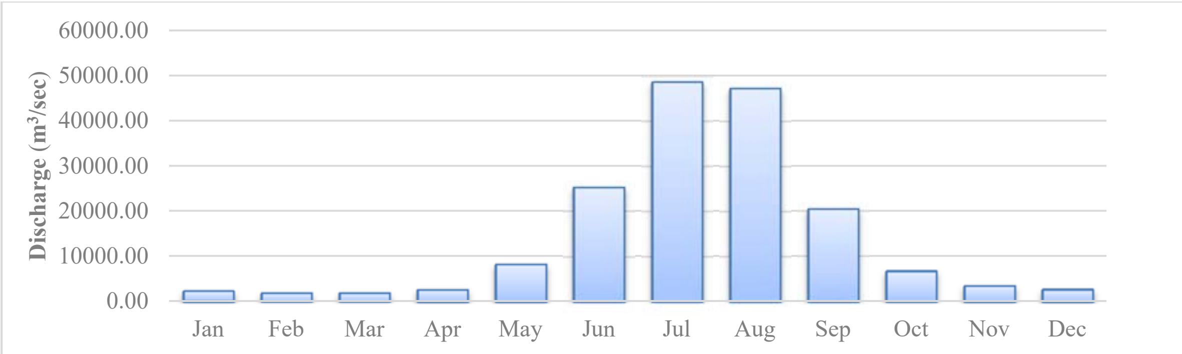

Fig. 8: Monthly discharge in the Bagrot River (1966 - 2009)

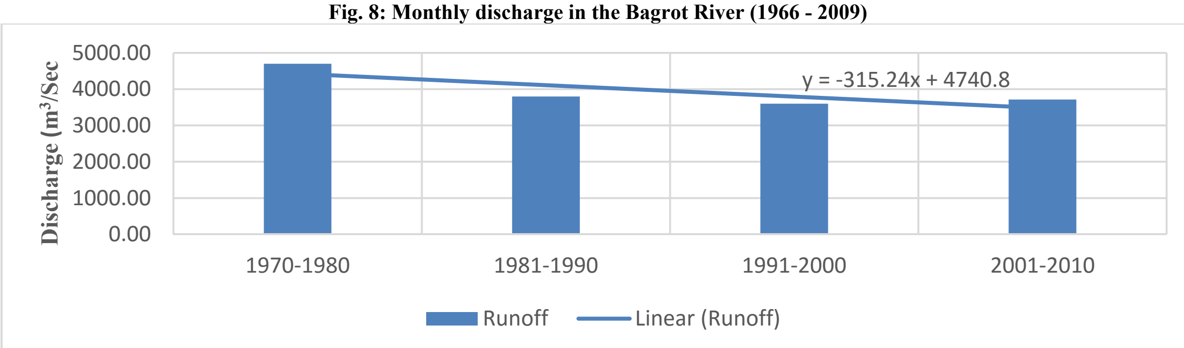

Fig. 9:Decadal Change in Bagrot River Runoff

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