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Recent Climate Variability in Kashmir Valley, India and its Impact on Streamflows of the Jhelum River

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Abstract

Streamflow trend is a robust indicator of the changes in meteorological inputs at a catchment scale and provides vital information about the seasonal and long-term storages of water in soil, snow and glaciers. Due to the mountainous terrain of the Kashmir Himalaya, the network of meteorological observatories is very scanty and inadequate. Therefore, the trends in the observed streamflows, temperature and precipitation shall provide a composite indication of the impact of changing climate at the basin level. Mann-kandall test was used to determine the trends in the annual, seasonal streamflows and meteorological variables (temperature and precipitation) from 1980-2010. Pearson correlation test was used to analyze the relation among the three hydro-meteorological variables. Results from the four observation stations revealed that the Jhelum streamflows have decreased in spite of the increase in the glacier-melt due to the rising temperature. Overall, the precipitation has marginally decreased in the Kashmir valley during the observation period. A good correlation was observed between the winter precipitation (snowfall) and spring streamflows at all the observation stations. The results indicated that the depleting streamflows in the Jhelum river is influenced by the seasonal precipitation and increasing temperature and consequent glacier loss in the Jhelum basin. It is believed that, if, the trend continues, the depleting streamflows will have adverse impact on the water-dependent sector like agriculture, horticulture, and tourism in the Kashmir Himalaya.

Keywords: Streamflows, Mann-kandall, Himalaya, Jhelum

Introduction

The high mountains in the Hindu-Kush-Karakoram-Himalayan (HKKH) belt are known as the "Water Tower of Asia" (Viviroli *et al*., 2007; Immerzeel *et al*., 2010) due to their important role in feeding a large population of about I billion people living in the major HKKH river basins of the South Asia (Ives and Messerli, 1989). The Himalayan rivers support one of the most heavily irrigated regions in the world in Pakistan and north India (Romshoo, 2012; Tiwari *et al.*, 2009). The economy of the Indus, Ganges and Brahamputra basins is largely dependent on water resources originating in the Himalayas for irrigation, domestic water supplies and hydropower generation (Karim and Veizer, 2002; Archer *et al.*, 2010). The mountainous Himalayan Kashmir valley is drained by river Jhelum that forms one of the important tributary of Indus River and comprises of 24 watersheds (Meraj *et al.*, 2017). The river is fed by combination of meltwater from glaciers, snow fields, seasonal snow packs and direct runoff from rainfall (Romshoo *et al*., 2015; Murtaza and Romshoo, 2016). The water resources in the region are vulnerable due to the changing climate and its impacts on snow and ice reserves (Barnett *et al*., 2005;

Romshoo *et al.,* 2015). Seasonal storage of water in the form of snow and ice delays the timing of runoff due to the freezing temperatures during winters (Kaser *et al*., 2010) and sustains the water supplies for various sectors for the rest of the hydrological year. Impact of climate change on hydrology and other dependent sectors is an active area of research locally, regionally and globally during the last 5-6 decades (Romshoo *et al.,* 2015; Rashid *et al.,* 2015). The published data has shown that a warming climate brings about an appreciable change in precipitation with the consequent reduction in runoff, by affecting the available water resources, evaporation, and soil moisture, as well as increasing the risk of flooding (Barnett, *et al.,* 2005; Cogley, 2011; Nepal *et al.,* 2014). The vulnerability of water resources to climate is further exacerbated due to the burgeoning population growth. In regions where the water supply is currently dominated by melting snow or ice, the increase in surface temperatures will have serious consequences for the hydrological cycle. Barnett *et al.* (2005) suggested that the reduction in snowpack and the early melting of winter snow is responsible for lower flows during summer and autumn when the demand for waters is high. Over the last century, the Himalaya has shown a stronger warming trend than the northern hemisphere average for every season (Immerzeel *et al.,* 2009). Studies have suggested that a decrease of the streamflows in the Indus river is due to the increasing temperature and decreasing snow precipitation in the higher reaches (Rees and Collins 2006; Briscoe and Qamar, 2007; Akhtar *et al.,* 2008; Immerzeel *et al.,* 2009; Berthier *et al.,* 2007; Eriksson *et al.,* 2009; Bookhagen and Burbank, 2010; Sharif *et al.,* 2012; Romshoo *et al.,* 2017). However, the effects of climate change on glaciers and streamflows in the Himalaya is still not clear in some areas (Archer *et al.,* 2010; Immerzeel *et al.,* 2010; Bolch *et al.,* 2012; Sharif *et al*., 2012). Hence the present study was carried out in the Kashmir valley, Himalaya so as to assess the changes in the streamflow trends under changing climate particularly the temperature and precipitation variables.

Study Area

The valley of Kashmir lies between the Greater Himalayan range in the north and the Pir Panjal range in the south, situated between latitude 33^0 55' to 34^0 50' and longitude, 74^0 30' to 75^0 35' in India. The location of the study area and the observation stations selected for analyses in this study are shown in **Figure 1.** The total area of the Jhelum basin, which encompasses the Kashmir valley, is approximately 15,836 km^2 (Wadia, 1979). The river Jhelum, having a length of about 160 kms in the Kashmir valley, originates from the karstic springs in the mountainous Pir Panjal range in the South Kashmir, traverses through the middle of the valley and discharges out through a gorge meeting Neelum river in Muzafarabad, Pakistan. The river is fed by 24 perennial tributaries and some of them are fed by the glaciers, the largest among them is the Kolahoi glacier in the Lidder watershed. River Jhelum drains alluvial lands in the Kashmir Valley known as the rice bowl of Kashmir. The average rainfall in the valley is highly variable, ranging from 650 mm at Srinagar to more than 1500 mm in the higher reaches of Pahalgam and Sonamarg areas. The average temperature ranges from 2.5^0C in winter to 19.8^0 C in summer (Husain, 1998). The weather has a marked seasonality in temperature and precipitation, dominated by mid latitude frontal western disturbances. The region experiences four distinct seasons: winter (December to February), spring (March to May), summer (June to August), and autumn (September to November). The western disturbances are most active during winter and spring and decrease substantially as summer progresses. Most of the Kashmir valley is not affected by summer monsoon systems (Immerzeel *et al.*, 2009), however monsoon rains have been observed over the regions around Pir Panajal and even beyond during late summer. In the upper catchments (>2000 m altitude) in valley, precipitation generally falls as snow from late autumn to early spring.

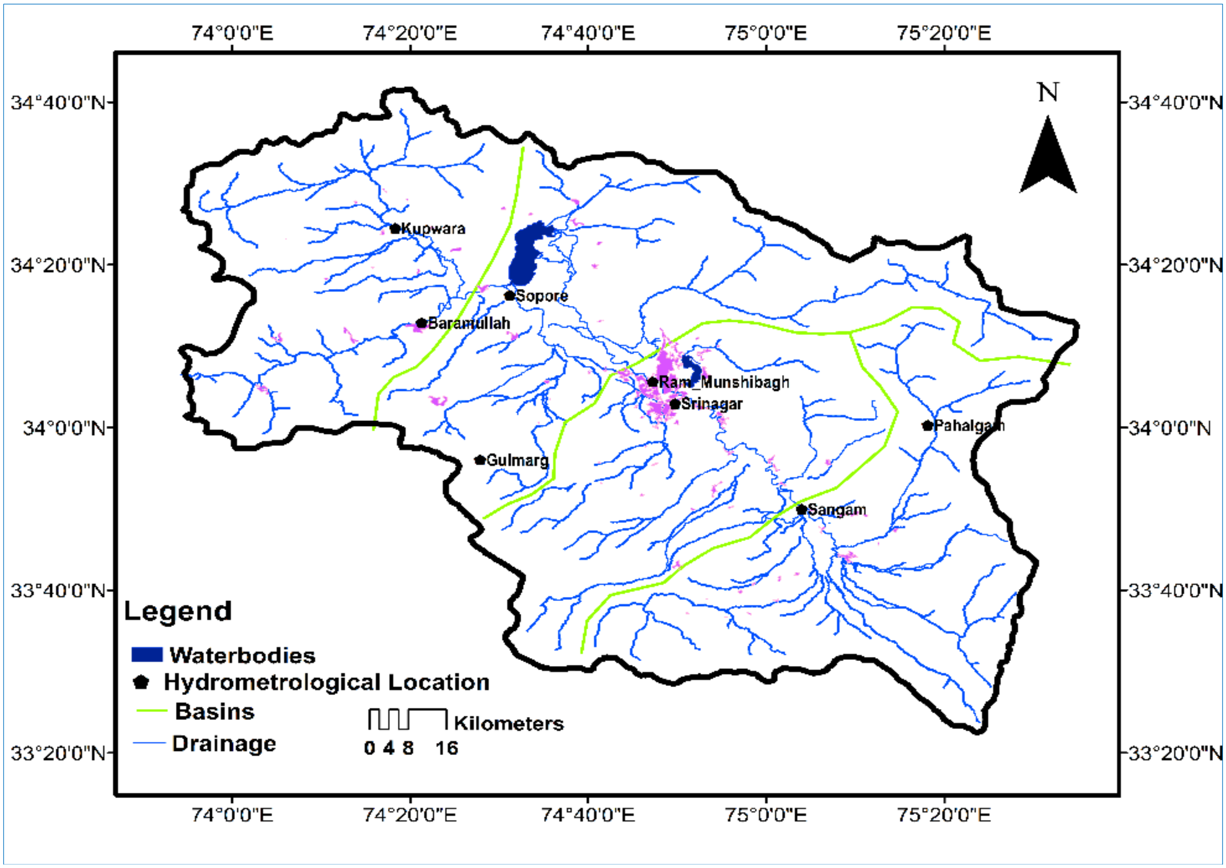

Figure 1. Study area map of Jhelum Basin

Materials and Methods

For the purpose of analyzing the hydro-meteorological trends and interse relations, the entire Kashmir valley was divided into four basins as shown in the **Figure 1**; Pahalgam-Sangam basin; Srinagar basin; Sopore-Gulmarg basin and Baramulla-Kupwara basin.

Data used

Streamflows measurement on Jhelum river in the Kashmir valley is carried out manually using the gauges. Streamflow measurements are usually made once daily during all the seasons. Climatological data, temperature and precipitation were obtained from the Indian Meteorological Department (IMD), Pune. The time series of the hydro-meteorological data in the basin from 1980 to 2010 was analyzed for four hydrological stations at Sangam, Srinagar, Sopore and Baramullah, and three meteorological stations (temperature and precipitation) at Pahalgam, Srinagar, Gulmarg and Kupwara as shown in **Figure1.**

Methodology

Trend analysis of time series hydrological and meteorological data is of practical importance because of the insights it provides about its past and future variability and is generally conducted using either a parametric or a nonparametric test. Hydro-meteorological time series data are not characterized by normally distributed pattern, and therefore nonparametric tests are considered more robust compared to their parametric counterparts (Hess *et al.*, 2001). The Mann-Kendall test (Mann, 1945; Kendall, 1975) is one of the most widely used non-parametric tests for trend detection in hydro-meteorological time series data (Burn, 2008; Burn *et al.*, 2010; Khattak *et al.*, 2011; Sharif *et al.*, 2013). Mann-Kendall has the advantage of the robustness against departures from any normality in data. Additionally, it is less affected by outliers because its statistic is based on the sign of differences, and not directly on the value of the random variables. The statistic S, as given in **Eq. (1),** is computed by comparing each value of the time series with the remaining in a sequential order. Accordingly, Mann-kendall test was used for trend analysis in this study and the correlation between the river streamflows, precipitation and temperature was determined using Pearson Correlation Coefficient. The significance (S) was measured at three levels of significance; 99% (S=0.01), 95% (S=0.05) and 90% (S=0.1).

The test statistic S is:

$$\boldsymbol{S} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathbf{sig}\left(X_j - X_i\right) \quad \textbf{(1)}$$

Each data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S. (**Eq. 2**).

$$sgn\left(X_j - X_i\right) = \begin{cases} +1 & if\ \left(X_j - X_i\right) > 0 \\ 0 & if\ \left(X_j - X_i\right) = 0 \\ -1 & if\ \left(X_j - X_i\right) < 0, \end{cases} \quad \textbf{(2)}$$

X_i and X_j are the sequential data values, n is the length of the data set. For samples greater than 10, the test is conducted using normal distribution (Helsel and Hirsch, 1992) with the mean (E) and variance (Var) shown in **Eq. (3) and Eq. (4).**

$$\mathbf{E[S] = 0} \quad \textbf{(3)}$$

$$\mathrm{Var}(S) = \frac{1}{18} n\left[(n-1)(2n+5) - \sum_{p=1}^{q} tp(tp-1)(2tp+5)\right] \quad \textbf{(4)}$$

where, tp is the number of ties value for the p^{th} group and q is the number of tied group.

The standardized test statistic (Zmk) is calculated in **Eq. (5)** by:

$$\boldsymbol{Zmk}\begin{bmatrix} \dfrac{s-1}{\sqrt{var(s)}}\, if\ s > 0 \\ \dfrac{s+1}{\sqrt{var(s)}}\, if\ s < 0 \\ 0\ if\ s = 0 \end{bmatrix} \tag{5}$$

Where, the value of Zmk is the Mann-Kendall test statistic that follows standard normal distribution with mean of zero and variance of one. In a 2-sided test for determining a trend, the null hypothesis H_0 is accepted if $-Z_{1-\alpha/2} \leq Zmk \leq Z1_{-\alpha/2}$. Where, α is the significance level that indicates the trend strength. Trend evaluation using Mann-Kendall test relies on two important statistical metrics– the trend significance level or the p-value, and the trend slope β, which provides the rate of change in the variable allowing determination of the total change during the analysis period. The presence of serial correlation in a data set can affect the outcome of the Mann-Kendall test; the version of the trend test used herein incorporates a correction, developed by (Yue *et al.*, 2002). The variance of Mann-Kendall statistic S also incorporates a correction for ties when Ri = Rj (Salas, 1993).

Pearsons Correlation Coefficient (*r)* measures the strength and the direction of a straight-line relationship and was used for determining the correlation between annual and seasonal temperature, precipitation and river streamflows. This test has been used by a number of researchers to determine the correlation among different hydrometrological parameters **Eq. (6)**.

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2}\sqrt{n(\sum y^2) - (\sum y)^2}} \tag{6}$$

Results and Discussion

The Pahalgam-Sangam basin (**Figure 1)** lies towards southeast of the Kashmir valley. Steep mountain ridges characterized by deep narrow gorges are the most striking feature of the basin. It is an important glaciated basin in the Kashmir valley known for its pristine and varied water resources in the form of snow, glaciers, springs, streams and alpine water bodies (Murtaza and Romshoo, 2016). There are more than 100 glaciers in the basin with the Kolahoi and Shishram being the major glaciers in the basin covering an area of about 10.25 km^2 and 8.5 km^2 respectively. Most of the other glaciers in the basin are very small (less than 1 km^2). These glaciers and snow packs contribute significantly to the streamflows for drinking water and irrigation in the valley. The basin records the lowest annual average temperature of 9°C. The analysis of annual temperature in the basin from 1980-2010 using Mann Kendall test shows a very significant increase (S=0.01, Kandall Score=255). Whereas the annual precipitation shows decrease but non-significant trend, kandall score=-43. The annual observed streamflow at the Sangam station in the basin showed significant decreasing trend at 0.05 level of significance with kandall score= -117 (**Table 1 and Figure 2**). The Pearson's correlation coefficient (r) test showed a good correlation between annual streamflows and annual precipitation.

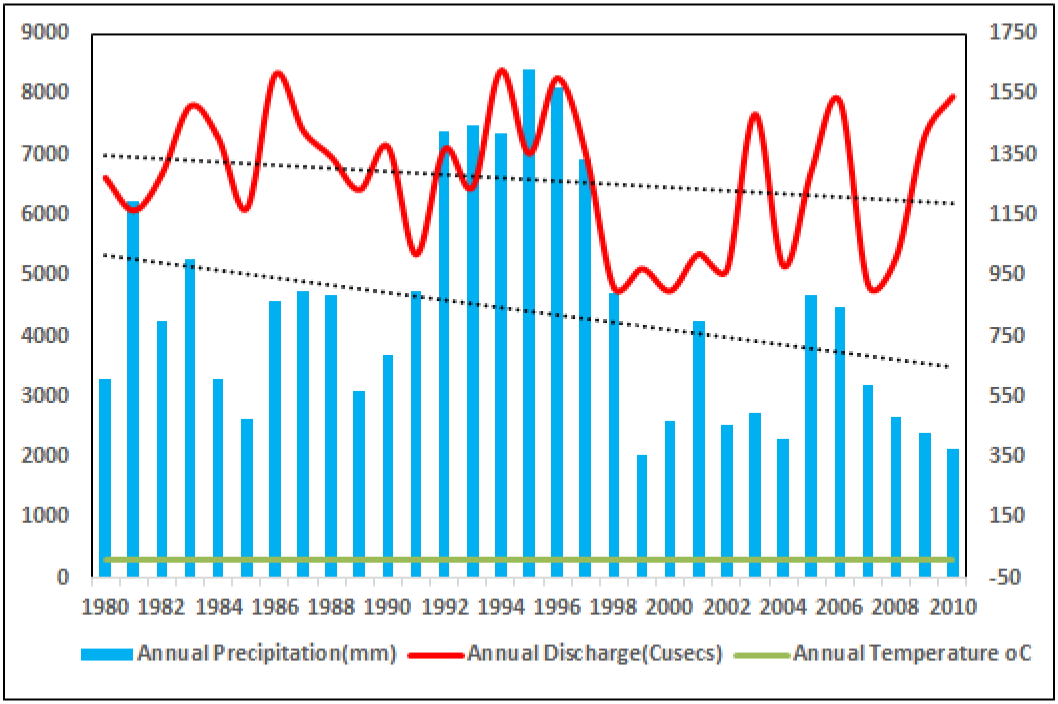

Figure 2: Annual trend in precipitation, discharge and temperature for Phalgam-Sangam Basin

In winter season both streamflows at the Sangam station and precipitation showed decreasing but insignificant (NS) trend with Kandall score = -59 and -43 respectively (**Figure 3a and Table 1**). It is important to mention here that the winter streamflows at the Sangam station is showing a reasonably good correlation with the winter temperature indicating melting of glaciers even during winters. The spring streamflows showed decreasing trend (S = 0.1, Kandall Score = -110) under decreasing precipitation trend at 95% significance level (S = 0.05, Kandall score = -99) (**Figure 3b and Table 1**). During summer season, precipitation showed increasing but insignificant trend while as streamflows showed significant decreasing trend at 0.1 level of significance (**Table 1 and Figure 3c**).

The autumn temperature shows a significant increase (S = 0.05, Kandall score = 135), however, the streamflows showed significant decreasing trend at 0.1 level of significance but precipitation showed insignificant decreasing trend (**Figure 3d**). The basin shows decrease in the streamflows despite decrease in the overall precipitation particularly during winter and spring seasons. One reason could be the increased snow- and ice-melt even during winter and spring seasons due to the higher temperature and increasing trend that is also corroborated from high correlation value of winter temperature with winter streamflows despite lower winter precipitation. It is also suggested by various researchers that the reduction in snow packs and the melting of winter snow earlier in spring seasons in Himalaya during the last several decades due to stronger warming trend particularly during winters (Barnett *et al.*, 2005; Immerzeel *et al.*, 2009; Dar and Romsho 2012). Kaab *et al.* (2012) also revealed higher rates of snow- and glacier-loss in the Kashmir Himalayas. The observed warming trend particularly during winter and spring seasons along with a decrease in the observed precipitation rates will result in a shift in the timing and quantity of streamflows in the basin.

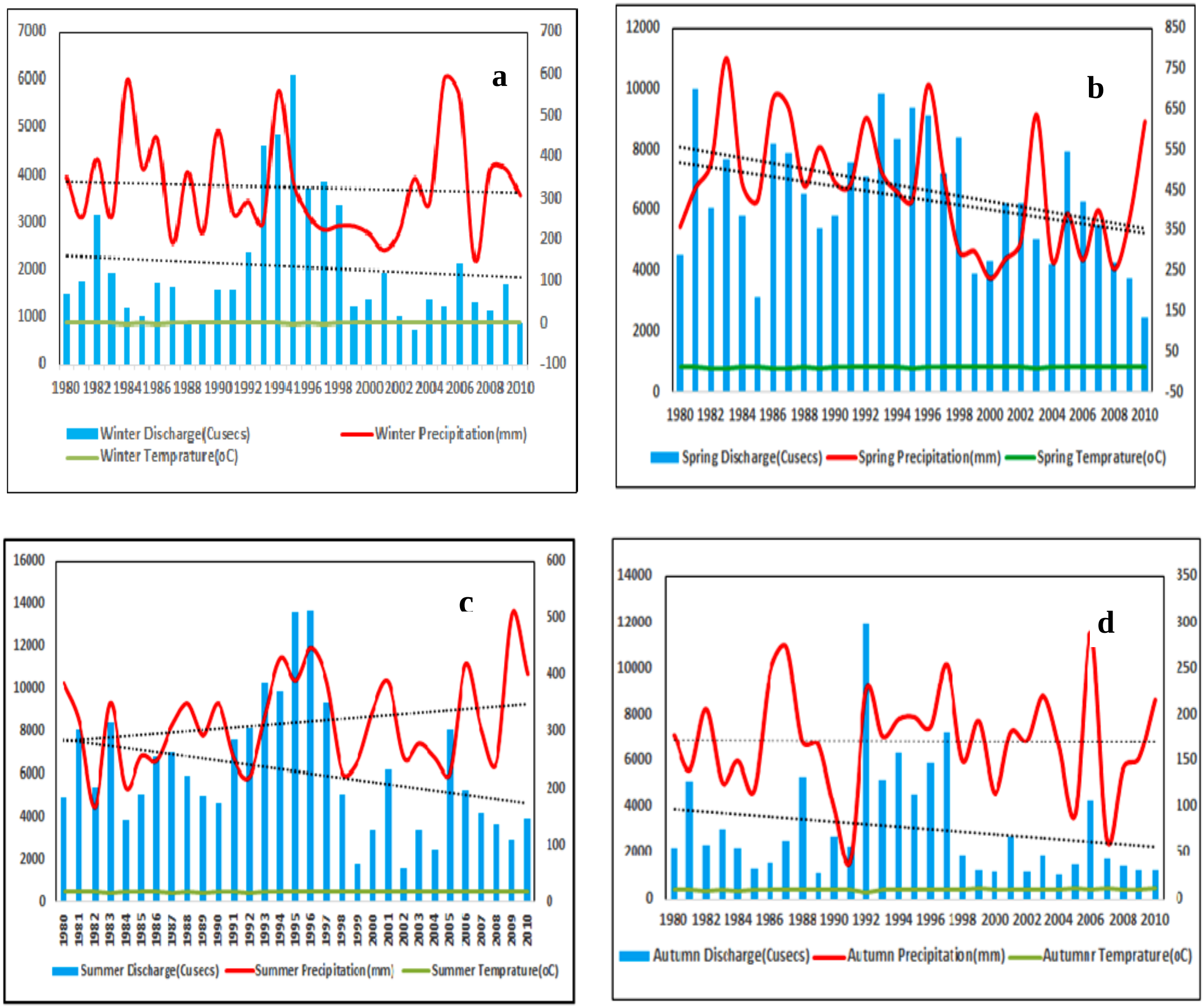

Figure 3 (a-d): Seasonal trend in precipitation, discharge and temperature for Phalgam-Sangam Basin

Table 1: Stastical analysis of precipitation, discharge and temperature for Phalgam-Sangam Basin

Name of the Test	Season	Kandall Score	Test statistic	a=0.1	a=0.05	a=0.01	Result
	Sreamflows at Sangam Station						
Mankendall Test	Average annual	-117	-1.972	1.645	1.96	2.576	S(0.05)
	Winter Season	-59	-0.986	1.645	1.96	2.576	NS
	Spring Season	-110	-1.853	1.645	1.96	2.576	S (0.1)
	Summer Season	-101	-1.7	1.645	1.96	2.576	S (0.1)
	Autumn Season	-106	-1.785	1.645	1.96	2.576	S (0.1)
	Precipitation at Phalgam Station						
	Season	**Kandall Score**	**Test statistic**	**a=0.1**	**a=0.05**	**a=0.01**	**Result**
Mankendall Test	Average annual	-43	-0.714	1.645	1.96	2.576	NS
	Winter Season	-43	-0.714	1.645	1.96	2.576	NS
	Spring Season	-99	-2.498	1.645	1.96	2.576	S (0.05)
	Summer Season	55	0.918	1.645	1.96	2.576	NS
	Autumn Season	17	0.034	1.645	1.96	2.576	NS
	Temperature of Phalgam Station						
	Season	**Kandall Score**	**Test statistic**	**a=0.1**	**a=0.05**	**a=0.01**	**Result**
Mankendall Test	Annual average	255	4.119	1.645	1.96	2.576	S (0.01)
	Winter Season	184	3.811	1.645	1.96	2.576	S (0.01)
	Spring Season	213	3.438	1.645	1.96	2.576	S (0.01)
	Summer Season	107	1.719	1.645	1.96	2.576	S (0.1)
	Autumn Season	135	2.416	1.645	1.96	2.576	S (0.05)

The Srinagar basin lies in the center of the Kashmir valley (**Figure 1**) and is highly urbanized basin in the valley with varied land use and land cover distribution. Climatically, the basin is warmer due to its high urbanization with the average observed annual temperature remaining above 19°C and the average annual observed precipitation of 760 mm. The average annual temperature in the basin is showing an increasing trend (S=0.05, Kandall score =125). The annual streamflows at Ram-munshibagh, Srinagar is showing an insignificant decrease while as the annual precipitation is showing a decreasing trend at 95% significance level with S=0.05, Kandall score= -150 (**Figure 4 and Table 2**). Pearson's correlation coefficient (r) between the annual precipitation and streamflows was 0.55.

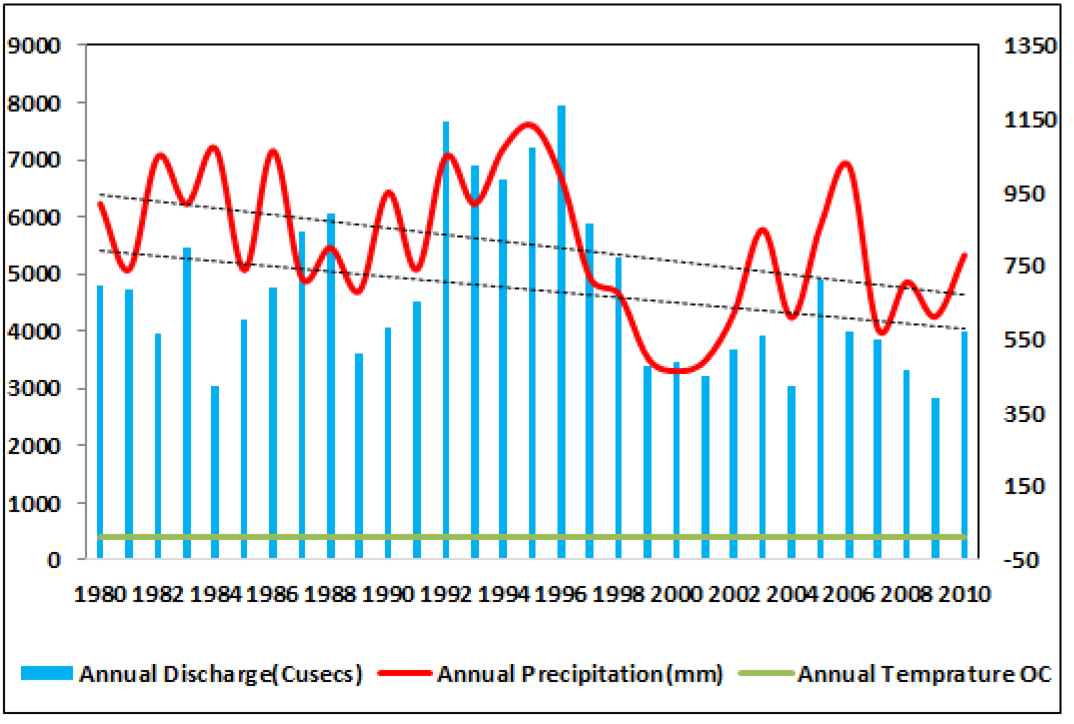

Figure 4: Annual trend in precipitation, discharge and temperature for Srinagar Basin

The winter (Dec-Feb) temperature is showing a significant increasing trend (S=0.05, Kandall score=125) with insignificant (NS) decreasing trend in streamflows and significant decrease in the winter precipitation (S=0.1, Kandall score=-89) as shown in **Figure 5a and Table 2.** The spring temperature shows an increasing trend at (S=0.05, kandall score=153), whereas the spring precipitation and streamflows shows decreasing trend as shown in **Figure 5b and Table 2.** The correlation coefficient (r) between the winter and spring precipitation and streamflow of the same seasons is 0.05 and 0.16 respectively. However, the summer and autumn temperature showing an insignificant increasing trend (NS). Whereas the summer precipitation and autumn streamflow shows a decreasing trend at 0.1 and 0.01 significance level with kandall score of -105 (**Figure 5c-d and Table 2**). *r* was found quite good between the summer streamflows and summer precipitation. The autumn precipitation and temperature are showing insignificant decreasing trend for the basin. The analysis of the hydro-meteorological data in the basin reveals that overall there is significant increase in the seasonal and annual temperatures in the basin with significant decrease only in the spring streamflows.

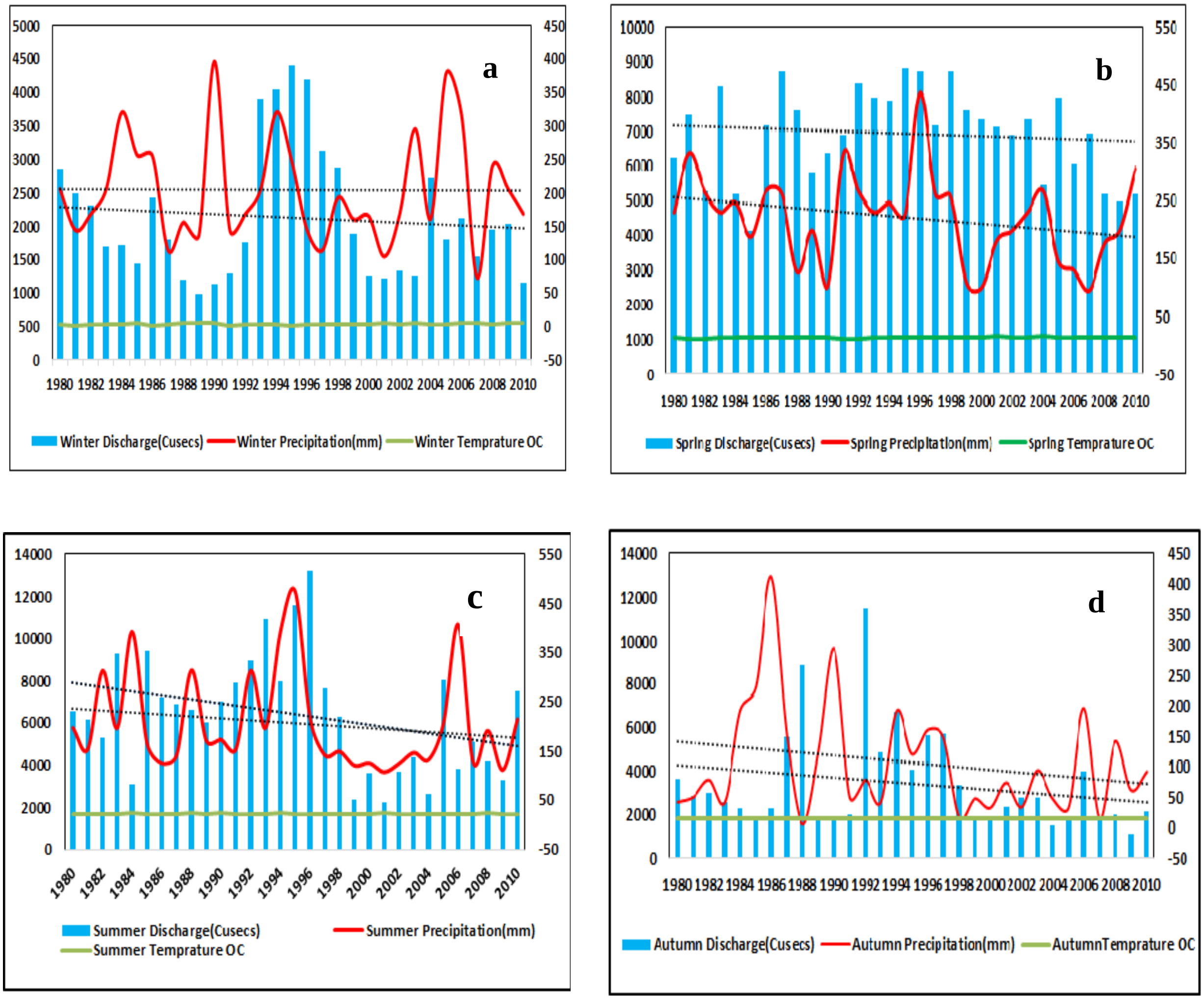

Figure 5(a-d): Seasonal trend in precipitation, discharge and temperature for Srinagar Basin.

One of the reasons for this insignificant decrease in the annual river streamflows with significant decrease in spring streamflows is attributed to the high urbanization and decreasing precipitation in the form of snow in winter seasons during these years (Hahn *et al.*, 1976, Hurrel, 1996, Lu *et al.*, 2002, Ye *et al*., 2001, Raicich *et al.*, 2003, Romshoo *et al.*, 2015). Land use and land cover change (LUCC) has been recognized as an important driver for environmental change at all spatial and temporal scales (Turner *et al.*, 1994). The type and distribution of LULC significantly affects a number of hydrological processes (Badar *et al.*, 2013, Matheussen *et al.*, 2000; Fohrer *et al.*, 2001; Quilbe *et al.*, 2008). Srinagar city is not only the largest urban center both in terms of population and areal extent in the Kashmir valley but also the rapidly growing city among all the Himalayan urban centers (Bhat, 2002).

Table 2: Stastical analysis of precipitation, discharge and temperature for Srinagar Basin.

Name of the Test	Season	Kandall Score	Test statistic	a=0.1	a=0.05	a=0.01	Result
	Sreamflows at Ram-Munshibagh Station						
Mankendall Test	Average annual	-109	-1.839	1.645	1.96	2.576	NS
	Winter Season	-39	-0.646	1.645	1.96	2.576	NS
	Spring Season	-43	-0.714	1.645	1.96	2.576	NS
	Summer Season	-81	-1.36	1.645	1.96	2.576	NS
	Autumn Season	-105	-1.768	1.645	1.96	2.576	S (0.01)
	Precipitation at Srinagar Station						
Mankendall Test	Annual average	-150	-1.216	1.645	1.96	2.576	S (0.05)
	Winter Season	-89	0.287	1.645	1.96	2.576	S (0.1)
	Spring Season	-167	-1.087	1.645	1.96	2.576	S(0.01)
	Summer Season	-105	-1.07	1.645	1.96	2.576	S (0.1)
	Autumn Season	-68	0.892	1.645	1.96	2.576	NS
	Temperature at Srinagar Station						
Mankendall Test	Annual average	125	2.108	1.645	1.96	2.576	S (0.05)
	Winter Season	97	1.394	1.645	1.96	2.576	S(0.05)
	Spring Season	153	2.413	1.645	1.96	2.576	S (0.05)
	Summer Season	23	0.374	1.645	1.96	2.576	NS
	Autumn Season	55	0.918	1.645	1.96	2.576	NS

Badar *et al.* (2013) studied hydrological response to land use changes in Dal catchment, a part of the Srinagar basin and found that the changing LULC types like built-up contributed highest to the runoff in the catchment primarily due to the increased impervious surface cover in the catchment that impedes the infiltration of rainfall into the ground. Tali (2013) studied the LULC changes in the Srinagar city and found that the areal extent of the city has increased by 403.3 km^2 from 1901 to 2011. Unplanned urban growth in a basin leads to the poor land management of the basin with inadequate drainage system that often leads to water logging and flood like situations whenever rainfall occurs (Davies *et al.*, 2008).

The Gulmarg-Sopore basin is situated in the center of Kashmir Valley between Pir Panjal and Great Himalayan mountain ranges (**Figure 1**). The basin has significant snow cover, forests and is also famous for the Wular Lake that is one of the largest fresh water lakes in Asia (Meraj *et al.*, 2017). The waters from most parts of the valley are drained into the lake before discharging from the valley through a narrow gorge near Baramullah. Thus, the analysis of the data from the basin will provide an important information regarding the overall response of the streamflows of the river Jhelum before it leaves the Kashmir valley. The trend analysis of the annual precipitation data of Gulmarg station in the basin from 1980-2010 showed a significant decrease (S=0.05 and Kandall score= -109) as shown in **Table 3, and Figure 6**. The average annual temperature of the basin showed a significant increase (S=0.01, Kandall score=205). The average annual streamflows showed a significant decrease (S=0.01) during the period.

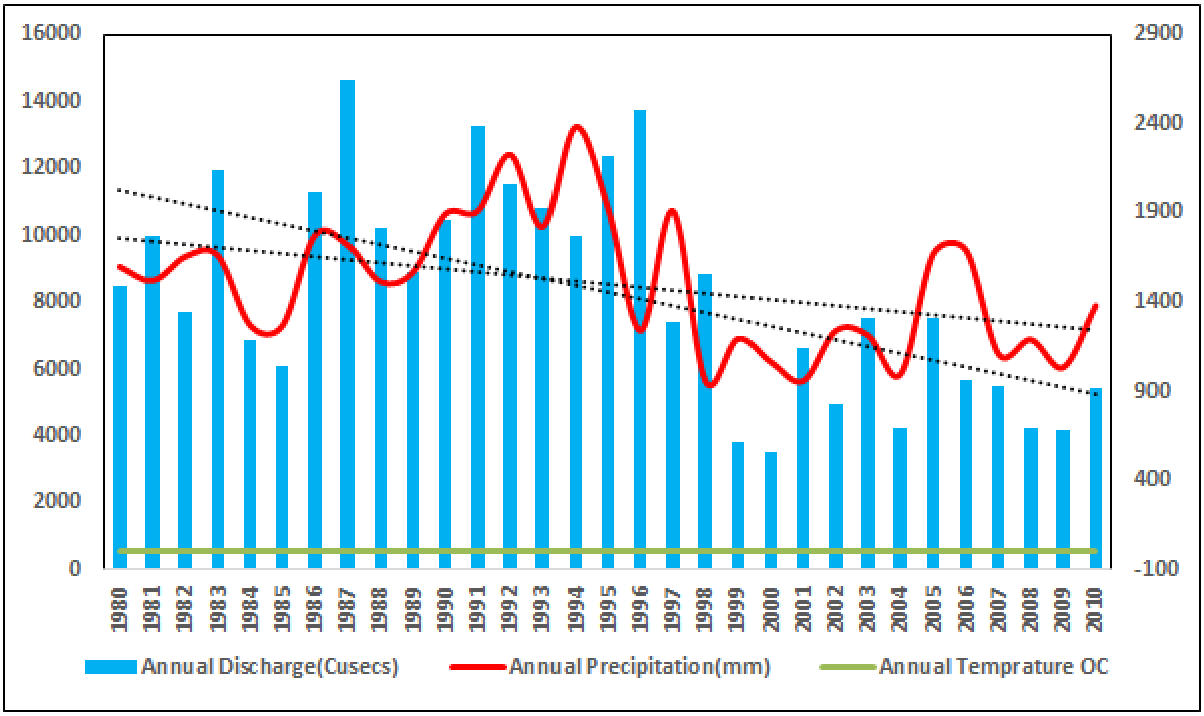

Figure 6: Annual trend in precipitation, discharge and temperature for Gulmarg-Sopore Basin

The seasonal analysis of the winter (Dec-Feb) and spring (March-May) precipitation and streamflows shows a significant decrease (S=0.01) with significant increase in temperature (S=0.05, **Figure 7a-b).** The summer precipitation showed an insignificant trend (NS) but the streamflows in summer shows very significant decreasing trend (S=0.01, Kandall=-161) and the autumn streamflows and precipitation showed a decreasing trend at 0.05 and 0.1 level of significance Kandall score= -126 and -64 respectively. (**Table 3, Figure 7c-d**). A high correlation was found between the annual and spring streamflows and precipitation but a lower correlation coefficient was found between the winter precipitation and winter streamflow. The spring streamflows showed a good relation with the winter precipitation and temperature respectively. While as the summer and autumn precipitation showed good correlation with the streamflows.

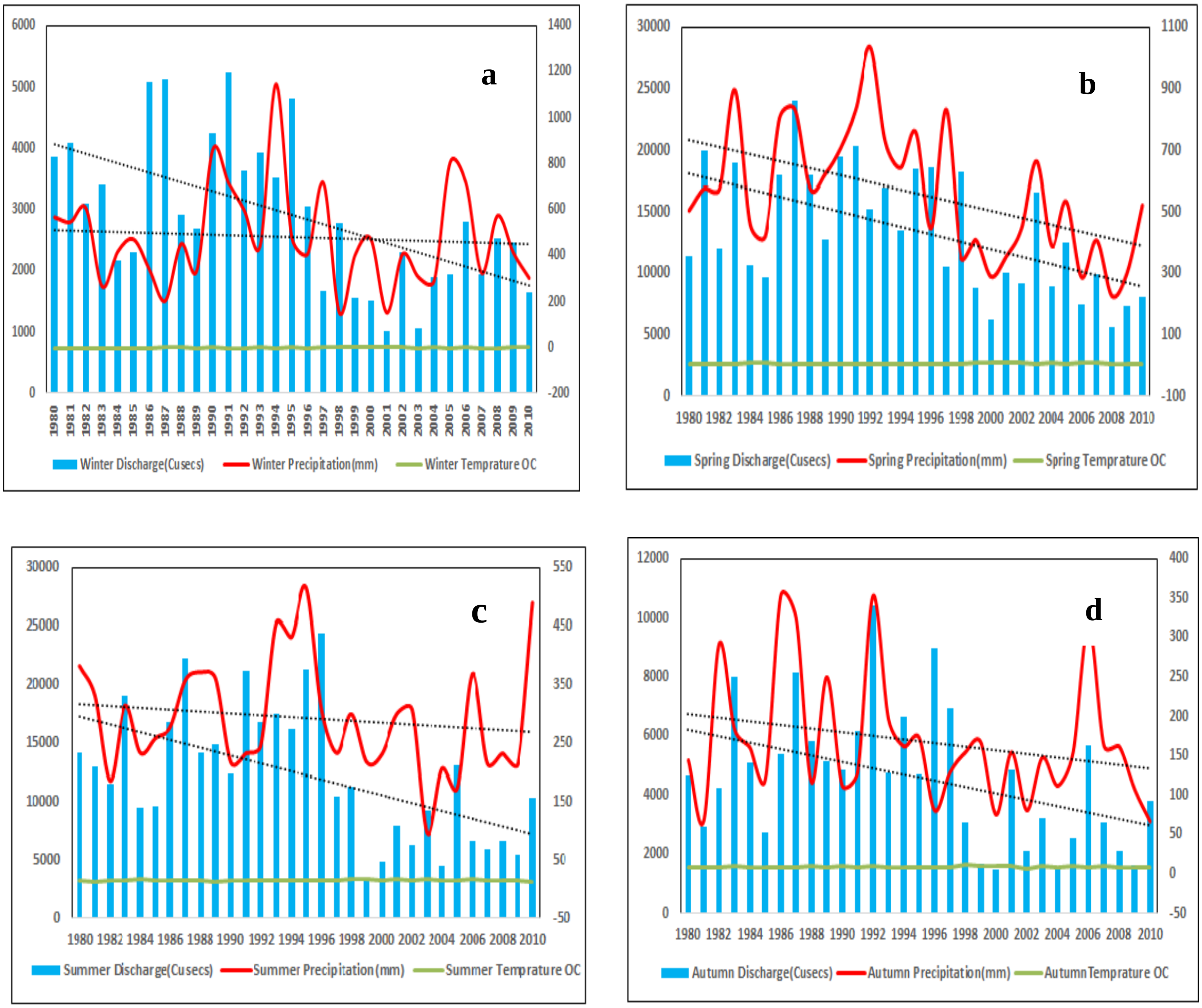

Figure 7(a-d): Seasonal trend in precipitation, discharge and temperature for Gulmarg-Sopore Basin.

Table 3: Stastical analysis of precipitation, discharge and temperature for Gulmarg-Sopore Basin.

Name of the Test	Streamflow at Sopore Station						
	Season	**Kandall Score**	**Test statistic**	**a=0.1**	**a=0.05**	**a=0.01**	**Result**
Mankendall Test	Average annual	-185	-3.127	1.645	1.96	2.576	S (0.01)
	Winter Season	-181	-3.059	1.645	1.96	2.576	S (0.01)
	Spring Season	-201	-3.399	1.645	1.96	2.576	S (0.01)
	Summer Season	-161	-2.719	1.645	1.96	2.576	S (0.01)
	Autumn Season	-126	-2.123	1.645	1.96	2.576	S (0.05)
Mankendall Test	**Precipitation at Gulmarg Station**						
	Average annual	-109	-1.615	1.645	1.96	2.576	S(0.05)
	Winter Season	-99	-0.153	1.645	1.96	2.576	S(0.01)
	Spring Season	-149	-2.515	1.645	1.96	2.576	S (0.01)
	Summer Season	24	-1.445	1.645	1.96	2.576	NS
	Autumn Season	-64	-1.394	1.645	1.96	2.576	S(0.1)
Mankendall Test	**Temperature of Gulmarg Station**						
	Annual average	205	2.923	1.645	1.96	2.576	S (0.01)
	Winter Season	236	2.43	1.645	1.96	2.576	S (0.05)
	Spring Season	119	2.006	1.645	1.96	2.576	S (0.05)
	Summer Season	59	0.986	1.645	1.96	2.576	NS
	Autumn Season	128	2.159	1.645	1.96	2.576	S (0.05)

The Baramullah–Kupwara basin lies in the northwest of the Kashmir valley (**Figure 1**) as the Jhelum drains out from the Wular Lake till it leaves the valley at Uri gorge. The streamflows shows a significant decrease (S=0.01, Kandall score=-161) during the observation from 1980 to 2010. The annual precipitation at Kupwara showed a decreasing trend (S=0.1, kandall score=-64) with a significant increasing trend observed in the annual temperature (S=0.01, kandall score=173, **Figure 8 and Table 4**). A low correlation Coefficient was observed between the annual streamflows and annual precipitation.

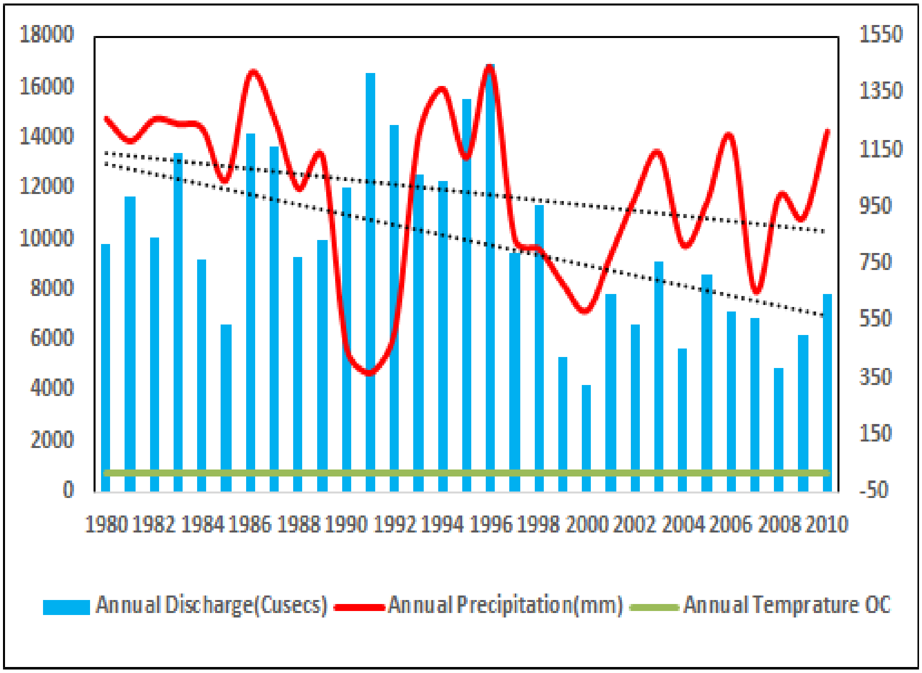

Figure 8: Annual trend in precipitation, discharge and temperature for Baramullah–Kupwara Basin

Winter precipitation and streamflows showed a decreasing trend but no significant (**Table 4 and Figure 9a**). Precipitation showed a correlation of r`=0.60 with temperature which showed an increasing trend (S=0.01, Kandall score=173). The spring and the summer precipitation showed a decreasing trend (S= 0.01and S=0.1) with significant increasing trend observed in the spring (S=0.01) and summer temperature(S=0.05). The spring and summer streamflows showed a decreasing but insignificant trend (**Figure 9b and c**). A good correlation was found between the spring streamflows and spring precipitation. The spring streamflows and winter precipitation shows a good correlation coefficient (r). The summer precipitation and streamflows also showed a good correlation coefficient (r) from the analysis of the data. The autumn temperature showed an increasing trend (S=0.05, Kandall score=159), precipitation a decreasing trend (S=0.1, Kandall score= -81) and streamflows a decreasing trend (S=0.1, Kandall score=-103**, Figure 9d**). A good correlation was observed between the autumn precipitation and streamflows at Baramullah.

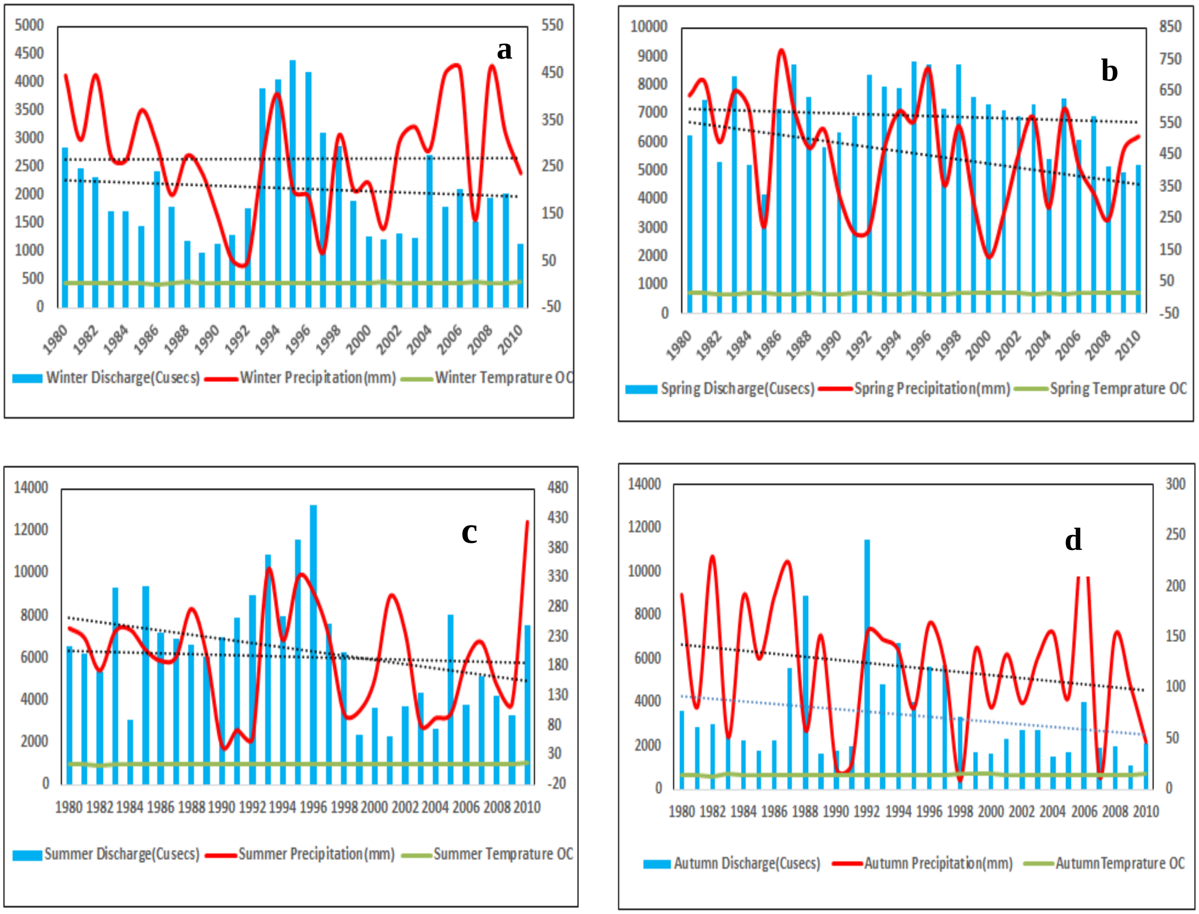

Figure 9(a-d): Seasonal trend in precipitation, discharge and temperature for Baramullah–Kupwara Basin.

The results clearly indicate that from 1980-2010, there has been a significant increase (S=0.01 and S=0.05) in the annual and seasonal temperatures observed in all basins of the Kashmir valley particularly during spring and winter seasons. Analysis of the annual and seasonal precipitation data in the basins indicated an overall decreasing trend at (S=0.05 and S=0.1). Kumar and Jain 2010; Archer *et al.*, 2010; Bhutiyani *et al.*, 2007, have also noted major change in temperature and precipitation throughout the valley. The streamflows are affected by various natural and anthropogenic factors, and therefore showing variable trend ranging from insignificant to very significant decrease. However, the observed streamflow at the outlet of the valley basins (Baramullah-Kupwara and Gulmarg-Sopore) showed an overall significant decreasing trend (S=0.01) from 1980-2010.

Table 4: Stastical analysis of precipitation, discharge and temperature for Baramullah- Kupwara Basin.

Name of the Test	Season	Kandall Score	Test statistic	a=0.1	a=0.05	a=0.01	Result
	Streamflow at Baramullah Station						
Mankendall Test	Average annual	-161	-2.719	1.645	1.96	2.576	S (0.01)
	Winter Season	-35	-0.578	1.645	1.96	2.576	NS
	Spring Season	-55	-0.918	1.645	1.96	2.576	NS
	Summer Season	-81	-1.36	1.645	1.96	2.576	NS
	Autumn Season	-103	-1.734	1.645	1.96	2.576	S (0.1)
	Precipitation at Kupwara Station						
Mankendall Test	Average annual	-64	-2.031	1.645	1.96	2.576	S (0.1)
	Winter Season	-95	-1.555	1.645	1.96	2.576	NS
	Spring Season	-103	-1.255	1.645	1.96	2.576	S (0.01)
	Summer Season	-84	-1.4	1.645	1.96	2.576	S (0.1)
	Autumn Season	-81	-1.127	1.645	1.96	2.576	S (0.1)
	Temperature of Kupwara Station						
Mankendall Test	Annual average	173	3.62	1.645	1.96	2.576	S (0.01)
	Winter Season	166	2.43	1.645	1.96	2.576	S (0.01)
	Spring Season	161	3.195	1.645	1.96	2.576	S (0.01)
	Summer Season	106	1.462	1.645	1.96	2.576	S(0.05)
	Autumn Season	159	0.68	1.645	1.96	2.576	S(0.05)

In contrast, the urbanized and glaciated basins i,e Srinagar and Pahalgam-sangam respectively showed an insignificant decrease in the streamflow due to the different causal factor and phenomenon discussed above. The results show strong connections between the observed streamflows and climate changes. Seasonally a strong connection was observed between spring streamflows and winter snowfall precipitation. The recent decrease in the winter precipitation as observed in this study is well corroborated by the findings reported elsewhere in the mountainous regions (Hahn *et al*., 1976, Hurrel, 1996, Lu *et al*., 2002, Ye *et al.*, 2001, Raicich *et al.*, 2003). The observed increase in the temperature over the Kashmir valley has led to the increased glacier/snow melt in the Jhelum River which is evident from increasing trend in the observed streamflows during spring despite decreasing precipitation in the Pahalgam-sangam basin where there is still significant snow and glacier cover for most part of the hydrological year. Although, urbanization is widespread throughout the valley and has definitely affected the hydrological processes but the effect is more pronounced in the highly urbanized Srinagar basin where the increase in the surface runoff due to the lower infiltration over the concrete surfaces often causes frequent inundation and water logging. Further the increase in runoff is also because of the observed changes in the wetland hydrology in the Srinagar basin due to the siltation and loss of wetlands in the basin (Romshoo *et al.*, 2018). Similar scenario has been reported by various researchers in the basin or elsewhere (Tali *et al.*, 2013. Badar *et al.*, 2013, Gupta and Sen, 2008, Zaz and Romshoo, 2012).

The prevailing hydro-climatic conditions in the valley are likely to become critical under the future plausible scenarios of climate change. The IPCC in its Assessment Report (Houghton *et al.*, 2001) states that the globally averaged surface temperature is projected to increase by 1.4 to 5.8^{0}C over the period 1990 to 2100. On the basis of the recent climate model simulations, it is likely that nearly all the land areas will warm more rapidly than the global average, particularly, those at the northern high latitudes during the cold season.

Conclusion

The statistical analyses of the hydro-metrological data in the Kashmir valley from 1980-2010 showed an overall significant increase in the annual temperature particularly during spring and winter seasons with variable but overall insignificant decreasing trend observed in the annual precipitation. The changes in the climatic conditions have made a significant impact on the seasonal and annual streamflows in river Jhelum. The Baramullah-Kupwara and Gulmarg-Sopore basins are showing very significant decrease in both annual and seasonal streamflows mainly due to the decrease in the observed precipitation. However, the Pahalgam-Sangam basin shows insignificant decrease in annual flow but an increasing trend in the spring flows despite observed decrease in the precipitation as the flows are supplemented by the increased contribution from the ice-melt due to the increasing temperatures in the basin. The highly-urbanized Srinagar basin also shows insignificant decrease in the annual and seasonal flow due to the higher runoff contribution in the basin because of the increasing concrete surfaces. The decrease in the observed streamflows with decreasing precipitation and increase in temperature will have significant impact on the agriculture, water availability for drinking water supplies, energy generation, winter tourism and flooding.

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