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# Trends Analysis of Stream Flow at Different Gauging Stations in Upper Jhelum River

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Author YP collected the field data, ground truthing field surveys, collation and compilation of the information gathered, collected the secondary information from various sources, data analysis and compilation of results; Author AKM provide overall guidance and contributed in planning and design of the sequence of activities as well technical guidance. Author AS helped the student with his technical expertise in using the software's for different kinds of analytical work, collection of the remote sensing data from the various sites and organizing the data analysis work as well as performed logical analysis and drawing meaningful conclusions from the results. Author DKS acted as the main facilitator for undertaking this research work under the overall guidance and mobilized the resources from the State Department and worked as one of the important links between Academia and State Department for Water Resources. Author RNS provided the much needed guidance to the student in shaping his research work. Author SS performed data analysis using the statistical tools and techniques such as the Modified Mann-Kendall Test (MMKT) and Sen's Slope Estimator (SSE). All authors read and approved the final manuscript.*

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## ABSTRACT

Analysis of stream flow trends plays a significant role in the flood forecasting and hydrologic drought assessment related investigations besides study of water resource management In this study, the long-term stream flow data recorded at different gauging stations in Upper Jhelum River (UJR) in Jammu and Kashmir (J &K) state basin were estimated using the Modified Mann-Kendall Test (MMKT) and Sen's Slope Estimator (SSE).Long term time series data of ten gauging stations

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used for trend analysis were annual maximum and monthly maximum stream flows for the years (1980-2016) for the months of occurrence of flood in UJRB. It was observed that six gauging stations out of the ten showed a significant decreasing trend in discharge and depth of flow in the UJRB at 0.05 probability level of significance. However the results of the monthly and seasonal maximum stream flow analysis showed that during spring season (March to May) about 90% of the gauging stations depicted downward trends in the summer season (Jun to Aug) all the gauging stations showed downward stream flow trends and approximately 60% of the gauging stations showed downward trends in the month of September (first month of autumn). This analysis resulted into quantification of flood magnitudes and its periodicity of occurrences to develop flood mitigation strategies. Nonetheless, such investigation of water flow in the river would also assist in regional hydrologic studies besides occurrence of flood and hydrologic droughts.

*Keywords: Stream flow; flood; trend analysis; Mann-Kendall test; Theil-Sen estimator.*

## 1. INTRODUCTION

Changes in rainfall and other forms of precipitation are one of the most critical factors determining the overall impact of climate change. Minor shift in the climatic pattern due to rising air temperature and varying precipitation is expected to affect mountainous river systems [1]. Climate change can cause significant impacts on the water resources by disturbing the hydrological cycle [2,3]. Stream flow constitutes a major phase in the hydrological cycle. Climate warming can accelerate the water cycle and alter the spatial and temporal distribution patterns of the regional water resources [4,5,6,7]. The spatio-temporal variability of stream flow in watersheds needs to be studied extensively to manage the limited water resources more effectively and to mitigate the stress on water depletion [8]. Stream flow varies over space and time with the range of temporal scale varying from minutes (e.g. in the case of flash floods) to decades (e.g. in the case of water resource assessments). Moreover, the river flow regimes describe the temporal patterns of flow variability.

The Kashmir valley has faced several floods in July 1841, July 1893, July 1903, 1929, 1948, September 1950, September 1957, July 1959, September 1992, 1996, September 2006, September 2014, March 2015, and April 2017. Due to the floods of September 2014 in Jehlum River, about 22 lakh people in approximately 287 villages of Kashmir Valley were estimated to be affected [9]. Over 300 people lost their lives across J & K, including 85 persons from Kashmir Valley. A preliminary survey by the government revealed that the flood damaged over 3.50 lakh structures, including 2.50 lakh residential houses and affected 12 lakh families in 5500 flood affected villages across the state. It was observed that the floods were the result of abrupt hydro-climatic phenomenon due to climate change parameters [10]. Hydrologic uncertainty necessitates that the rainfall, runoff and stream flows (daily, weekly, fortnightly, mean monthly, seasonal or annual) time series data should be thoroughly and scientifically studied and analyzed to establish the trends, patterns and distribution of rainfall and other associated variables.

The Mann-Kendall test is a non-parametric statistical method used for trend analysis of time series data [11]. Due to its simplicity and broader application, World Meteorological Organization (WMO) has recommended this method to assess the monotonic trend in hydro-meteorological time- series [12]. The stream flow data from 395 U.S. gauging stations in climate-sensitive regions were analyzed using the Mann-Kendall test [13]. It showed a general upward stream flow trends, barring a few Northwestern and Southeastern regions exhibited downward stream flow trends. The stream flow data collected from 11 Canadian gauging stations for 30–50 years were analyzed and it was observed that during this period, the average annual stream flow decreased for southern cities and the average monthly stream flow frequently decreased for all stations [14]. Similarly, it was observed on the basis of analyzing 31 years long monthly stream flow data for 26 Turkish basins which indicated downward stream flow trends. Such change could be attributed to a drop in rainfall and a rise in temperature during the period of analysis [15]. During the 40 years long period (1962-2001) in West England, the analysis of seasonal and annual stream flow data pertaining to 56 gauging stations resulted in significant upward stream flow trends for both high and low flows, whereas the average stream flow remained relatively stable [16,17]. Further, with increase of the length of record to 75 years (1929–2004), the stream flow of Dee River in Northeast Scotland, while investigating the spatio-temporal variability of stream flow and rainfall, it was concluded that the snowfall was highly correlated to downward rainfall trends. A large number of factors contribute to snowfall changes in hilly catchment area having heavy snowfalls. Further, it has also been observed that in order to highlight the peak stream flow in a correlation system, the use of hourly data were far more superior to that of daily measurements.

It was observed that selection of gauging stations also had an effect on the regional pattern of trends and significant increase in trends in annual, winter and spring duration was noticed [18], while the summer stream flow trends were different in each of the different periods studied. Stream flow data of three different period viz., 1920-2005, 1941-2005 and 1961-2000, in high altitude Himalayan mountain setting, using the Mann-Kendall test confirmed the findings of other workers in similar agro-climates. On the basis of analysis of a fairly long time series stream flow data of 71 years (1945–2005) belonging to 187 sub-basins in the Iberian Peninsula, U.K. It was concluded that the highest flow exhibited downward trends in annual, winter and spring time scale. In another study, 40 years (1969–2008) data of 89 catchment areas in Nordic countries were analyzed and results showed that irregular runoff increases in the seasonal data analyses were results of the influence of high flow in the winter and fall, and low flow in the spring. Observations of low lands in Southeast England revealed the presence of spatial heterogeneity in trends. Therefore, when increasing the scale of the basin in a study area, the spatial heterogeneity needs to be considered [19].

The stream flow data for 12 stations located in the mountainous western region of Iran for a period of 40 years (1970–2009) were analyzed using the Mann-Kendall test. Analysis showed the existence of substantial trends in stream flow during the months of October and November in majority of the stations [20]. Further, the stream flow data of 96 years (1913–2008) in Hawaii were analyzed using the Mann-Kendall test, which exhibited that the maximum flow exhibited downward stream flow trends [21]. The Mann-Kendall test is primarily used to determine whether a series of numbers demonstrate a significant trend or not. However, it cannot be used to calculate the extent of the upward or downward trend. Therefore, a trend slope calculation method is normally used in conjunction with the Mann-Kendall test. Mann-Kendall-Sneyers and the Mann-Kendall test for Kaidu River basin, located in the Northwestern Arid Region of China, were performed for analysing the 50 years (1960-2009) of annual stream flow data. It was observed that the Kaidu River basin had significant increase in the annual stream flow [22] and that the change point occurred in 1993. The Mann-Kendall test analysis of stream flow data of Sava River showed the significant effect of long term periodicity of annual flows on the time series trend [23].

The monthly, seasonal and annual stream flow data of 20 hydrometric stations located in Karkheh River Basin, in Iran were analyzed for 38 years (1974-2011). The analysis of stream flow data by using the Mann-Kendall test showed that stream flow trend has decreased in all three time scales [24]. In another study, the monthly, seasonal and annual stream flows data of of three headwater region located in northwest China for a duration of 57 years (1956-2012), were analyzed using Man Kendall trend test. It was observed that both the high and low flows decreased and increased in the Yellow River Basin (YRB) and the Yangtze River Basin (YARB), respectively. However, in the Lancang River Basin (LRB), the high flow decreased while the low flow increased [25]. To infer the results more precisely and calculate the slope of the trend line more precisely, Theil-Sen estimator was being used. In such analysis, it was used together with other trend analysis methods to perform quantitative analyses on significance of trend [26,27,28,29,30]. Thus, in the present study, the Theil-Sen estimator was also used to calculate the trend slopes precisely to obtain the extent of trend changes.

Climate change is responsible for the increasing trend and intensity of extreme weather events [31]. The study basin falls in the Himalayan region and it is reported that number of rainy days in the Himalayan region may increase by 5–10 days on an average in the 2030s [32]. It would increase by more than 15 days in the eastern part of the Jammu and Kashmir. The intensity of rainfall is likely to increase by 1–2 mm/day [33]. The projections for 2030's indicate that the annual rainfall in the Himalayan region is likely to increase in 2030s with respect to 1970s range from 5% to 13% with some areas of Jammu and Kashmir showing an increase up to 50% [33]. Studies also indicated that extreme rain events are becoming more frequent as compared to moderate rain events. Rainfall is also becoming highly variable at both spatial and temporal scales and of unseasonal nature. In the state of J&K, structures for flood control systems are traditionally designed based on the assumption of stationarity in hydrological processes such as river stage and discharge. In view of recent floods in Upper Jhleum River Basin of J&K, detection of trends in long time series of stream flow data in Jhelum River at different segments is of scientific interest and practical importance. It is also essential for planning of future water resources and flood forecasting and protection systems.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

The study area in the Upper Jhelum River Basin (UJRB) is situated between the geographical coordinates of 33°21′48″N to 34°15′20″N latitude and 74°30′37″E to 75° 32′31″E longitude. The delineated catchment in the Jhelum river basin has an area of 5802 km$^2$. Srinagar city which is the largest urban center in the valley is settled on both the sides of Jhelum River and is experiencing a fast spatio-temporal growth. Jhelum River flows through India and Pakistan having a total length of about 725 km, out of which about 117 km lies in India. River Jhelum originates from Verinag spring situated at the Pir-Pranjal in the South-Eastern part of Kashmir valley in India. It flows through Srinagar city, the capital of Jammu and Kashmir and the Wular Lake before entering Pakistan. The location Map of the study area as shown in Fig. 1.

March is the rainiest month for Srinagar as Srinagar city receives more rain in the month of March than in the monsoon season. The average rainfall for the month of March is 115.6 mm, while the average is 60 mm and 70 mm in July and August, respectively. Srinagar, Jammu and Kashmir receives 710 mm annual rainfall. On an average, there are 103 days per year with more than 0 mm of rainfall. 1 mm or 8.6 days with a quantity of rain, sleet, snow etc. per month. The drainage of the study area is well developed. The Drainage network of UJRB catchment is depicted in the Fig. 2.

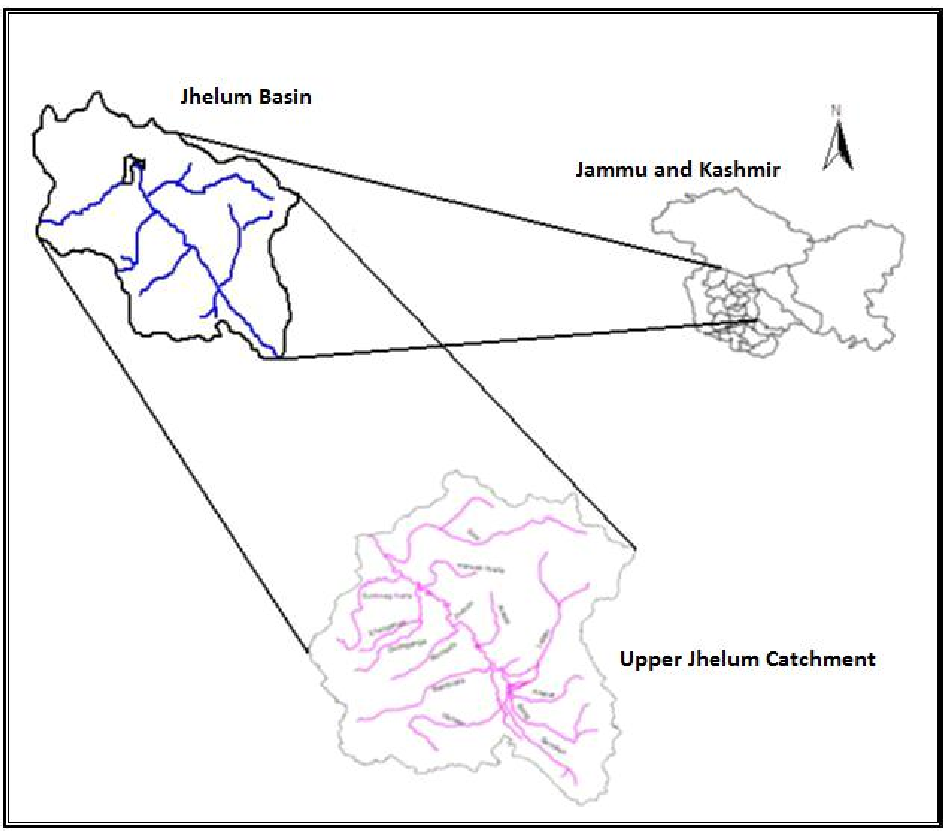


**Fig. 1. Location map of the study area**

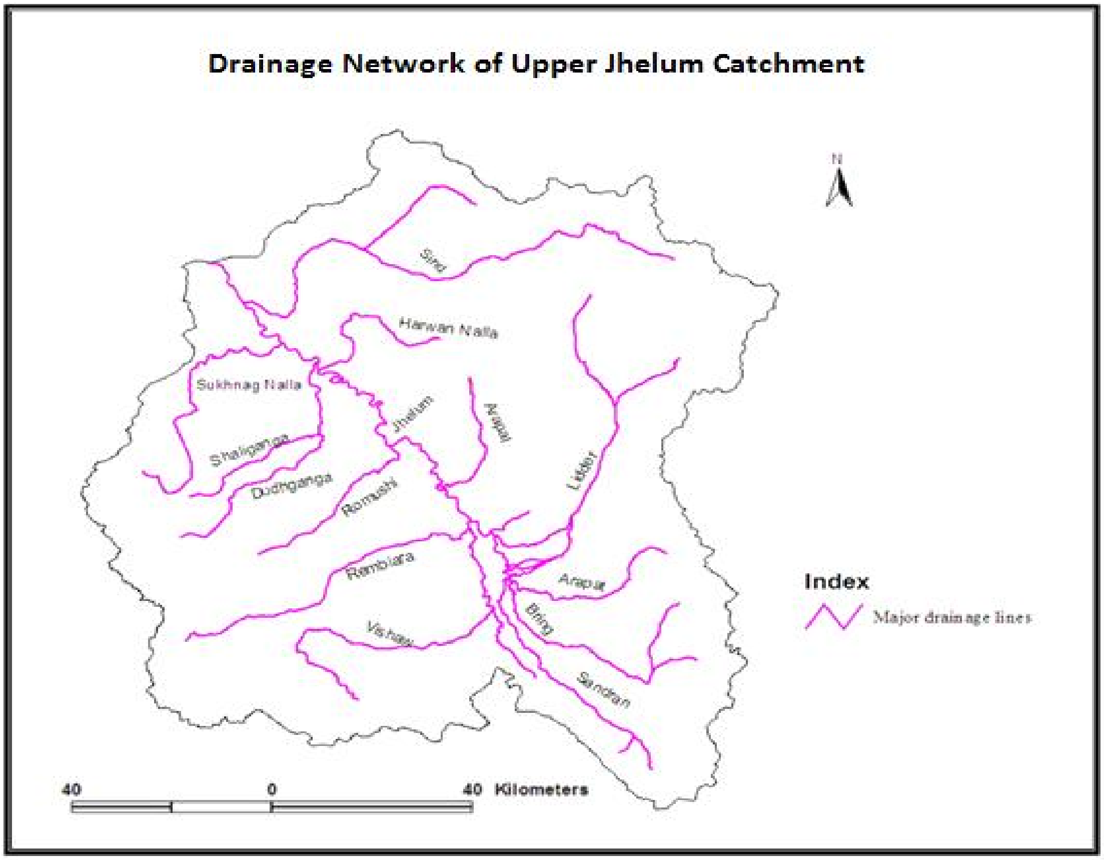


**Fig. 2. Drainage network of upper Jhelum catchment**

## 2.2 Modified Mann Kendall Test (MMKT)

To assess the significance of trends in the hydrological time series the Modified Mann-Kendall Test (MMKT); a nonparametric statistical test, can be used [34,35,36]. The hypothesis in Mann-Kendall test is that the data are independent and randomly ordered. However, the existence of positive autocorrelation in the data increases the possibility of detecting trends when actually none exists. This test often ignores a well-known fact that the data is auto-correlated in some cases. A theoretical relationship was derived to calculate the variance of the Mann-Kendall test statistics for auto correlated data [37]. The empirical formula for calculating the variance of S in this case of auto-correlated data is given by equation 1:

$$V(s) = var(S).\frac{n}{n_S^*} = \frac{\mathrm{n(n-1)(2n+5)}}{18}.\frac{n}{n_S^*} \quad (1)$$

Where, $\frac{n}{n_S^*}$ represents a correction due to the autocorrelation in the data. The correction of the autocorrelation in the data is given by the equation 2:

$$\frac{n}{n_S^*} = 1 + \frac{2}{n(n-1)(n-2)} \times \sum_{i-1}^{n-1}(n-1)(n-i-1)(n-i-2)\rho_S(i) \quad (2)$$

where, n is the actual number of observations and $\rho_s\ (i)$ is the autocorrelation functions of the rank of the observations. The advantage of the approximation in equation (2) is that by using the rank of the observations, the variance of S can be evaluated by equations (1) and (2) without the need for either the normalized the data or either autocorrelation function. The Z value can be used to determine whether the time series data exhibits a significant trend. The Z value is computed as below:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, if\ S > 0 \\ 0 \qquad , if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, if\ S < 0 \end{cases} \quad (3)$$

$Z > Z_{\alpha/2}$ signifies that the time series data show a significant trend. A positive (negative) S value means a significant upwards (downward) trend, α is the significance level. Because varying α corresponding to varying $Z_{\alpha/2}$, the method suggests that the definition of significant trend in statistic changes. In this study, the significant level is set at 0.05.making $Z_{\alpha/2}$=1.96. Therefore, when the time series data produces Z>1.96, there is a significant upward or downward trend.

## 2.3 Sen's Slope Estimator (SSE)

In this study, the (SSE) was used to calculate the trend slopes. The Sen's slope was introduced by Sen in [38] to calculate true trend slopes [39]. The (SSE) is widely used due to its simplicity in computation, analytical estimates of confidence intervals and robustness to outliers which are the prime advantages over the general slope estimation method. This approach involves computing slope for all the pairs of time points and then using the median of these slopes as an estimate of the overall slope. Sen's method proceeds by calculating the slope of the line using all data pairs, as shown in the following equation:

$$Q_i = (x_j - x_k)/(j-k) \tag{4}$$

Where, $x_j$ and $x_k$ are the data values at time j and k (j> k) respectively. If there are n values $x_i$ in the time series, we get as many N= {(n+1)/2} as slope estimate Q. Sen's estimator of slope is simply given by the median of these N values of Equations 5 and 6:

$$Q = Q_{\{(N+1)/2\}} \tag{5}$$

$$Q = ½ [Q_{N/2} + Q_{\{(N+2)/2\}}] \text{ if N is even} \tag{6}$$

N values of $Q_i$ are ranked from smallest to largest and the median of slope or (SSE)is computed as Equations 7 and 8:

$$Q_{med} = ½\, Q\, (N+1)\text{ , if N is odd; and} \tag{7}$$

$$Q_{med} = ½ [Q_{N/2} + Q_{\{(N+2)/2\}}] \text{ if N is even} \tag{8}$$

At the end, $Q_{med}$ is computed by a two sided test at 100 (1-α) % confidence interval and then a true slope can be obtained by the non-parametric test. Positive values of $Q_i$indicates an increasing trend and a negative value of $Q_i$ shows decreasing trend in the time series.

# 3. RESULTS AND DISCUSSION

## 3.1 Analysis of Trends in Annual Maximum Stream Flows

Trend analysis results pertaining to annual maximum stream flow at different gauging stations of Jhelum river basin is presented in Table 2. A significance level of α=0.05 was set as the standard and subsequently Z $_{\alpha/2}$ value of 1.96 was used to ascertain the existence of trend in the data. It was observed from Table a that total of four gauging stations out of the ten in the study area were having an upwards stream flow trends but was non-significant at 0.05 probability level. The stream flow trends in the Arwani was mostly increasing followed by Pampore, Awantipora and Khanabal gauging stations, with a test values of 0.991,1.841, 2.086 and 0.176, respectively. Time series plot for annual maximum stream flow at Arwani Gauging station is given in Fig. 3. Moreover; six gauging stations of UJRB showed a non-significant downward trend in stream flow. The Batkoot gauging station indicated a decreasing trend with highest slope followed by Verinag, Nayina, Munshibagh, Padshahibagh and Sangam gauging stations, with Sen's slopestatistics of -2.111, -0.281, -0.121, -0.534, -0.350 and -0.488; respectively. Time series plot for annual maximum stream flows at Awantipora and Batkoot Gauging stations is shown in Fig. 4. However, it was observed that the maximum stream flow data at ten gauging stations of UJRB did not exhibited and significant trend at 0.05 probability level of significance. But, the probability level and the positive and negative values of the MK test value (z) and Sen's slope mentioned in Table 2 provides information of trend at specific probability levels.

## 3.2 Analysis of Seasonal Trends in Maximum Stream Flows

The long- term monthly maximum stream flow trends were investigated using the gauging station data. The maximum stream flow of each gauging stations from March to September was tabulated. Different months were grouped into three seasons *viz*. spring (March to May), summer (June to August), autumn (September). However, in autumn season only one month was considered because of the chance of flood occurrence during this month and non-occurrence of flood during October and November months.

**Table 1. Coordinates and altitudes of the selected gauging stations of upper Jhelum river basin (UJRB)**

| S. No. | Station | Latitude (Degree°) | Longitude ( Degree°) | Altitude (m) |
|---|---|---|---|---|
| 1 | Verinag | 33.53 | 75.27 | 1890 |
| 2 | Arwani | 33.78 | 75.07 | 1601 |
| 3 | Khanabal | 33.74 | 75.13 | 1600 |
| 4 | Sangam | 33.84 | 75.06 | 1600 |
| 5 | Nayina | 34.81 | 75.03 | 1602 |
| 6 | Awantipora | 33.92 | 75.01 | 1600 |
| 7 | Batkoot | 33.93 | 75.29 | 1922 |
| 8 | Pampore | 34.01 | 74.91 | 1987 |
| 9 | Padshibagh | 34.06 | 74.84 | 1589 |
| 10 | Munshibagh | 34.07 | 74.83 | 1587 |

**Table 2. Trend analysis results using modified Mann-Kendall test (MMKT) for the annual maximum stream flow for 10 gauging stations in UJRB**

| S. No | Gauging Station | Record Length | Modified Mann-Kendal parameter (z) | Slope Estimator | p-value | Trend |
|---|---|---|---|---|---|---|
| 1 | Verinag | 1980-2016 | -1.492 | -0.281 | 0.200 | Absent |
| 2 | Arwani | 1980-2016 | 1.033 | 0.991 | 0.436 | Absent |
| 3 | Khanabal | 1980-2016 | 0.562 | 0.176 | 0.802 | Absent |
| 4 | Sangam | 1980-2016 | -0.092 | -0.488 | 0.906 | Absent |
| 5 | Nayina | 1980-2016 | -0.576 | -0.121 | 0.565 | Absent |
| 6 | Awantipora | 1980-2016 | 0.602 | 2.086 | 0.547 | Absent |
| 7 | Batkoot | 1980-2016 | -1.792 | -2.111 | 0.166 | Absent |
| 8 | Pampore | 1980-2016 | 0.785 | 1.841 | 0.548 | Absent |
| 9 | Padshibagh | 1980-2016 | -0.118 | -0.350 | 0.906 | Absent |
| 10 | Munshibagh | 1980-2016 | -0.261 | -0.534 | 0.794 | Absent |

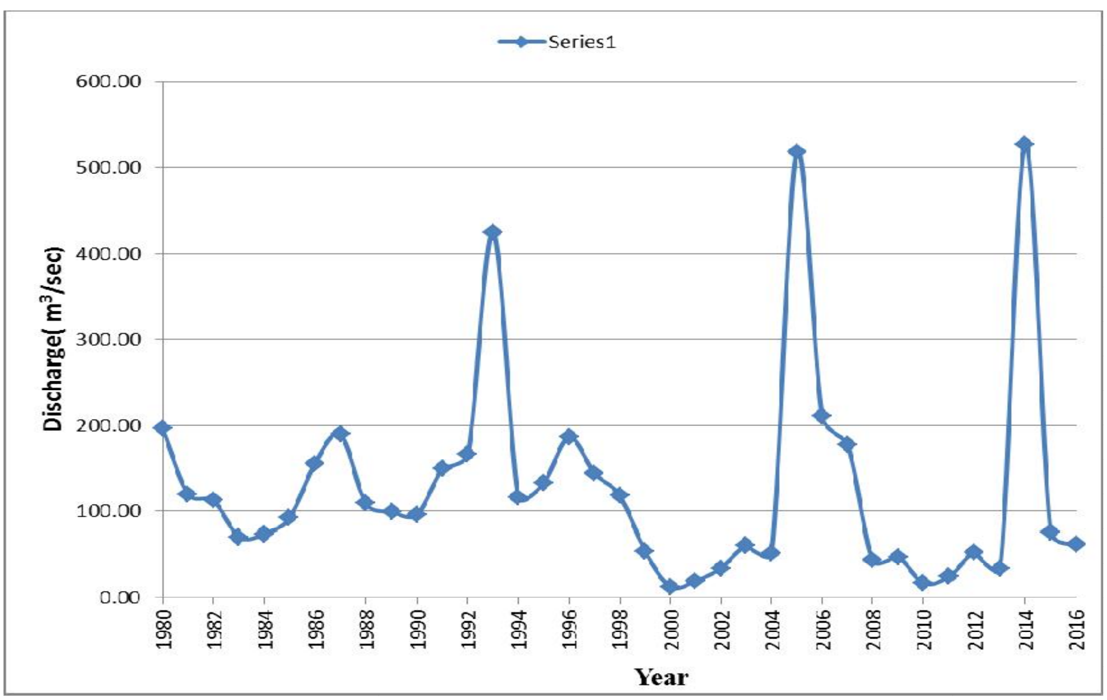


**Fig. 3. Time series plot for annual maximum stream flow at Arwani Gauging station**

### 3.3 Spring Season Trends

The MMK trend test results of monthly maximum stream flow during three months of spring season are presented in Table 3, 4 and 5, respectively. It was observed from Table 3 that nine gauging stations of UJRB showed a decreasing stream flow trends in the month of March. The stream flow trends in the Batkoot was mostly decreasing followed by Nayina, Sangam, Padshahibagh, Munshibagh, Khanabal, Pampore, Awantipora and Arwani gauging stations, with Sen's slope of -0.626, -0.151, -3.987, -3.012, -2.917, -0.089, -0.680, -0.461 and -0.035, respectively. However, the stream flow trends in the station Verinag was increasing with test value of -0.115. Moreover Batkoot and Nayina stations showed significant decreasing trends at 0.05 probability level with (SSE)values varying from 0.626 and -0.151, respectively. Time series plot for monthly maximum stream flow in the months of March, April and May at Batkoot Gauging station is given in Fig. 5. It was observed from Table 4 and Fig. 5 that in the month of April nine gauging stations of UJRB showed a decreasing stream flow trends. The stream flow trends in the Batkoot was mostly decreasing followed by Awantipora, Verinag, Sangam, Nayina, Arwani, Munshibagh, Padshahibagh and Pampore gauging stations, with Sen's slope of -0.948, -3.051, -0.228, -4.075, -0.156, -0.292, -1.364, -0.849 and -0.262, respectively. However the stream flow trends in the station Khanabal was increasing with test value of 0.048. Moreover, Batkoot station showed significant decreasing trends at 0.05 probability level with (SSE) value -0.948. The time series plots for monthly maximum stream flow (spring season) at Khanabal Gauging station is given in Fig. 6.

**Table 3. Trend analysis results using modified Mann-Kendall test (MMKT) for the monthly maximum stream flow (March month) for 10 gauging stations in UJRB**

| S. No | Gauging Station | Record Length | Modified Mann-Kendal parameter (z) | Slope Estimator | p-value | Trend |
|---|---|---|---|---|---|---|
| 1 | Verinag | 1980-2016 | 0.205 | -0.115 | 0.205 | Absent |
| 2 | Arwani | 1980-2016 | -0.170 | -0.035 | 0.865 | Absent |
| 3 | Khanabal | 1980-2016 | -0.837 | -0.089 | 0.663 | Absent |
| 4 | Sangam | 1980-2016 | -1.792 | -3.987 | .073 | Absent |
| 5 | Nayina | 1980-2016 | -1.988 | -0.151 | 0.047 | Present |
| 6 | Awantipora | 1980-2016 | -0.288 | -0.461 | 0.774 | Absent |
| 7 | Batkoot | 1980-2016 | -2.603 | -0.626 | 0.002 | Present |
| 8 | Pampore | 1980-2016 | -0.379 | -0.680 | 0.346 | Absent |
| 9 | Padshibagh | 1980-2016 | -1.530 | -3.012 | 0.126 | Absent |
| 10 | Munshibagh | 1980-2016 | -1.399 | -2.917 | 0.162 | Absent |

**Table 4. Trend analysis results using modified Mann-Kendall test (MMKT) for the monthly maximum stream flow (April month) for 10 gauging stations in UJRB**

| S. No | Gauging Station | Record Length | Modified Mann-Kendal parameter (z) | Slope Estimator | p-value | Trend |
|---|---|---|---|---|---|---|
| 1 | Verinag | 1980-2016 | -1.819 | -0.228 | 0.289 | Absent |
| 2 | Arwani | 1980-2016 | -0.955 | -0.292 | 0.442 | Absent |
| 3 | Khanabal | 1980-2016 | 0.379 | 0.048 | 0.830 | Absent |
| 4 | Sangam | 1980-2016 | -1.635 | -4.075 | 0.102 | Absent |
| 5 | Nayina | 1980-2016 | -1.413 | -0.156 | 0.158 | Absent |
| 6 | Awantipora | 1980-2016 | -1.884 | -3.051 | 0.060 | Absent |
| 7 | Batkoot | 1980-2016 | -2.381 | -0.948 | 0.017 | Present |
| 8 | Pampore | 1980-2016 | -0.262 | -0.285 | 0.794 | Absent |
| 9 | Padshibagh | 1980-2016 | -0.432 | -0.849 | 0.634 | Absent |
| 10 | Munshibagh | 1980-2016 | -0.798 | -1.364 | 0.425 | Absent |

**Table 5. Trend analysis results using modified Mann-Kendall test (MMKT) for the monthly maximum stream flow (May month) for 10 gauging stations in UJRB**

| S. No | Gauging Station | Record Length | Modified Mann-Kendal parameter (z) | Slope Estimator | p-value | Trend |
|---|---|---|---|---|---|---|
| 1 | Verinag | 1980-2016 | -2.237 | -0.295 | 0.253 | Absent |
| 2 | Arwani | 1980-2016 | -0.863 | -0.272 | 0.388 | Absent |
| 3 | Khanabal | 1980-2016 | -0.811 | -0.094 | 0.417 | Absent |
| 4 | Sangam | 1980-2016 | -1.395 | -2.526 | 0.115 | Absent |
| 5 | Nayina | 1980-2016 | -0.824 | -0.120 | 0.201 | Absent |
| 6 | Awantipora | 1980-2016 | -0.340 | -0.454 | 0.734 | Absent |
| 7 | Batkoot | 1980-2016 | -2.407 | -1.376 | 0.016 | Present |
| 8 | Pampore | 1980-2016 | 0.366 | 0.478 | 0.588 | Absent |
| 9 | Padshibagh | 1980-2016 | -0.445 | -0.823 | 0.657 | Absent |
| 10 | Munshibagh | 1980-2016 | -1.661 | -2.211 | 0.021 | Present |

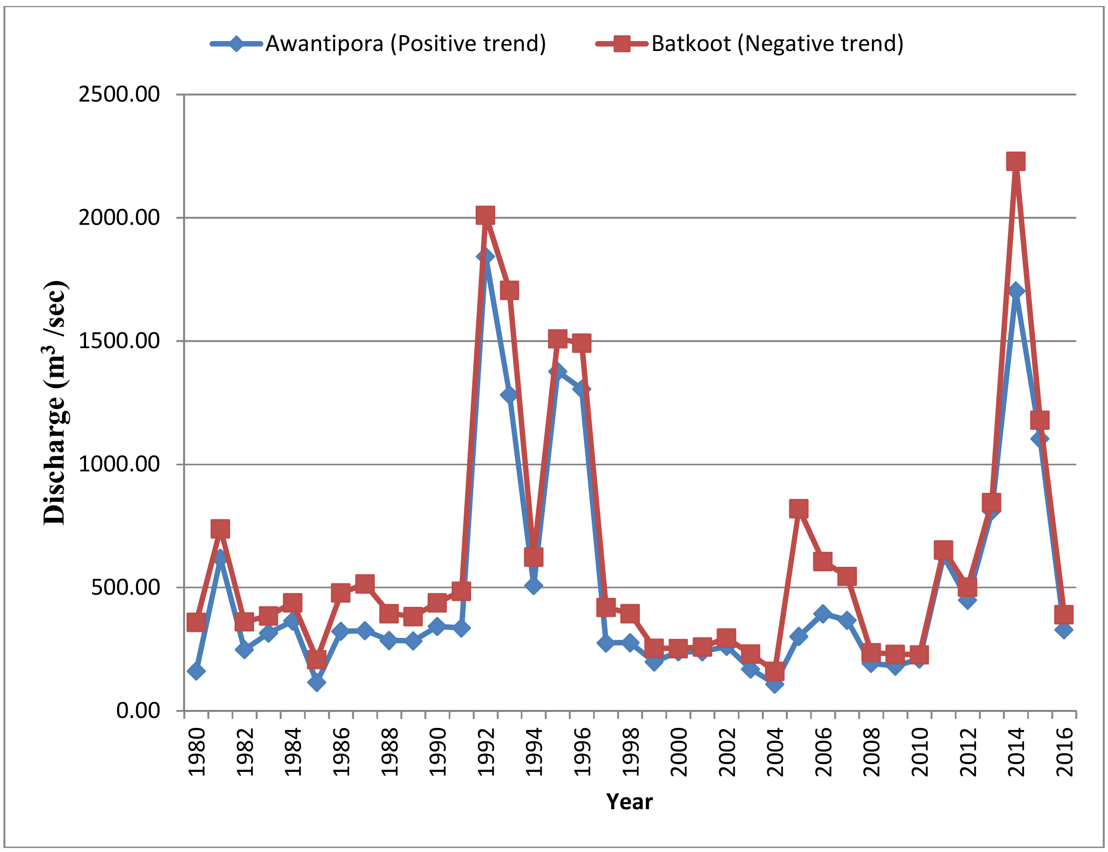


**Fig. 4.Time series plot for annual maximum stream flow at Awantipora and Batkoot Gauging stations**

It was observed from Table 5 that in the month of May nine gauging stations of UJRB showed a decreasing stream flow trends. The stream flow trends in the Batkoot was mostly decreasing followed by Verinag, Munshibagh, Sangam, Arwani, Nayina, Khanabal, Padshahibagh and Awantipora gauging stations, with Sen's slope of -1.376, -0.295, -2.211, -2.526, -0.272, -0.120, -0.094, -0.823 and -0.454, respectively. However the stream flow trends in the station Pampore was increasing with test value of 0.478. Moreover, Batkoot station showed significant decreasing trends at 0.05 probability level with (SSE) value -1.376.

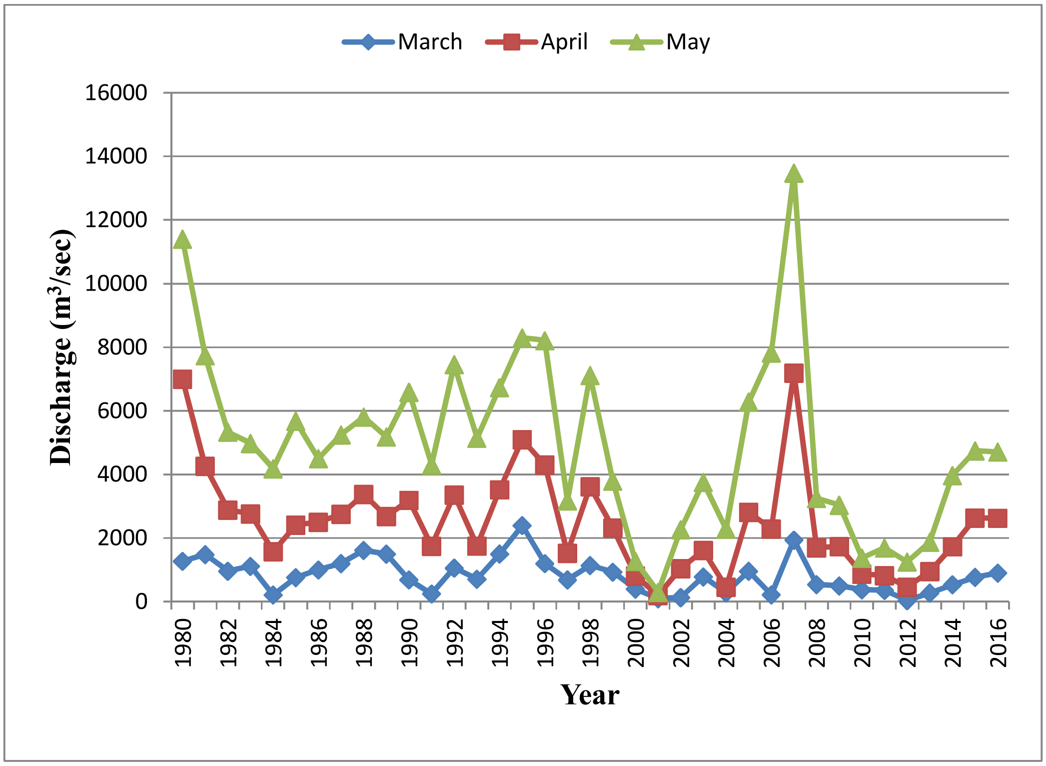


**Fig. 5.Time series plot for monthly maximum stream flow at Batkoot Gauging station**

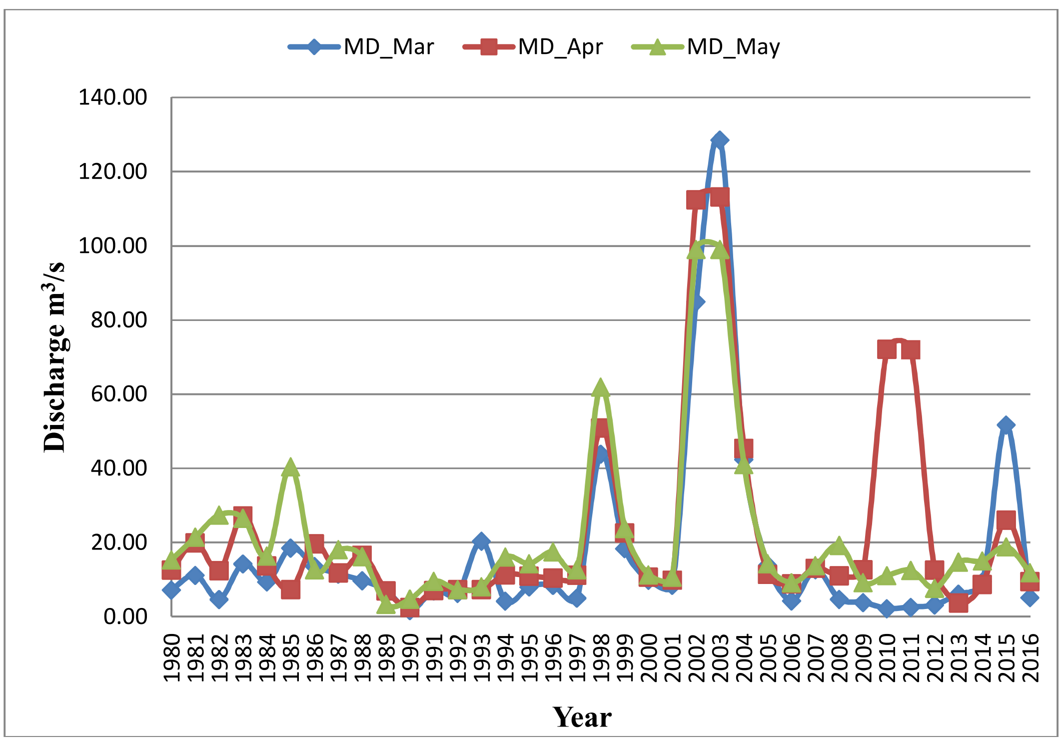


**Fig. 6. Time series plots for monthly maximum stream flow (spring season) at Khanabal Gauging station**

### 3.4 Summer Season Trends

The MMK trend test results of monthly maximum stream flow during three months of summer season are presented in Table 6, 7 and 8, respectively. It was observed from Table 6 that all the ten nine gauging stations of UJRB showed a decreasing stream flow trends in the month of June. The stream flow trends in the Batkoot was mostly decreasing followed by Verinag, Padshahibagh, Khanabal, Sangam, Munshibagh, Pampore, Nayina, Arwani and Awantipora gauging stations, with Sen's slope of -2.338, -0.227, -2.494, -0.145, -3.021, -1.670, -0.788, -0.109, -0.197 and -0.741 respectively. Moreover Batkoot station showed significant decreasing trends at 0.05 probability level with (SSE)value -2.338. The time series plot for monthly maximum stream flow in the months of June, July and August at Batkoot gauging station (Fig. 7).

It was observed from Table 7 that all the ten gauging stations of UJRB showed a decreasing stream flow trends in the month of July. Among these stations stream flows in Verinag gauging station was mostly decreasing followed by Batkoot, Padshibagh, Sangam, Awantipora, Munshibagh, Nayina, Arwani, Khanabal and Pampore gauging stations with (SSE)values -0.260, -1.975, -4.756, -6.000, -3.374, -6.170, -0.155, -0.434, -0.183 and -1.257 respectively. Moreover Verinag, Batkoot, Padshibagh, Sangam, Awantipora and Munshibagh gauging stations showed significant decreasing trends at 0.05 probability level with (SSE) values -0.260, -1.975, -4.756, -6.000, -3.374 and -6.170 respectively. Time series plots for monthly maximum stream flow (summer season) at Sangam are given in Fig. 8. Also, the time series plots for monthly maximum stream flow (summer season) at Verinag are given in Fig. 9. It was observed from Fig. 7, 8, 9 and Table 8 that all the ten gauging stations of UJRB showed a decreasing stream flow trends in the month of August. Among these stations Verinag gauging station showed mostly decreasing followed by

**Table 6. Trend analysis results using modified Mann-Kendall test (MMKT) for the monthly maximum stream flow (June month) for 10 gauging stations in UJRB**

| S. No | Gauging Station | Record Length | Modified Mann-Kendal parameter (z) | Slope Estimator | p-value | Trend |
|---|---|---|---|---|---|---|
| 1 | Verinag | 1980-2016 | -1.818 | -0.227 | 0.171 | Absent |
| 2 | Arwani | 1980-2016 | -0.562 | -0.197 | 0.689 | Absent |
| 3 | Khanabal | 1980-2016 | -1.256 | -0.145 | 0.388 | Absent |
| 4 | Sangam | 1980-2016 | -1.243 | -3.021 | 0.115 | Absent |
| 5 | Nayina | 1980-2016 | -0.706 | -0.109 | 0.480 | Absent |
| 6 | Awantipora | 1980-2016 | -0.510 | -0.741 | 0.610 | Absent |
| 7 | Batkoot | 1980-2016 | -2.498 | -2.338 | 0.012 | Present |
| 8 | Pampore | 1980-2016 | -0.720 | -0.788 | 0.672 | Absent |
| 9 | Padshibagh | 1980-2016 | -1.426 | -2.494 | 0.243 | Absent |
| 10 | Munshibagh | 1980-2016 | -0.772 | -1.670 | 0.440 | Absent |

**Table 7. Trend analysis results using modified Mann-Kendall test (MMKT) for the monthly maximum stream flow (July month) for 10 gauging stations in UJRB**

| S. No | Gauging Station | Record Length | Modified Mann-Kendal parameter (z) | Slope Estimator | p-value | Trend |
|---|---|---|---|---|---|---|
| 1 | Verinag | 1980-2016 | -3.3492 | -0.260 | 0.010 | Present |
| 2 | Arwani | 1980-2016 | -1.347 | -0.434 | 0.178 | Absent |
| 3 | Khanabal | 1980-2016 | -1.138 | -0.183 | 0.480 | Absent |
| 4 | Sangam | 1980-2016 | -2.132 | -6.000 | 0.001 | Present |
| 5 | Nayina | 1980-2016 | -1.844 | -0.155 | 0.065 | Absent |
| 6 | Awantipora | 1980-2016 | -2.027 | -3.374 | 0.016 | Present |
| 7 | Batkoot | 1980-2016 | -2.564 | -1.975 | 0.010 | Present |
| 8 | Pampore | 1980-2016 | -0.628 | -1.257 | 0.530 | Absent |
| 9 | Padshibagh | 1980-2016 | -2.407 | -4.756 | 0.035 | Present |
| 10 | Munshibagh | 1980-2016 | -1.923 | -6.170 | 0.048 | Present |

Pampore, Khanabal, Sangam, Batkoot, Munshibagh, Arwani, Nayina and Padshibagh gauging stations with (SSE) values -0.322, -3.403,-0.232, -3.276, -1.151, -3.013, 0.341, -0.183 and -1.478 respectively. Moreover, Verinag station showed significant decreasing trends at 0.05 probability level with (SSE) value -0.322.

### 3.5 Autumn Season Stream flow Trends

The MMK trend test results of monthly maximum stream flow during September month of Autumn season are presented in Table 9. It was observed from Table 9 that total four out of the ten gauging stations in the study area were having upwards stream flow trend but were

**Table 8. Trend analysis results using modified Mann-Kendall test (MMKT) for the monthly maximum stream flow (August month) for 10 gauging stations in UJRB**

| S. No | Gauging Station | Record Length | Modified Mann-Kendal parameter (z) | Slope Estimator | p-value | Trend |
|---|---|---|---|---|---|---|
| 1 | Verinag | 1980-2016 | -3.729 | -0.322 | 0.001 | Present |
| 2 | Arwani | 1980-2016 | -1.373 | 0.341 | 0.170 | Absent |
| 3 | Khanabal | 1980-2016 | -2.158 | -0.232 | 0.140 | Absent |
| 4 | Sangam | 1980-2016 | -1.870 | -3.276 | 0.061 | Absent |
| 5 | Nayina | 1980-2016 | -1.321 | -0.183 | 0.569 | Absent |
| 6 | Awantipora | 1980-2016 | -1.269 | -1.811 | 0.312 | Absent |
| 7 | Batkoot | 1980-2016 | -1.740 | -1.151 | 0.161 | Absent |
| 8 | Pampore | 1980-2016 | -2.472 | -3.403 | 0.052 | Absent |
| 9 | Padshibagh | 1980-2016 | -1.138 | -1.478 | 0.255 | Absent |
| 10 | Munshibagh | 1980-2016 | -1.426 | -3.013 | 0.154 | Absent |

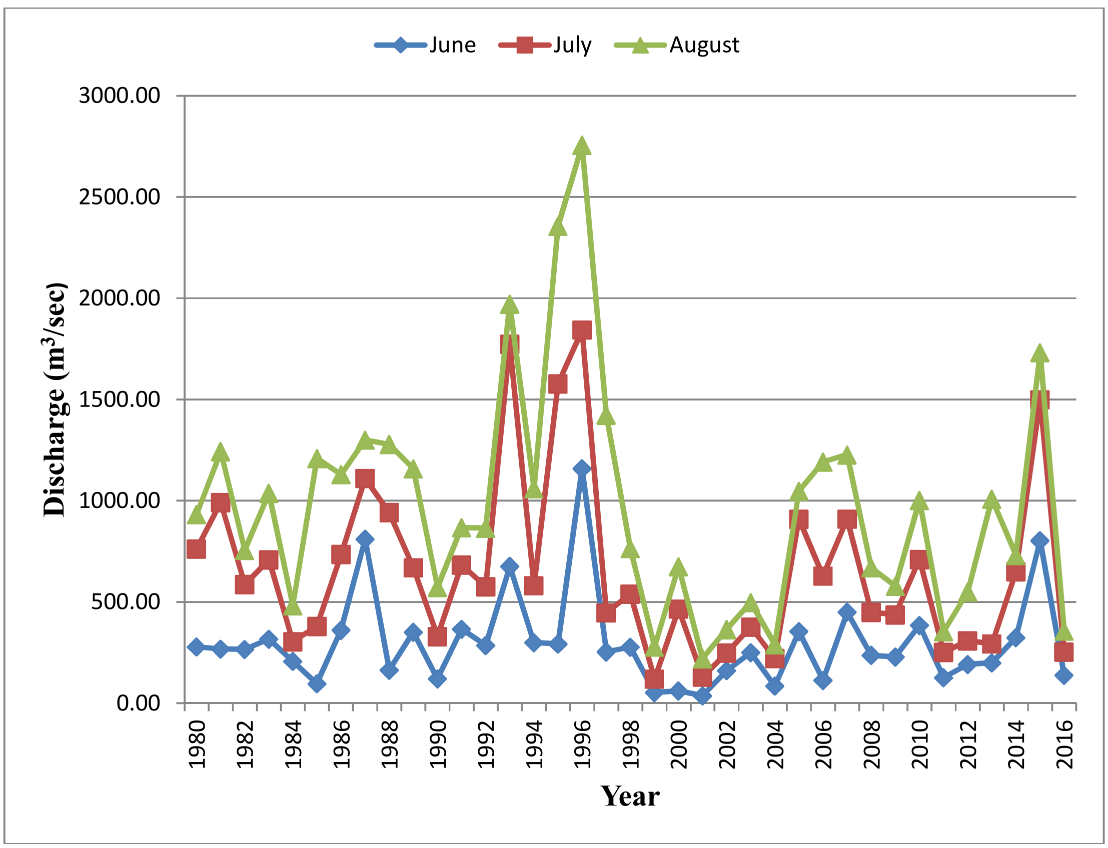


**Fig. 7. Time series plot for monthly maximum stream flow at Batkoot Gauging station**

non-significant at 0.05 probability level. The stream flow trends in Pampore was mostly increasing followed by Munshibagh, Khanabal and Padshibagh gauging stations with (SSE) values of 2.823, 0.980, 0.054 and 0.474, respectively. The time series plots for monthly maximum stream flow (autumn season) at Pampore Gauging station are depicted in the Fig. 10. Also, the time series plots for monthly maximum stream flow (autumn season) at

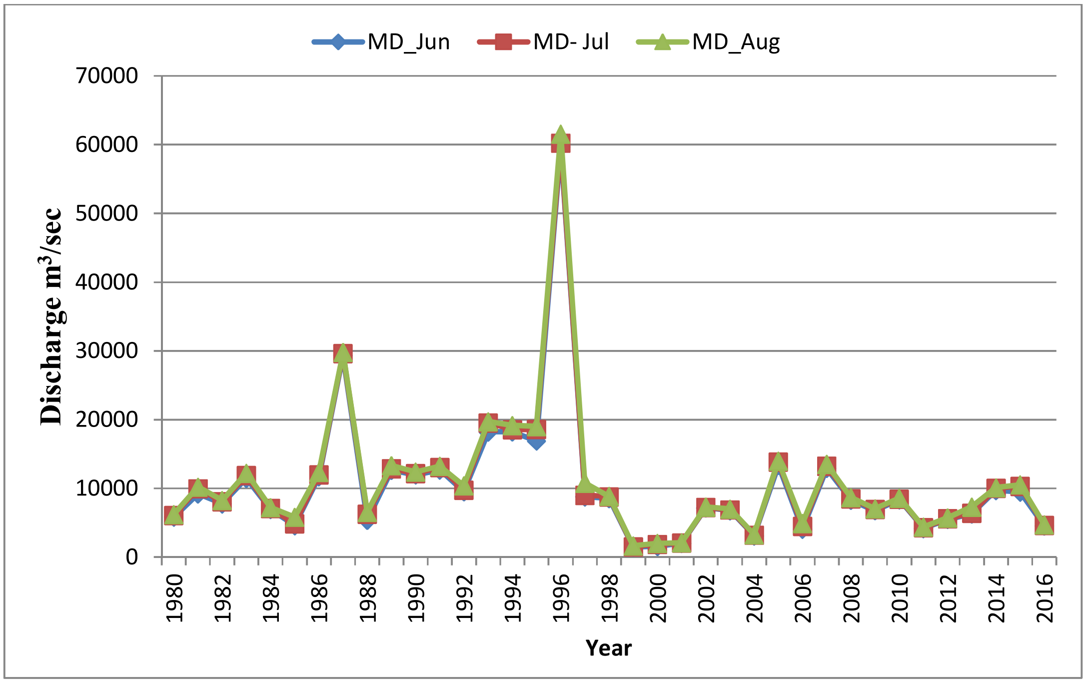


**Fig. 8. Time series plots for monthly maximum stream flow (summer season) at Sangam Gauging station**

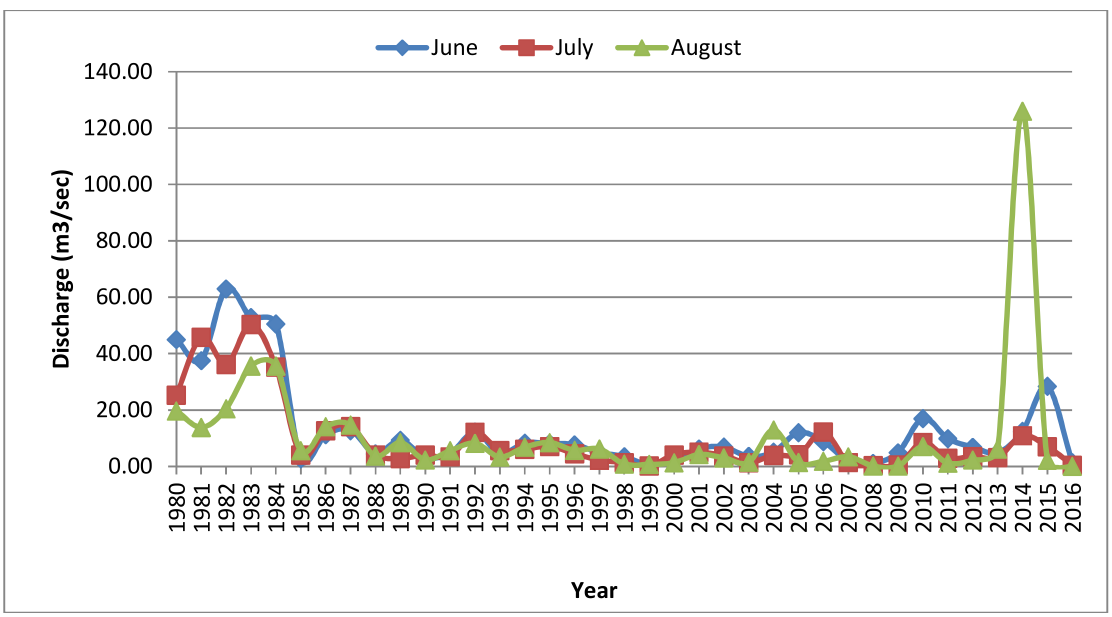


**Fig. 9. Time series plots for monthly maximum stream flow (summer season) at Verinag Gauging station**

Verinag Gauging station are depicted in the Fig 11. Six gauging stations of UJRB showed decreasing stream flow trends in August. Among these stations, Verinag gauging station showed mostly decreasing trends followed by Batkoot, Nayina, Awantipora, Sangam and Arwani respectively, with (SSE)values -0.210, -0.912, -0.173, -0.805, -0.234 and -0.011, respectively. Verinag station showed a significant decreasing trend at 0.05 probability level with (SSE) value -0.210.

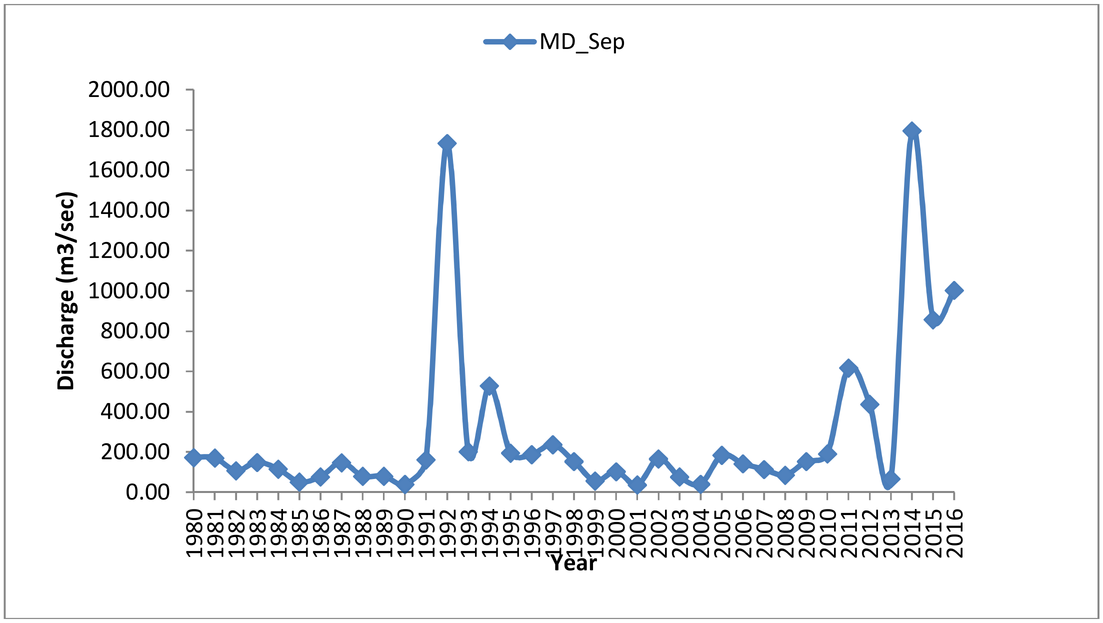


**Fig. 10. Time series plots for monthly maximum stream flow (autumn season) at Pampore Gauging station**

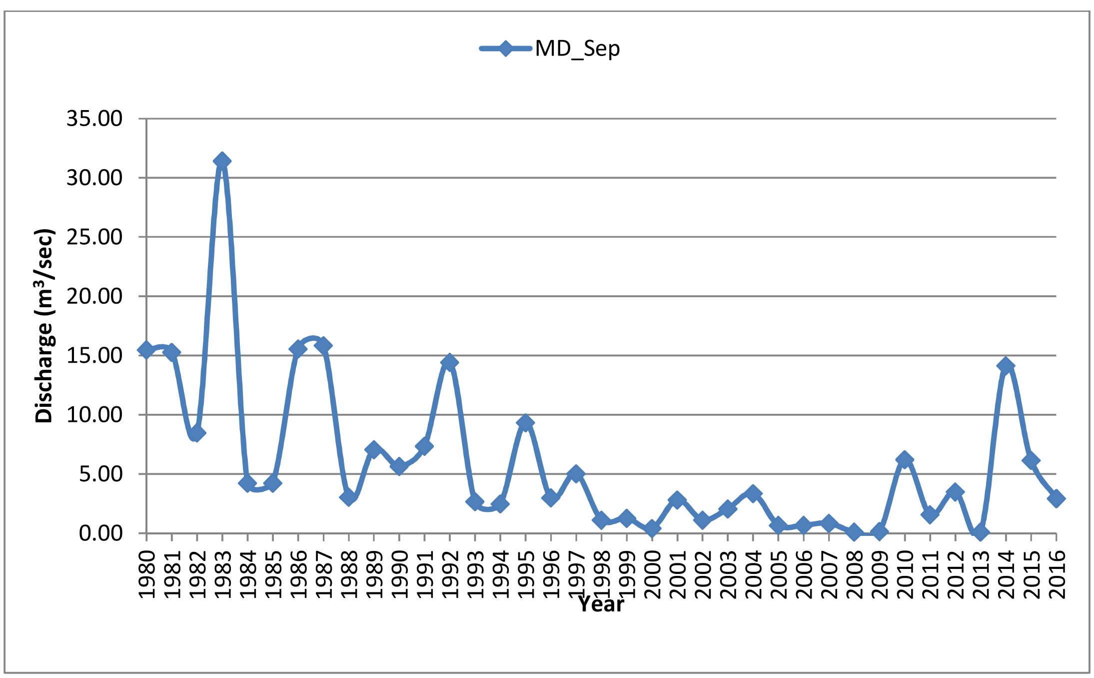


**Fig. 11. Time series plots for monthly maximum stream flow (autumn season) at Verinag**

**Table 9. Trend analysis results using modified Mann-Kendall test (MMKT) for the monthly maximum stream flow (September month) for 10 gauging stations in UJRB**

| S. No | Gauging Station | Record Length | Modified Mann-Kendal parameter (z) | Slope Estimator | p-value | Trend |
|---|---|---|---|---|---|---|
| 1 | Verinag | 1980-2016 | -3.729 | -0.210 | 0.001 | Present |
| 2 | Arwani | 1980-2016 | -0.066 | -0.011` | 0.973 | Absent |
| 3 | Khanabal | 1980-2016 | 0.562 | .054 | 0.798 | Absent |
| 4 | Sangam | 1980-2016 | -0.039 | -0.234 | 0.974 | Absent |
| 5 | Nayina | 1980-2016 | -1.910 | -0.173 | 0.301 | Absent |
| 6 | Awantipora | 1980-2016 | -0.510 | -0.805 | 0.746 | Absent |
| 7 | Batkoot | 1980-2016 | -2.106 | -0.912 | 0.211 | Absent |
| 8 | Pampore | 1980-2016 | 1.531 | 2.823 | 0.347 | Absent |
| 9 | Padshibagh | 1980-2016 | 0.366 | 0.474 | 0.809 | Absent |
| 10 | Munshibagh | 1980-2016 | 0.576 | 0.980 | 0.671 | Absent |

## 4. CONCLUSIONS

In this study, the maximum stream flow data from 10 gauging stations in UJRB were obtained, and their trends were analyzed using the Modified Mann-Kendall test. The trend slopes were also calculated. Based on the maximum annual stream flow analysis, it could be concluded that about 60% stations in the UJRB exhibited significant downward stream flow trends, while the rest of the gauging stations exhibited upward stream flow trends. In terms of overall trends, upward stream flow trends were primarily found in the Arwani gauging station followed by Pampore, Awantipora and Khanabal gauging stations, whereas downward stream flow trends were mostly observed in the Batkoot gauging station followed by Verinag, Nayina, Rammunshibagh, Padshahibagh and Sangam gauging stations. The results of the trend slope analysis revealed that the amount of change in the Nayina gauging station was recorded as the least. The results of monthly and seasonal maximum stream flow analysis show that in the spring about 90% of the gauging stations showed downward stream flow trends, all the gauging stations in the summer showed downward trends in stream flow and only 60% of the gauging stations showed downward stream flow trends in the month of September. Thus we can conclude that although the trend was not explicitly established in long term stream flow results, the seasonal trends of varying degrees were surely present in the stream flow data.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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