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Trend analysis of rainfall and runoff in the Jhelum basin of Kashmir Valley

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ABSTRACT

Trend analysis of rainfall and runoff at selected locations of the basin can be good indicator of the flood prediction. In this study, Modified Man Kendall Test (MMKT) was undertaken to observe the existence of significant trends in the rainfall depth of both annual and monsoon periods for a period of 30 years (1980-2009), for six stations in the Jhelum River Basin (JRB) in India (viz. Srinagar, Quazigund, Pahalgam, Gulmarg, Kupwara and Kokernag). Besides this, the maximum and minimum stream flow measured at six hydrologic monitoring stations in JRB (viz. Sangam, Awantipora, Padshibagh, Munshibagh and Baramulla) for a period of 30 years (1980 to 2009) were also subjected to MMKT using a developed interface in MATLAB. It was observed that only Kupawara, Gulmarg and Kokernag stations exhibited significant decreasing trend of annual rainfall depth at 0.05 significance level corroborated by Sen's slope -12.51, -18.14 and -15.1 respectively. Whereas, the monsoon rainfall depth for only Kupwara showed significant decreasing trend at 0.05 level of significance but the magnitude of decrease was less as indicated by Sen's slope of -1.94 as compared to the annual rainfall depth. It was also observed that the decreasing trend of annual rainfall is more than that of the monsoon rainfall which indicated low probability of occurrence of flood due to rainfall in the JRB. Moreover, the Awantipora and Munshibagh runoff monitoring stations exhibited decreasing trend in the peak discharge and Baramulla, Awantipora, and Asham showed decreasing trend of minimum discharge at P=0.05. Nonetheless, it was observed that long term trend analysis of rainfall and surface runoff of JRB would serve as a good indicator of flood occurrences under changing climate.

Key words: MATLAB, Modified Man Kendall Test, Rainfall, Runoff rate, Trend analysis

Agriculture is the most susceptible sector to climate change related hazards. This is due to the fact that climate change affects two of the most important direct agricultural production inputs and these are precipitation and temperature (Philip *et al*. 2014).Precipitation is a major factor that plays a key role in the cycle of water resources and provides information on changes in climate (IPCC 2013). It affects both the spatial and temporal patterns of water availability. Increases in precipitation trends can also result in an increase in the frequency of floods and could thereby impact the life and property of the masses. On the other hand, a decrease in precipitation trend could imply an increase in instances of drought. As a result, such irregularities in precipitation, i.e. droughts and floods can affect the ecological system adversely (Zhang *et al*. 2013). The eco-hydrological system has been affected by these irregular precipitation events (Beniston and Stephenson 2004). Freshwater availability in many river basins in India is likely to decrease due to climate change (Gosain *et al*. 2006).

Trends and changes in climatological variables such as temperature and precipitation are very important for water management particularly to fulfill the future challenges due to global warming and rapid growth in population (Cannarozzo *et al*. 2006, Oguntunde *et al*. 2006). Investigations of rainfall trends are necessary to understand the significance of changes in climate for the development and management of water resources (Haigh 2004). Azmat *et al*. (2017) used the Pearson and Kendall rank correlation tests to scrutinize snow cover trends and correlation between temperature, precipitation, snow cover area (SCA) and stream-flow records, they observed that there was a slightly increasing tendency in temperature and precipitation during the years 1961–2013. Moreover, high-altitude areas contribute to the stream-flow largely in the form of snow- and glacier-melt during the early summer season. Basistha *et al*. (2009) observed that rainfall has decreased in the Indian Himalayas during last century as a sudden shift, rather than gradual trend. Zhang *et al*. (2011) used the Mann–Kendall test to examine variation in monthly precipitation during 1960–2000

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(40 years) on a spatial and temporal basis, and the results revealed the presence of declining trends at about 45% stations annually in northeastern China. India is among the highly affected countries where alteration of rainfall patterns and increase in temperature has been noticed (IPCC 2014, Dash *et al*. 2011, Jain and Kumar 2012, Jain *et al*. 2013, Kundu *et al*. 2015, Abeysingha *et al*. 2014). Shaloo *et al*. (2016) examined the trends of rainfall and temperature in six districts of Haryana by using 41 years (1969-2009) rainfall temperature data and found non-significant decreasing trends of annual rainfall depth except Palwal and Kaithal districts. Mirza *et al*. (1998) carried out trend and persistence analysis for the Ganges, Brahmaputra and Meghna river basins. They showed that precipitation in the Ganges basin is, by and large, stable. Furthermore, one of three sub-divisions of the Brahmaputra basin shows a decreasing trend, while another shows an increasing trend. Singh *et al*. (2008a) studied the changes in rainfall in nine river basins of northwest and central India and found an increasing trend in annual rainfall in the range of 2–19% of the mean per 100 years. The frequency of heavy rainfall events during the southwest monsoon has shown an increasing trend over certain parts of the country, whereas a decreasing trend has been observed during winter, pre-monsoon and post-monsoon seasons (Sinha Ray and Srivastava 1999). There has been a westward shift in rainfall activity over the Indo-Gangetic Plain region (Mall *et al*. 2007).

Li *et al*. (2014) investigated spatial and temporal fluctuations in annual precipitation using a 50-years dataset from 1960 to 2009 by applying the Mann– Kendall test and observed that there was a considerable declining trend in precipitation. Liu *et al*. (2014) conducted a trend analysis to examine the extreme precipitation and noticed a rise in extreme precipitation events in China.

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 (Duhan *et al*. 2013). 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. 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% (Pasquini *et al*. 2007). 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.

The specific objectives of this study were to analyze the trends of rainfall and stream-flow on different time scale, i.e. monthly, seasonal and annual for six gauging stations of Jammu and Kashmir using the long term daily rainfall and stream-flow data, for the period from 1980 to 2009 (30 years). Trend analysis was undertaken using Modified Mann-Kendall non-parametric test with Sen's slope estimator for detecting trends and its magnitude for identifying the changing climate at regional scales.

MATERIALS AND METHODS

The Jhelum River is a river of North-Western India and Eastern Pakistan. It is a tributary of the Chenab River and has a total length of about 725 kilometers. The River Jhelum rises from Verinag Spring situated at the foot of the Pir Panjal in the south-eastern part of the Kashmir. It's joined by its tributaries Lidder River al Khannabal and Sind River at Shadipora in Kashmir valley. It flows through Srinagar and the Wular Lake before enterring Pakistan through a deep narrow gorge. The flat alluvial basin measures 150 km from South-East to North-West and 42 km from South-West to North-East. Altitude of the study area varies from 1500 to 1800 m above the mean sea level and the little bit of the land is from South-East to North-West. The study area in the Jhelum basin is situated between the geographical coordinates of 33° 21′ 48″ N to 34° 27′ 52″ N latitude and 74° 30′ 37″ E to 75° 35′ 36″ E longitude. The total area of the basin is 8600 km^2. The Kashmir Valley receives moderate to heavy snowfall during the months of December-February. Across from the PirPanjal range, the South Asian monsoon is no longer a factor and most precipitation falls in the spring from South West cloud-bands. Because of its closeness to the Arabian Sea, Srinagar receives as much as 635 millimeters of rain from this source, with the wettest months being March to May with around 85 millimeters per month. In Kashmir valley the recorded high temperature is 33°C and the recorded low is −18°C.

The rainfall data were acquired from regional office of Indian Meteorological Department (IMD) at Srinagar, J and K, whereas the river discharge data were acquired from the office of Irrigation and Flood Control division, Srinagar J and K. With the intention to trace the long term fluctuations in climatic parameters over the years and to establish the relationship with river discharge (water availability) as climate changes, monthly rainfall and river discharge data covering a period of 30 years (1980- 2009) were collected and analyzed. The main objective of this study was to study the trends present in the rainfall patterns over a long period of time by analyzing time series data of annual and seasonal. Co-ordinates and altitudes of selected gauging stations are shown in Table 1 and 2.

In present study, statistical significance of the trend in the time series was analyzed by using non-parametric Modified Man Kendall Test (MMKT) and the magnitude

Table 1 Coordinates and altitudes of the selected rainfall gauging stations of JRB

Station	Latitude (N) (Degree)	Longitude (E) (Degree)	Altitude (m)
Quqzigund	33.44	75.19	1680
Pahalgam	34.02	75.40	1700
Srinagar	34.10	74.85	1580
Gulmarg	34.08	74.42	1650
Kokernag	33.73	74.15	1700
Kupwara	33.43	74.12	1600

Table 2 Coordinates and altitudes of the selected hydrological monitoring stations of JRB

Station	Latitude (N) (Degree)	Longitude (E) (Degree)	Altitude (m)
Sangam	33.84	75.06	1600
Awantipora	33.92	75.02	1602
Padshaibagh	34.06	74.84	1600
Munshibagh	34.07	74.83	1580
Asham	34.25	74.62	1580
Baramulla	34.22	74.35	1700

of the trend in a time series was analyzed using the Sen's slope estimator.

The Mann-Kendall test (Mann 1945, Kendall 1975) is a nonparametric statistical test that can be used to assess the significance of trends in the hydrological time series. The null hypothesis in Mann-Kendall test is that the data are independent and randomly ordered. The existence of positive autocorrelation in the data increases the possibility of detecting trends when actually none exists. Hamed and Rao (1998) derived a theoretical relationship to calculate the variance of the Mann-Kendall test statistics for auto correlated data. The empirical formula for calculating the variance of S in this case of auto-correlated data is given by equation (1):

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

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 equation (2):

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

$$(n-i-2)\ ps\ (i) \qquad (2)$$

where, n is the actual number of observations and $p_s\ (i)$ 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 equation (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 by equation (3):

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

$Z > Z_{\alpha/2}$ 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.

In this study, the Sen's slope estimator is used to calculate the trend slopes .The Sen's slope was introduced (Sen 1968) to calculate true trend slopes. The Sen's slope estimator 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 (4):

$$Q_i = \frac{X_j - X_k}{(j-k)} \qquad (4)$$

where, x_j and x_k are the data values at time j and k (j>k) respectively (Sen 1968). 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 given by equations (5) and (6):

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

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

N values of Q_i are ranked from smallest to largest and the median of slope or Sen's slope estimator is computed by equations (7) and (8):

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

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

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.

RESULTS AND DISCUSIONS

Analysis of trends in annual rainfall

Trend analysis results pertaining to annual rainfall at different gauging stations of Jhelum River Basin (JRB) 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 can be observed from Table 3 that all six gauging stations in the study area were having a decreasing rainfall trends and three gauging stations out of six showed significant decreasing trend at 0.05 probability level.

Table 3 Trend analysis results using modified Mann-Kendall test for the annual rainfall for 6 gauging stations in JRB

Gauging station	Record length	Modified Mann-Kendal Test statistics	Sen's Slope Estimator	p-value	Trend
Quazigund	1980-2009	-1.43	-7.92	0.154	Absent
Pahalgam	1980-2009	-1.07	-5.64	0.284	Absent
Kokernag	1980-2009	-2.43	-15.1	0.015	Present
Srinagar	1980-2009	-2.14	-7.88	0.254	Absent
Gulmarg	1980-2009	-1.64	-18.14	0.003	Present
Kupwara	1980-2009	-2.86	-12.51	0.004	Present

Table 4 Trend analysis results using modified Mann-Kendall test for the monsoon rainfall for six gauging stations in JRB

Gauging station	Record length	Modified Mann-Kendal Test Result	Sen's Slope Estimator	p-value	Trend
Quazigund	1980-2009	0.57	0.68	0.57	Absent
Pahalgam	1980-2009	1.46	3.67	0.14	Absent
Kokernag	1980-2009	-0.43	-0.71	0.38	Absent
Srinagar	1980-2009	-1.04	-1.14	0.12	Absent
Gulmarg	1980-2009	-1.82	-3.12	0.07	Absent
Kupwara	1980-2009	-2.11	-1.94	0.03	Present

The rate of such decline as indicated by Sen's slope was highest in Gulmarg gauging station followed by Kokernag, Kupwara, Quazigund, Srinagar and Pahalgam gauging stations, with Sen's slope statistics of -18.14, -15.1, -12.51, -7.92, -7.88 and -5.64, respectively. Time series plot for annual rainfall at all six gauging stations is given in Fig 1. However, it was observed that the annual rainfall at three gauging stations of UJRB, *viz.* Kupwara, Kokernag and Gulmarg gauging stations showed significant decreasing trends at 0.05 probability level with Sen's slope estimator values -18.14,-15.10, and-12.51, respectively. The probability level and the positive and negative values of the MMK test value (z) and Sen's slope mentioned in Table 3 provides information of trend at specific probability levels.

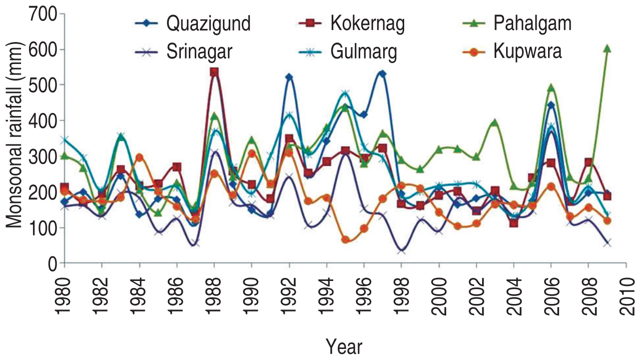

Fig 2 Trend analysis of monsoonal rainfall at six gauging stations of JRB.

Analysis of trends in monsoonal rainfall

Trend analysis results pertaining to monsoonal rainfall at different gauging stations of Jhelum river basin with 0.05 probability level of significance is presented in Table 4. It was observed from Table 4 that the trend of monsoon rainfall depth in four gauging stations out of the six in the study area was observed to be decreasing. However, it was observed that only one gauging station out of six showed significant decreasing trend at 0.05 probability levels. The probability level and the positive and negative values of the MMK test value (z) and Sen's slope mentioned in Table 4 provides information of trend at specific probability levels. The rate of such decline as indicated by Sen's slope was highest in Gulmarg gauging station followed by Kupwara, Srinagar and Kokernag gauging stations, with Sen's slope statistics of -3.12, -1.94,-1.14 and -0.711, respectively. Time series plot for monsoon rainfall at all Gauging stations is presented in Fig 2. However, the monsoon rainfall trends in of Pahalgam and Quazigund were observed to be increasing with Sen's slope estimator values of 3.67 and 0.68, respectively.

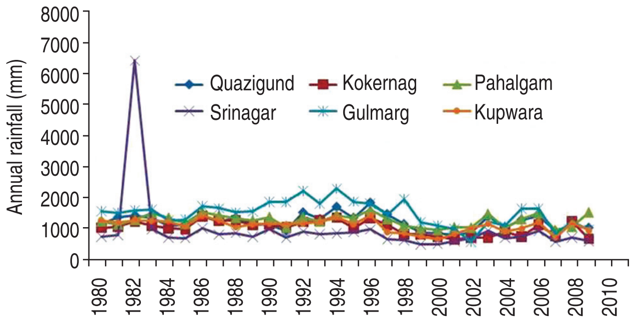

Fig 1 Trend analysis of annual rainfall at six gauging stations of JRB.

Analysis of trends in annual maximum stream flows

Annual maximum stream flow trend at different gauging stations of JRB is presented in Table 5. Trend of annual maximum stream flow for all the six hydrological monitoring stations exhibited a decreasing trend, out of which three stations were statistically significant at 0.05 probability level. Moreover, the rate of such decrease was highest for Baramulla and decreased subsequently for Asham, Munshibagh, Sangam Awantipora and Padshibagh gauging stations with Sen's slope statistics of -12.441, -9.571, -7.306, -5.345, -3.841 and -2.764, respectively.

Similarly, the annual maximum stream flow for six gauging stations is shown in Fig 3. However, it was observed that the maximum stream flow data at Awantipora and Munshibagh gauging stations showed significant decreasing trends at 0.05 probability level with Sen's slope estimator values -3.841 and -7.306, respectively. The probability level of significance and the positive and negative values of the

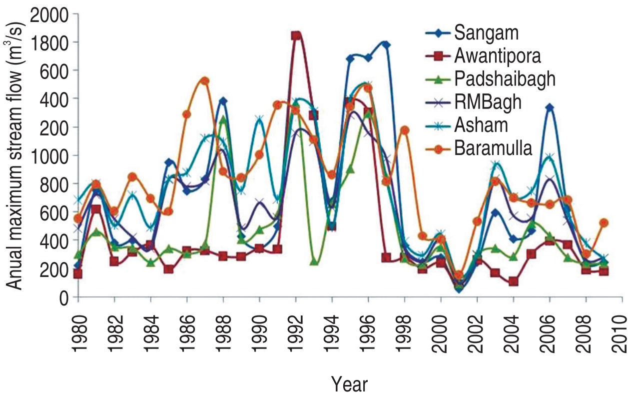

Fig 3 Trend analysis of annual maximum stream flow at six gauging stations of JRB.

Table 5 Trend analysis results using modified Mann-Kendall test for the yearly maximum stream flow for 6 gauging stations in JRB

Gauging station	Record length	Modified Mann-Kendal test result	Sen's slope estimator	p-value	Trend
Awantipora	1980-2009	-1.178	-3.841	0.001	Present
Sangam	1980-2009	-0.714	-5.345	0.268	Absent
Padshibagh	1980-2009	-0.839	-2.764	0.402	Absent
Munshibagh	1980-2009	-1.089	-7.306	0.037	Present
Asham	1980-2009	-1.249	-9.571	0.116	Absent
Baramulla	1980-2009	-1.677	-12.441	0.048	Present

MMK test value (z) and Sen's slope mentioned in Table 5 provides information of trend at specific probability levels.

Annual minimum stream flow trend at different gauging stations of Jhelum river basin is presented in Table 6. It was observed that all gauging stations in the study area were having a decreasing stream flow trends and three gauging stations out of six showed a significant trend at 0.05 probability level.

Decreasing rate of annual minimum stream flow at Baramulla was highest followed by Asham, Awantipora, Padshibagh, Munshibagh and Sangam gauging stations, with Sen's slope statistics of -9.371,-0.913, -0.546, -0.536, -0.495 and -0.303, respectively. However, it was observed that the gauging stations at Baramulla, Awantipora, and Asham of JRB showed significant decreasing trends at 0.05 probability level with Sen's slope estimator values -9.371, -0.546 and -0.913, respectively.

Table 6 Trend analysis results using modified Mann-Kendall test for the annual minimum stream flow for six gauging stations in JRB

Gauging station	Record length	Mann-Kendal test result	Slope estimator	p-value	Trend
Awantipora	1980-2009	-2.231	-0.546	0.026	Present
Sangam	1980-2009	-1.695	-0.303	0.090	Absent
Padshibagh	1980-2009	-1.231	-0.536	0.369	Absent
Munshibagh	1980-2009	-1.160	-0.495	0.336	Absent
Asham	1980-2009	-2.105	-0.913	0.035	Present
Baramulla	1980-2009	-2.266	-9.371	0.023	Present

In this study, annual and monsoon rainfall data for 6 gauging stations in the basin and the maximum and minimum stream flow data from 6 hydrologic monitoring stations in JRB were analyzed using the Modified Mann-Kendall test. The slope of trend lines were also estimated using Sen's slope estimator. The maximum annual rainfall trend in all six gauging stations exhibited decreasing trend out of which three stations were statistically significant at 0.05 probability level. The rate of such decline as indicated by Sen's slope was highest in Gulmarg gauging station followed by Kokernag, Kupwara, Quazigund, Srinagar and Pahalgam gauging stations. Similarly, the trends of monsoon rainfall depth in four gauging stations out of the six in the study area were observed to be decreasing. It was observed that the existence of trend based on the analysis using rainfall depth during monsoon and that of maximum annual values were different. Therefore, the trend analysis should be carried out for the rainfall depth during different time periods to predict occurrence of flood in the region. Further, the trend of annual maximum stream flow for six hydrological monitoring stations exhibited a decreasing trend, out of which three stations were statistically significant at 0.05 probability level. Moreover, the rate of such decrease was highest for Baramulla followed by Asham, Munshibagh, Sangam, Awantipora and Padshibagh gauging stations. Similarly, the annual minimum stream flow trends in the Baramulla indicated highest decreasing rate followed by Asham, Awantipora, Padshibagh, Munshibagh and Sangam gauging stations. Such analysis generally provides a background and basic information on occurrence of flood in the basin under changing climate.

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