Trend analysis of hydro-meteorological parameters in the Jhelum River basin, North Western Himalayas

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Abstract
The Jhelum River basin drains the entire Kashmir valley and is susceptible to floods, surrounded by the Himalayan Mountain range. The trend analysis of hydro-meteorological data is crucial for planning and managing various activities (agriculture, design of hydraulic structures) in the basin. The present study aims to analyze the trends in the annual maximum and annual average discharge, annual maximum, and annual average rainfall for the Jhelum River basin. The trend analysis was performed using the Mann–Kendall (M–K) test, Sen’s slope, and innovative trend analysis (ITA) at various hydro-meteorological stations. The outcomes of trend analysis using the ITA test showed non-monotonic trends at multiple stations for different time series data and brought forth more significant data to analyze changes in hydro-meteorological data. Moreover, the overall trend shows a significant decrease in annual average rainfall and discharge, while annual maximum rainfall and discharge revealed a significant increasing trend via ITA. The trend analysis depicts changes in hydro-meteorological data which would be useful for future management of water resources. Moreover, changes in the discharges in the Jhelum River are due to climatic change and anthropogenic activities in the basin.

1 Introduction

There are drastic shifts in the earth’s climate due to anthropogenic exercises activities. IPCC (2013) certifies that anthropogenic activities are the predominant factor in global warming and led to an ascent in average temperature by 0.89 °C for the period of 1901–2012. Trend analysis of discharges at a preferred site on a river is critical for planning, design, management of hydraulic structures, and flood plain zoning. Furthermore, trend analysis of hydro-meteorological data provides valuable information to assess the impact of climate change (Kumar et al. 2009; Subash et al. 2011; Chen and Geogakakos 2014; Darand et al. 2015; Kishore et al. 2016; Sa’adi et al. 2019). The consequences of climate change are supposed to bring significant hydrological changes, like decreasing or increasing trends increased reoccurrence intervals of extreme events. The aforesaid changes can harm the already fragile environment of Kashmir and can cause damage to Kashmir’s economy by negatively affecting sectors like horticulture and tourism.

The trend analysis of precipitation from the last decades at various spatio-temporal scales has been a major issue (Shafiq et al. 2016). The analysis can also be useful for solving different uncertainties in data (Sing and Sontakke 1999). Numerous studies have been carried out to detect a trend in hydro-meteorological data sets throughout the globe (Douglas et al. 2000; Wu et al. 2008; Kumar et al. 2009; Yin et al. 2010; Shadmani et al. 2012; Tekleab et al. 2013; Bezak et al. 2014; Darand et al. 2015; Cheo 2016; Belihu et al. 2018; Tehrani et al. 2019; Zakwan 2018; Zakwan and Ara 2019; Zakwan et al. 2019; Chandole et al. 2019; Zakwan and Ahmad 2021). The aforesaid studies provide a sustainable solution to the various problems in agriculture, irrigation, and river basin management (Burgueno et al. 2004; Rasool et al. 2016).

The study area is located in the North Western (NW) Himalayas that, as already discussed, has a very fragile environment. The Himalayan region is becoming warmer and is affecting the hydrology of the Indus basin (Immerzeel et al. 2009). Many researchers have found that there is a significant decrease in the discharge in the Indus River, which is primarily due to rising temperatures and reduced...
snowfall in the high-altitude regions (Rees and Collins 2006; Berthier et al. 2007; Akhtar et al. 2008; Bookhagen and Burbank 2010; Romshoo et al. 2017; Mahmood and Jia 2017). Moreover, studies depict a rise in temperature and a decline in precipitation in the NW Himalayan region (Archer and Fowler 2004; Ahmad et al. 2014).

In the light of the above-mentioned studies, the current study involves the identification of long-term hydro-climatic changes by applying MK, Sen’s Slope, and Innovative-Sen trends. To analyze hydro-climatic variables (Streamflow and precipitation) involves Streamflow of 7 gauging stations on Jhelum River and six meteorological stations. Moreover, the study becomes all the more important because the Jhelum River basin is located in the Himalayas, where climate has high variability and unpredictability with confronting the impact of climate change. Any change in the trend of hydro-meteorological data of the study area can cause catastrophe because thirty floods have occurred in the Kashmir valley, and the recent one was in 2014 (Romshoo et al. 2017). Umar et al. (2021) studied modeling and flood frequency analysis of the Jhelum River and found more floods to occur in the future. The study will provide valuable information for the effective management of water resources in the influence of changing climate.

2 Study area

The Jhelum River basin ranging between 32° 22’ to 34° 43’ N latitude and 73° 52’ to 75° 42’ E longitude, stretches roughly over an area of 16,000 km² (Fig. 1). The area is bounded by Pir Panjal range southerly and southwestern ends and by the Greater Himalayan Range from the northern and north-east ends. The Jhelum River emanates from Verinag Spring below Banihal pass and flows through the valley from south to north. The Jhelum River basin consists of 24 sub-watershed and drains into the Jhelum River from the left and right bank sides. The length of the Jhelum River

![Study area](image-url)
up to the Indian Pakistan border is 402 km. The valley has large altitude variability of 1450–5500 MASL, due to which there is a huge climate anomaly. The average annual precipitation in Kashmir shows high variation ranges from 650 mm in Srinagar city to 1600 mm in high altitude places and with average temperature variation of 2.5 °C and 19.8 °C during winters and summers (Hussain 1987). There are currently eight hydropower projects running in the Jhelum basin, namely, upper Sindh-I, upper Sindh-II, Ganderbal, Pahalgam, Brenwar, lower Jhelum, Uri-I, and Uri-II.

3 Data and methodology

The hydro-meteorological data of seven gauging and six meteorological stations were collected from the irrigation and flood control department, Kashmir (IFC), and Indian Meteorological Department (IMD), Pune. The details of the hydro-meteorological stations are provided in Table 1 and depict the various characteristics of the study area due to the geographical variability. The data of 6 meteorological stations are available for a period of 37 years (1980–2017), and discharge data used in the study is also for 37 years (1980–2017) presented in Table 1. The amount of missing data at all stations is less than 1% in Table 1. The data of precipitation extremes used for frequency analysis that was checked for the following assumptions are as randomness, stationarity, and homogeneity. The 25 years of data is sufficient for frequency analysis of extremes (Gupta 2008). The Double mass curve (DMC) was applied for homogeneity of data (Tabari et al. 2011). Moreover, the randomness and stationarity were checked by using Wald and Wolfowitz (1943) and Mann–Kendall (MK) test at all stations.

### 3.1 Methodology

The present study uses the Mann–Kendall (MK) test, Sen’s slope estimator, and innovative trend analysis (ITA) tests to compare and evaluate the magnitudes and significance of trends obtained by the methods above. Before proceeding with trend analysis, data were checked for all necessary time-series assumptions like homogeneity, autocorrelation, randomness by methods DMC, and WW test. The second step involves preparing data in which annual average and annual maximum values of hydro-meteorological variables were used for trend analysis, and Sen’s slope estimator did magnitude computation.

### 3.2 Mann–Kendall (MK) test

The MK test is a nonparametric rank-based technique used to detect trends among hydro-meteorological variables (Birsan et al. 2005; Brabets and Walvoord 2009; Liang et al. 2010; Soltani et al. 2013; Wu and Qian 2017; Diop et al. 2017; Wu et al. 2018; Zakwan and Ara 2019; Fentaw et al. 2019; Al-Hasani 2020). Moreover, being nonparametric has the advantages of being robust, less sensitive to outliers, and does not depend on data distribution (Chevuturi et al. 2018). In the MK test, the null hypothesis $H_0$ means no significant trend in the data series. This implies that the null hypothesis rejection is indicative of a substantial trend in the data as is defined by Eq. 1 (Hirsch and Slack 1984) to compute the Mann–Kendall Statics ($S$):

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} Sgn(X_k - X_i)$$  \hfill (1)

### Table 1 Hydro-meteorological stations and data availability periods

| SN | SN | Discharge | Rainfall | Period          |
|----|----|-----------|----------|----------------|
|    |    | Annual max | Average (10 daily) | Annual max | Annual average |
| 1  | Sangam | A       | A       | A             | A             | 1980–2017     |
| 2  | Padshahi Bagh | A     | A       | A             | A             | 1980–2017     |
| 3  | Ram Munshi Bagh | A     | A       | A             | A             | 1980–2017     |
| 4  | Shadipora | A     | A       | A             | A             | 1980–2017     |
| 5  | Asham   | A     | A       | A             | A             | 1980–2017     |
| 6  | Sopore  | A     | A       | A             | A             | 1980–2017     |
| 7  | Baramullah | A   | A       | A             | A             | 1980–2017     |
| 8  | Gulmarg | A     | A       | A             | A             | 1980–2017     |
| 9  | Kupwara | A     | A       | A             | A             | 1980–2017     |
| 10 | Kokernag | A     | A       | A             | A             | 1980–2017     |
| 11 | Qazigund | A     | A       | A             | A             | 1980–2017     |
| 12 | Srinagar | A     | A       | A             | A             | 1980–2017     |
| 13 | Pahalgam | A     | A       | A             | A             | 1980–2017     |

A, available
where, $X_k$ = rank of the $k$th observation, while $X_i$, the rank of $i$th observation and $n$ = number of observations. When, $n \geq 10$, $S$ is almost normally distributed.

$$Sgn(X_k - X_i) = \begin{cases} +1, & X_k - X_i > 0 \\ 0, & X_k - X_i = 0 \\ -1, & X_k - X_i < 0 \end{cases}$$

(2)

### 3.3 Sen’s slope estimator

The MK test substantiates only whether there is any significant trend. However, Sen’s slope estimator is used to compute the magnitude of the trend, and the procedure was developed by Sen (1968). For $N$ sample pair, the slope is computed as follows:

$$Q_i = \text{median} \left( \frac{X_j - X_k}{j - k} \right) \text{ for } k = 1 \text{ to } N$$

(3)

In Eq. 3, $X_j$ and $X_k$ are data values at times $j$ and $k$ ($j > k$). When,

$$Q_{\text{med}} = \begin{cases} Q \left( \frac{N+1}{2} \right) & \text{if, } N \text{ is odd} \\ \frac{Q_2 + Q \left( \frac{N+2}{2} \right)}{2} & \text{if, } N \text{ is even} \end{cases}$$

(4)

When, $Q_{\text{med}}$ represents the trend in the data and values provides the steepness in the trend.

### 3.4 Innovative trend analysis (ITA)

ITA was developed by Şen (2012, 2014); in the procedure, the data is first divided into two halves, and after that, the data is sorted into ascending order. The First half of the series is placed along the x-axis of the Cartesian coordinate system (Zakwan et al. 2022). The 1:1 (45°) straight-line partition the figure into two equal triangular sections, the upper portion represents the increasing trend, and the lower portion represents a decreasing trend. Moreover, the data which lies on the straight line signifies no trend. In the ITA method slope of a straight line is computed as follows:

$$s = \frac{2 (\bar{Y}_2 - \bar{Y}_1)}{n}$$

(5)

$$\sigma_s = \frac{2\sqrt{2}}{n^{3/2}} \sqrt{1 - \rho_{\bar{Y}_1, \bar{Y}_2}}$$

(6)

where, $s$ = magnitude of slope and $\sigma_s$ = standard deviation slope.

The correlation coefficient between $Y_1$ and $\bar{Y}_2$ is computed as follows:

$$\rho_{\bar{Y}_1, \bar{Y}_2} = \frac{E(\bar{Y}_1 \bar{Y}_2) - E(\bar{Y}_1)E(\bar{Y}_2)}{\sigma_{\bar{Y}_1} \sigma_{\bar{Y}_2}}$$

(7)

$\rho_{\bar{Y}_1, \bar{Y}_2}$ denotes the cross-correlation coefficient between the two halves sorted into ascending order.

Confidence limits (CL) upper and lower are computed as follows:

$$\pm CL_{1-x} = 0^+ S_{\text{cri}} \sigma_s$$

(8)

where $S_{\text{cri}}$ is defined as the critical slope.

Figure 2 presents a graphical representation of ITA with a 1:1 straight line with the y-axis representing the second half of the time series and the x-axis representing first half of the time series. Furthermore, the scatter diagram shows low, medium, and high magnitude data points, and analysis

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Fig. 2  Diagrammatic representation of ITA (Zakwan and Ahmad 2021)
of graph reveals non-monotonic trend with low magnitude data is showing an increasing trend, medium magnitude data showing a decreasing trend and high magnitude data is not showing any trend thus provides detailed trend information which would be useful for further analysis.

4 Results and discussions

To comprehend the behavior of river and basin trend analysis of hydro-meteorological parameters is a primary step by applying various statistical trend tests. This study applied MK-test, Sen slope test, and ITA test to annual maximum, annual average discharge, and rainfall.

4.1 Rainfall

The results obtained for the ITA, MK, and Sen’s slope for annual maximum and an annual average of rainfall at different hydro-meteorological stations are presented in Table 2 and Table 3. A perusal of Table 2 and Table 3 reveals a significant increase in annual maximum rainfall and a significant decrease in annual average rainfall at all stations.

4.1.1 Qazigund

At Qazigund station trend slope computed by Eq. 5, ITA was maximum (0.94 mm/year) and greater than critical slope (0.17 mm/year), depicting a significant increasing trend in annual maximum rainfall at a 95% confidence level. The MK test has also shown an increasing trend (2.63 mm) but is statistically insignificant, as shown in Table 2. However, a negative trend was observed in annual average rainfall (−0.22 mm/year), which proved to be statistically significant via ITA methods in Table 3. Figure 3a presents a non-monotonic trend in which low magnitude annual maximum rainfall is decreasing; however, moderate and high-magnitude annual maximum rainfall shows an increasing trend which results in an overall increasing trend of maximum annual rainfall. Figure 4a shows a monotonic decrease in the annual average rainfall at Qazigund station.

4.1.2 Kokernag

A significant positive trend was observed for ITA at Kokernag in annual maximum rainfall with an increasing annual rate of 0.47 mm/year. Using MK test trend was also increasing with an annual rate of increase 0.31 mm/year, but statistically insignificant in Table 2. Moreover, the significant negative trend was recorded in annual average rainfall with an annual rate of decrease −0.25 mm/year via ITA in Table 3. Based on Fig. 3b, it can be inferred that the trend in maximum annual rainfall is non-monotonic, in which low magnitude rainfall remains unchanged for some period, and medium and high magnitude rainfall is showing an increasing trend. As a result, the general trend is increasing for maximum annual rainfall. As per Fig. 4b, it was observed that low magnitude average rainfall shows an increasing trend; however, medium and high magnitude average rainfall shows a decreasing trend which results in an overall decreasing trend.

### Table 2 Results at various meteorological stations for annual maximum rainfall

| Sites    | M–K      | Sen’s slope | ITA       |       |       |       |       |
|----------|----------|-------------|-----------|-------|-------|-------|-------|
|          | Z        |             | \(\bar{y}_1\) | \(\bar{y}_2\) | \(\sigma\) | \(S\) | Critical slope |
| Qazigund | 1.41     | 2.63        | 103.19    | 117.29| 38.11 | 0.94  | 0.17  |
| Kokernag | 0.78     | 0.31        | 50.97     | 58.03 | 15.49 | 0.47  | 0.14  |
| Pahalgam | 0.96     | 0.31        | 66.07     | 75.88 | 21.86 | 0.65  | 0.23  |
| Srinagar | 0.28     | 0.23        | 67.72     | 73.19 | 27.01 | 0.36  | 0.10  |
| Kupwara  | 0.67     | 0.37        | 85.74     | 94.40 | 16.45 | 0.57  | 0.18  |
| Gulmarg  | 0.89     | 0.44        | 58.66     | 69.44 | 25.74 | 0.71  | 0.08  |

### Table 3 Results at various meteorological stations for annual average rainfall

| Sites    | M–K      | Sen’s slope | ITA       |       |       |       |       |
|----------|----------|-------------|-----------|-------|-------|-------|-------|
|          | Z        |             | \(\bar{y}_1\) | \(\bar{y}_2\) | \(\sigma\) | \(S\) | Critical slope |
| Qazigund | −0.21    | −0.18       | 90.25     | 86.32 | 17.38 | −0.22 | 0.16  |
| Kokernag | 0.144    | −0.21       | 83.48     | 79.68 | 21.02 | −0.25 | 0.09  |
| Pahalgam | −0.21    | −0.23       | 101.05    | 96.82 | 17.99 | −0.28 | 0.15  |
| Srinagar | −0.31    | −0.20       | 54.86     | 51.59 | 13.62 | −0.24 | 0.07  |
| Kupwara  | −0.64    | −0.19       | 84.34     | 80.80 | 17.38 | −0.23 | 0.12  |
| Gulmarg  | −0.96    | −1.59       | 115.95    | 91.68 | 48.70 | −1.62 | 0.24  |
The Pahalgam station revealed a significant increasing trend for annual maximum rainfall via ITA with an annual rate of increase of 0.65 mm/year. The MK test also showed an increasing trend but statistically insignificant with an annual increase of 0.31 mm/year in Table 2. The annual average rainfall presented a significant decreasing trend with an annual decrease rate of $-0.28$ mm/year via ITA in Table 3. It can be concluded from Fig. 3c that a monotonic trend exists in the maximum annual rainfall. Figure 4c shows a non-monotonic trend with the increasing trend for low magnitude annual average rainfall and decreasing trend for moderate and high annual average rainfall leading to an overall decreasing trend for Pahalgam station.

4.1.4 Srinagar

The Srinagar station situated at the lowest altitude recorded a significant increasing trend with an increasing annual rate of 0.36 mm/year for annual maximum rainfall via ITA. The MK test shows an increasing trend but insignificant in Table 2. The annual rate of decrease in Srinagar was $-0.24$ mm/year for annual average rainfall via ITA (Table 3). Based on Fig. 3d, it was concluded that there is a monotonic increasing trend. From Fig. 4d, it can be observed that there exists a monotonic decreasing trend.
4.1.5 Kupwara and Gulmarg

The Kupwara and Gulmarg stations also revealed an increasing trend via ITA for annual maximum rainfall with an annual rate of increase of 0.57 mm/year and 0.71 mm/year. The MK test shows an increasing trend but insignificant in Table 2. The annual rate of decline in Kupwara was $-0.23$ mm/year and in Gulmarg was $-1.62$ mm/year for annual average rainfall via ITA in Table 3. From Fig. 3e and f, it can be observed both Kupwara and Gulmarg are showing a monotonic increasing trend for annual maximum rainfall. The Kupwara and Gulmarg station shows a monotonic decreasing trend for annual average rainfall as observed in Fig. 4e and f, respectively.

4.2 Discharge

Table 4 and Table 5 present the results of ITA, MK, and Sen’s slope for annual maximum and annual average discharge at different hydro-meteorological stations. A perusal of Table 4 and Table 5 divulges a significant increase in annual maximum discharge and a significant decrease in annual average discharge at all stations.

4.2.1 Sangam

The annual maximum trend analysis of discharge revealed an increasing trend via ITA analysis but was statistically significant in ITA methodology. Moreover, in ITA, the
rate of annual increase was 38.79 mm/year and for M–K annual rate of increase was 34.94 mm/year (Table 4). The annual average discharge presented decreasing trend via ITA and proved to be significant with an annual rate of decrease −18.87 mm/year, and for the M–K test annual rate of decrease was −15.36 mm/year in Table 5. Figure 5a shows a non-monotonic trend of annual maximum discharge with low magnitude discharges that are significantly decreasing; however, medium and high magnitude discharges are increasing. Therefore, the overall trend remains increasing for annual maximum discharge at Sangam, thus making the region more susceptible to floods. In the recent 2014 flood, maximum discharge was recorded at Sangam (Romshoo et al. 2017; Alam et al. 2018; Umar et al. 2021). Figure 5b illustrates a monotonic trend of annual maximum discharge at Padshahi Bagh station. The Padshahi Bagh station shows a non-monotonic trend as observed form (Fig. 6b) in which low magnitude discharge is increasing while medium and high annual average discharge is decreasing, due to which the overall trend is declining for annual average discharges.

### 4.2.2 Padshahi Bagh

The increasing trend was observed in annual maximum discharge for ITA with an increasing annual rate of 35.24 mm/year. It was proved to be statistically significant and for the M–K test annual rate of increase is 31.25 mm/year in Table 4. However, the annual average discharge has presented decreasing trend for ITA and was statistically significant with a decreasing annual rate of −42.63 mm/year. For M–K annual rate of decrease was −37.11 mm/year in Table 5. Figure 5b illustrates a monotonic trend of annual maximum discharge at Padshahi Bagh station. The Padshahi Bagh station shows a non-monotonic trend as observed form (Fig. 6b) in which low magnitude discharge is increasing while medium and high annual average discharge is decreasing, due to which the overall trend is declining for annual average discharges.

### 4.2.3 Ram Munshi Bagh

The annual maximum time series of discharge showed an increasing trend for ITA with an increasing annual rate of 31.57 mm/year and was statistically significant, and for M–K, annual increasing rate was 28.76 mm/year in Table 4. The annual average discharge represents decreasing trend for both MK and ITA tests but was proved statistically significant for ITA with an annual decreasing rate of −19.55 mm/year, and M–K was −16.01 mm/year in Table 4. Based on Fig. 5c, it can be depicted that annual maximum discharge exhibits a monotonic increasing trend at Ram Munshi Bagh. The Ram Munshi Bagh station, as per Fig. 6c, shows a non-monotonic trend in which low magnitude annual average discharge represents an increasing trend, while medium and high magnitude discharge represents decreasing trend that leads to a general trend of Ram Munshi Bagh declining.
4.2.4 Downstream stations

The downstream region stations Shadipora, Asham, Sopore, and Baramullah represent an increasing trend for annual maximum discharge for both ITA and MK tests but were proved statistically significant for ITA with an annual increase rate of 18.24, 27.22, 24.01, and 20.31 mm/year, respectively, in Table 4. Furthermore, the annual average discharge has represented a decreasing trend for all stations Shadipora, Asham, Sopore, and Baramullah. For ITA, trend was proved to be statistically significant with decreasing rates of $-26.25$, $-32.09$, $-39.50$, and $-52.08$ mm/year, respectively, in Table 5. The Shadipora show a non-monotonic trend as observed in Fig. 5d for the annual maximum annual discharges with low magnitude discharges show declining trend and medium and high magnitude discharges show increasing trend due to which overall discharge shows an increasing trend. However, Asham, Sopore, and Baramulla stations show a monotonic increasing trend for annual maximum discharge as observed from Fig. 5e–g. The Shadipora represents decreasing monotonic trend as observed in Fig. 6d for the annual average annual discharges. However, Asham, Sopore, and Baramulla stations show non-monotonic with a declining trend for low magnitude annual average discharge while increasing trend for high magnitude annual average discharge as observed from Fig. 6e–g.

The results discussed above depict that there is a generally increasing trend in both annual maximum rainfall
and discharge. Moreover, the annual average rainfall and discharge were overall governed by decreasing trends using MK and ITA tests. However, a statistically significant trend was proved in the ITA test. Many studies have shown an increase in the extreme rainfall and high discharge events in the Himalayan region. Mishra and Srinivasan (2013) detected that the frequency of severe rainfall phenomena and flooding of places shows an increasing trend in the NW Himalayan region. Mahmood and Jia (2017) reported a decrease in discharge in the upper Jhelum River basin because of decreasing rate of rainfall and the decrease was maximum in summers. Also, other studies have shown a significant decrease in the discharge in the Jhelum with decreasing precipitation (Romshoo et al. 2017; Ahmad et al. 2014). Furthermore, recent 2014 floods in the Jhelum River were mainly due to torrential rainfall in the basin (Mishra 2015). The flood frequency analysis of the Jhelum River has also shown a predominant increase in peak discharges at various return periods, leading to more floods in the region (Bhat et al. 2019; Umar et al. 2021). UL Shafiq et al. (2020) carried out a study and concluded a decreasing trend in precipitation and stream runoff in the Jhelum River basin using MK and Sen’s slope test.
5 Conclusion

The study involves trend analysis of hydro-meteorological data using ITA, M–K, and Sen’s slope test in the Jhelum River basin. The study depicts the decreasing trend in annual average rainfall and annual average discharge. However, annual maximum rainfall and annual maximum discharge showed an increasing trend. The M–K test shows monotonic trend results while the ITA test provides detailed trend results as data were subdivided into three categories, low, medium, and high, to analyze the behavior of trends in hydro-meteorological data in a detailed manner. In trend analysis of annual maximum rainfall and discharge via ITA for medium and high magnitude rainfall and discharge at all stations shows an increasing trend. Therefore, the Jhelum River basin is more prone to floods, as several previous studies discussed above reveal that torrential rainfall events are the leading cause of floods in the Jhelum River. The analysis also shows a significant decrease in the average annual discharge, which would adversely impact water resources in the future. The reliability of above analysis is largely dependent on the accuracy of observed data collection procedures. More advanced trend analysis methods such as innovative polygon trend analysis method can be applied to provide greater insight into the alteration in hydro-meteorological variables in the Jhelum River basin.

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Author contribution Sheikh Umar: data acquisition, trend analysis of hydro-meteorological data, interpretation of the results, manuscript writing, and submission. Mohammad Akbar Lone: conceptualization and supervision. Narendra Kumar Goel: supervision and editing. Mohammad Zakwan: supervision and editing.

Data availability The data used for this research are available from IMD Pune and the Planning Division of the Irrigation and Flood Control Department Jammu and Kashmir, India. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the authors with the permission of the said departments.

Code availability Not applicable.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

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References

Ahmad W, Fatima A, Awan UK, Anwar A (2014) Analysis of long-term meteorological trends in the middle and lower Indus Basin of Pakistan—a nonparametric statistical approach. Glob Planet Chang 122:282–291

Akhatar M, Ahmad N, Booij MJ (2008) The impact of climate change on the water resources of Hindukush– Karlakorom Himalaya region under different glacier coverage scenarios. J Hydrol 355(1–4):148–163

Alam A, Bhat MS, Farooq H, Ahmad B, Ahmad S, Sheikh AH (2018) Flood risk assessment of Srinagar city in Jammu and Kashmir, India. Int J Disaster Resilience Built Environ 9(2):112–129

Al-Hasani AA (2020) Trend analysis and abrupt change detection of streamflow variations in the lower Tigris River Basin, Iraq. Int J River Basin Manag 19(4):523–534

Archer DR, Fowler HJ (2004) Spatial and temporal variations in precipitation in the Upper Indus Basin, global teleconnections and hydrological implications. Hydrol Earth Syst Sci 8(1):47–61

Belhlu M, Abate B, Tekleab S, Bewket W (2018) Hydro-meteorological trends in the Gidabo catchment of the Rift Valley Lakes Basin of Ethiopia. Phys Chem Earth 104:84–101

Berthier E, Arnaud Y, Kumar R, Ahmad S, Wagon P, Chevallier P (2007) Remote sensing estimates of glacier mass balances in the Himalach Pradesh (Western Himalaya, India). Remote Sens Environ 108(3):327–338

Bezak N, Brilly M, Šraj M (2014) Flood frequency analyses, statistical trends and seasonality analyses of discharge data: a case study of the litija station on the Sava River. J Flood Risk Manag 9(2):154–168

Bhat MS, Alam A, Ahmad B, Kotlia BS, Farooq H, Taloor AK, Ahmad S (2019) Flood frequency analysis of river Jhelum in Kashmir basin. Quat Int 507:288–294

Birsan MV, Molnar P, Burlando P, Pfundler M (2005) Streamflow trends Switzerland. J Hydrol 314(1–4):312–329

Bookhagen B, Burbank DW (2010) Toward a complete Himalayan hydrological budget: spatiotemporal distribution of snowmelt and rainfall and their impact on river discharge. J Geophys Res Earth Surf 115(F3)

Brabets TP, Walvoord MA (2009) Trends in streamflow in the Yukon River basin from 1944–2005 and the influence of the Pacific decadal oscillation. J Hydrol 371(1–4):108–119

Burgueno A, Serra C, Lana X (2004) Monthly and annual statistical distributions of daily rainfall at the Fabra Observatory (Barcelona, NE Spain) for the years 1917–1999. Theor Appl Climatol 71(1):57–75

Chandole V, Joshi GS, Rana SC (2019) Spatio-temporal trend detection of hydro-meteorological parameters for climate change assessment in Lower Tapi river basin of Gujarat state, India. J Atmos Solar-Terr Phys 195:105130

Chen CJ, Georgakakos AP (2014) Hydro-climatic forecasting using sea surface temperatures: methodology and application for the southeast US. Clim Dyn 42(11–12):2955–2982

Cheo AE (2016) Understanding seasonal trend of rainfall for the better planning of water harvesting facilities in the Far-North region, Cameroon. Water Util J 13:3–11

Chevuturi A, Dimri AP, Thayyen RJ (2018) Climate change over Leh (Ladakh) India. Theor Appl Climatol 131(1–2):531–545

Darand M, Masoodian A, Nazaripour H, Daneshvar MM (2015) Spatial and temporal trend analysis of temperature extremes based on Iranian climatic database (1962–2004). Arab J Geosci 8(10):8469–8480

Diop L, Yasseen ZM, Bodian A, Djaman K, Brown L (2017) Trend analysis of streamflow with different time scales; a case study of the upper Senegal River. ISH J Hydraul Eng 24(1):105–114
Douglas EM, Vogel RM, Kroll CN (2000) Trends in floods and low
dflows in the United States: impact of spatial correlation. J Hydrol
240(1–2):90–105
Fentaw F, Melesse AM, Haitu D, Nigussie A (2019) Precipitation and
streamflow variability in Tekeze River basin, Ethiopia. Extrem
Hydrol Clim Var 103:121. Elsevier. https://doi.org/10.1016/j.hydroclim.0-12-815998-9.00010-5

Gupta RS (2008) Hydrology and hydraulic systems. Waveland, Long
Grove

Hirsch RM, Slack JR (1984) A nonparametric trend test for seasonal
data with serial dependence. Water Resour Res 20(6):727–732

Hussain M (1987) Geography of Jammu and Kashmir state. Rajesh
Publication, New Delhi, pp 11–18

Immerzeel WW, Droogers P, De Jong SM, Bierkens MF (2009) Large-
scale monitoring of snow cover and runoff simulation in Himala-
ayan River basins using remote sensing. Remote Sens Environ
113(1):40–49

IPCC (2013) Climate change 2013: the physical science basis. Con-
tribution of working group i to the fifth assessment report of the
intergovernmental panel on climate change. Cambridge University
Press, Cambridge

Kishore P, Jyothi S, Basha G, Rao SV, Rajeevan M, Velicogna I, Sut-
terley TC (2016) Precipitation climatology over India: validation
with observations and reanalysis datasets and spatial trends. Clim
Dyn 46(1–2):541–556

Kumar S, Merwaude V, Kam J, Thurner K (2009) Streamflow trends in
Indiana: effects of long term persistence, precipitation and sub-
surface drains. J Hydrol 374(1–2):171–183

Liang L, Li L, Liu Q (2010) Temporal variation of reference evapotra-
spiration during 1961–2005 in the Taer River basin of Northeast
China. Agric for Meteorol 150(2):298–306

Mahmood R, Jia S (2017) Spatial and temporal hydro-climatic trends
in the transboundary Jhelum River basin. J Water Clim Chang
8(3):423–440

Mishra AK (2015) A study on the occurrence of flood events over
Jammu and Kashmir during September 2014 using satellite
remote sensing. Nat Hazards 78(2):1463–1467

Mishra A, Srinivasan J (2013) Did a cloud burst occur in Kedarnath
during 16 and 17 June 2013? Curr Sci 105(10):1351–1352

Rasool R, ul Shafiq MU, Bhat MS, Asif MA, Ahmad H, Hassan H (2016)
Variability of precipitation regime in Ladakh region of India from
1901–2000. J Climatol Weather Forecast 4(165):2

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