Trend Analysis of Hydro-meteorological Parameters in the Jhelum River Basin, North Western Himalayas

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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 Himalayan Mountain range. The trend analysis of Hydro-meteorological data is crucial for planning and management of various activities (agriculture, design of hydraulic structures) in the basin. The purpose of the present study is 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 by using Mann-Kendall (M-K), 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 various stations for different time series data and bring forth more significant data to analyze changes in Hydro-meteorological data. Moreover, the overall trend shows a significant decreasing trend 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.

Key words:- River Jhelum; Hydrometereological variables; ITA; Trend analysis

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 ºC for the period/span 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; Khattak e al. 2011; Chen and Geogakakos et al. 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 frangible 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 many decades at various Spatio-temporal scales has been a major issue (Shafiq et al. 2016), in addition, the analysis can 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; Khattak et al. 2011; Shadmani et al. 2012; Tekleab et al. 2013; Bezak et al. 2014; Darand et al. 2015; Cheo 2016; Belihu et al. 2017; Nikzad Tehrani et al. 2018; Zakwan et al. 2018; Zakwan and Ara 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, 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 coolins 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 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 hydroclimatic 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. (2020) 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.

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 km^2 (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 is consisting of 24 sub-watershed and drains into the Jhelum River from the left and right bank sides. The length of the Jhelum River 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 650mm in Srinagar city to 1600mm in high altitude places and with average temperature variation of 2.5ºC and 19.8ºC 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.

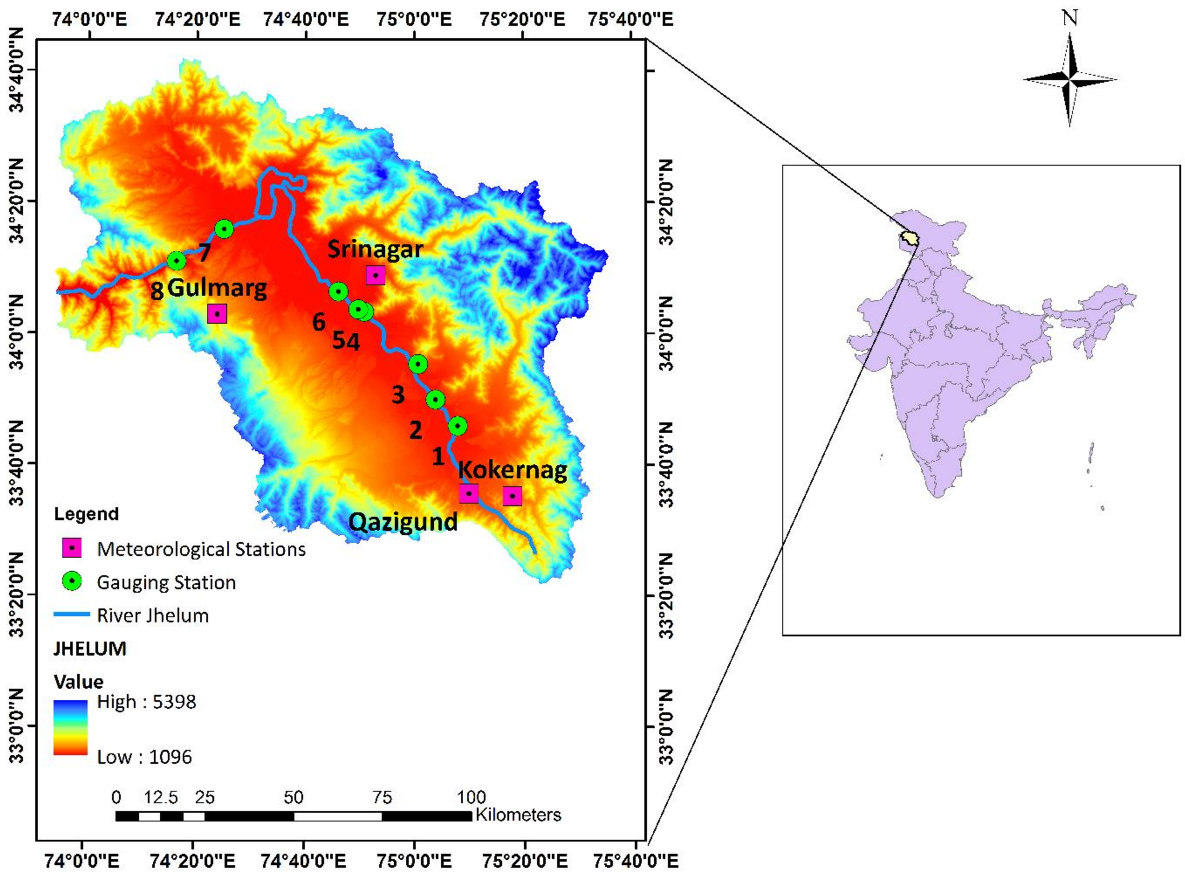

Fig. 1 Study area

Data and Methodology

The hydro-meteorological data of 8 gaugings and 6 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% Table 1. The data of precipitation extremes used for frequency analysis 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-Wolfowitz (WW) (1943) and Mann-Kendall (MK) test at all stations.

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

Methodology

The present study involves the use of the Mann-Kendall test (MK), Sen's slope estimator, and innovative trend analysis (ITA) tests for the comparison and evaluation of the magnitudes and significance of trends obtained by the aforesaid methods. Before, proceeding with trend analysis data was checked for all necessary time-series assumptions like homogeneity, autocorrelation, randomness by methods DMC and WW test. The second step involves the preparation of data in which average annual, and annual maximum values of hydro-meteorological variables were used for trend analysis and magnitude computation was done by Sen's slope estimator.

Mann-Kendall test (MK)

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 it 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 that there is 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 Equation. 1 (Hirsch and Slack 1984) to compute the test statics S:

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

Where, X_k = rank of the kth observation, while X_i the rank of ith observation and n = number of observations. When, $n \geq 10$, S is almost normally distributed.

$$sgn(\theta) = \begin{Bmatrix} +1, & \theta > & 0 \\ 0, & \theta = & 0 \\ -1, & \theta < & 0 \end{Bmatrix} \qquad (2)$$

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:

$$Q_i = median\left(\frac{X_j - X_k}{j - k}\right) for\ k = \ 1\ to\ N \qquad (3)$$

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

$$Q_{med} = \begin{Bmatrix} Q\left(\frac{N+1}{2}\right) & if, N\ is\ odd \\ \left[Q\frac{N}{2} + Q\frac{(N+2)}{2}\right]/2 & if, N\ is\ even \end{Bmatrix} \qquad (4)$$

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

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 data is being sorted into ascending order. The First half of the series is placed along the x-axis and the second half of the series is placed along the x-axis of the Cartesian coordinate system. The 1:1 (45^o) straight-line partition the figure into two equal triangular sections, the upper portion represents the increasing tern 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:

$$S = \frac{2(\bar{Y}_2 - \bar{Y}_1)}{n} \qquad (5)$$

$$\sigma_s = \frac{2\sqrt{2}}{n\sqrt{n}}\,\sigma\sqrt{1 - \rho_{\bar{Y}_1\bar{Y}_2}} \qquad (6)$$

Where, s = magnitude of slope and σ_s = standard deviation slope.

The correlation coefficient between $\bar{Y}_1$and $\bar{Y}_2$ are computed as:

$$\rho_{\bar{Y}_1\bar{Y}_2} = \frac{E(\bar{Y}_1\bar{Y}_2) - E(\bar{Y}_1)E(\bar{Y}_2)}{\sigma_{\bar{Y}_1}\sigma_{\bar{Y}_2}} \qquad (7)$$

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

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

$$CL_{1-\alpha} = 0 \pm S_{cri}\sigma_s \qquad (8)$$

Where S_{cri} is defined as the critical slope

Fig. 2 represents 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 ist half of the time series. Furthermore, the scatter diagram shows low, medium, and high magnitude data points, and analysis 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.

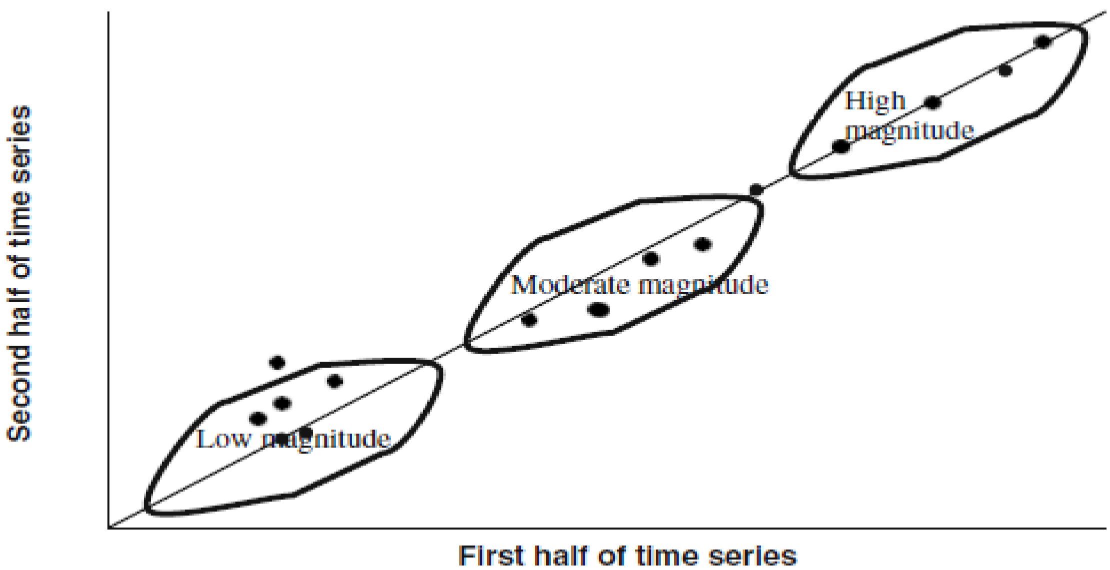

Fig. 2 Diagrammatic representation of ITA (Zakwan and Ahmad 2021)

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. In this study, MK-test, Sen slope test, and ITA test were applied to annual maximum, annual average discharge, and rainfall.

Rainfall

The results obtained for the ITA, MK, and Sen's slope for annual maximum and an annual average of rainfall at different hydrometeorological stations are presented in Table 2 and 3. A perusal of Table 2 and 3 reveals a significant increase in annual maximum rainfall and a significant decrease in annual average rainfall at all stations. The Qazigund station shows the highest slope during the first half of the time series about 103.19 cm and falls to 38.11 cm in annual maximum rainfall.

At Qazigund station trend slope computed by eq. for ITA was heights (0.94 mm/year) and greater than critical slope (0.17mm/year) depicting a significant trend at 95% confidence level. The MK test has also shown decreasing trend (2.63mm) 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 represents a non-monotonic trend in which low magnitude annual maximum rainfall is decreasing, however moderate and high-magnitude annual maximum rainfall is showing 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.

A significant positive trend was observed for ITA at Kokernag in annual maximum rainfall with an annual increasing rate of 0.47 mm/year and while using MK test trend was increase with an annual rate of increase 0.31mm/year, but statistically insignificant in table 2. Moreover, the negative significant trend was recorded in annual average rainfall with an annual rate of decrease

-0.25mm/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.

The Pahalgam station revealed a significant increasing trend for annual maximum rainfall via ITA with an annual rate of increase 0.65mm/year and for the MK test, it also showed an increasing trend but statistically insignificant with annual rate of increase 0.31mm/year in table 2. The annual average rainfall presented a significant decreasing trend with annual decrease rate of -0.28 mm/year via ITA in table 3. It can be concluded from Fig. 3c that there exists a monotonic trend in the maximum annual rainfall. Fig. 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 which leads to an overall decreasing trend for Pahalgam station.

The Srinagar station which is situated at the lowest altitude recorded a significant increasing trend with annual increasing rate of 0.36 mm/year for annual maximum rainfall via ITA and also 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.

The Kupwara and Gulmarg stations also revealed an increasing trend via ITA for annual maximum rainfall with annual rate of increase 0.57 mm/year and 0.71 mm/year, also for 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 table 3. From Fig. 3e and Fig. 3f, it can be observed both Kupwara and Gulmarg are showing a monotonic increasing trend for annual maximum rainfall. The Kupwara and Gulmarg station is showing a monotonic decreasing trend for annual average rainfall as observed in Fig. 4e and Fig. 4f respectively.

Table 2 Results at various meteorological stations for annual maximum rainfall

Sites	M-K		ITA				
	Z	Sen's slope	$\bar{Y}_1$	$\bar{Y}_2$	σ	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		ITA				
	Z	Sen's slope	$\bar{Y}_1$	$\bar{Y}_2$	σ	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

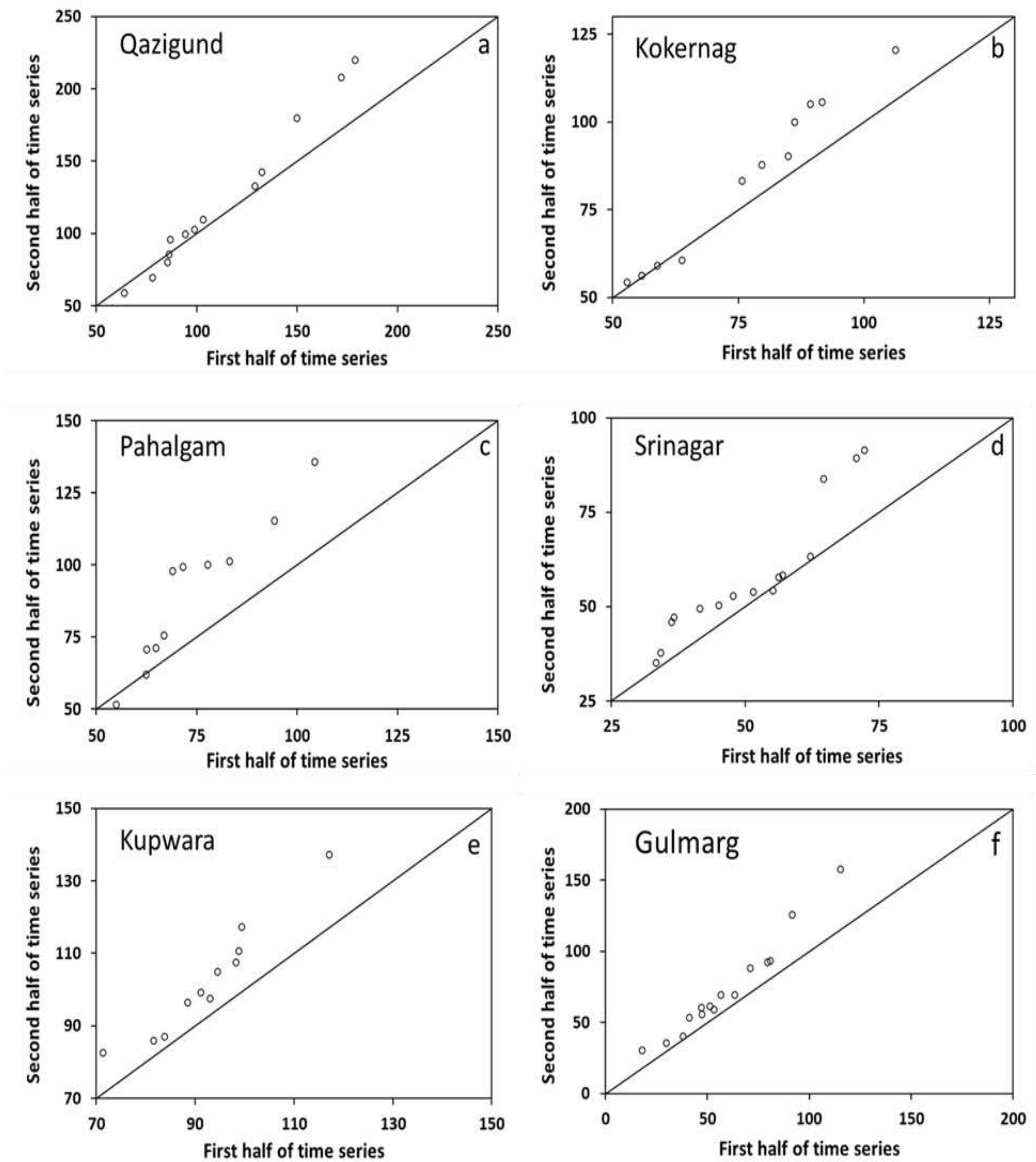

Fig 3 a-f Trend of annual maximum rainfall for ITA at six meteorological stations

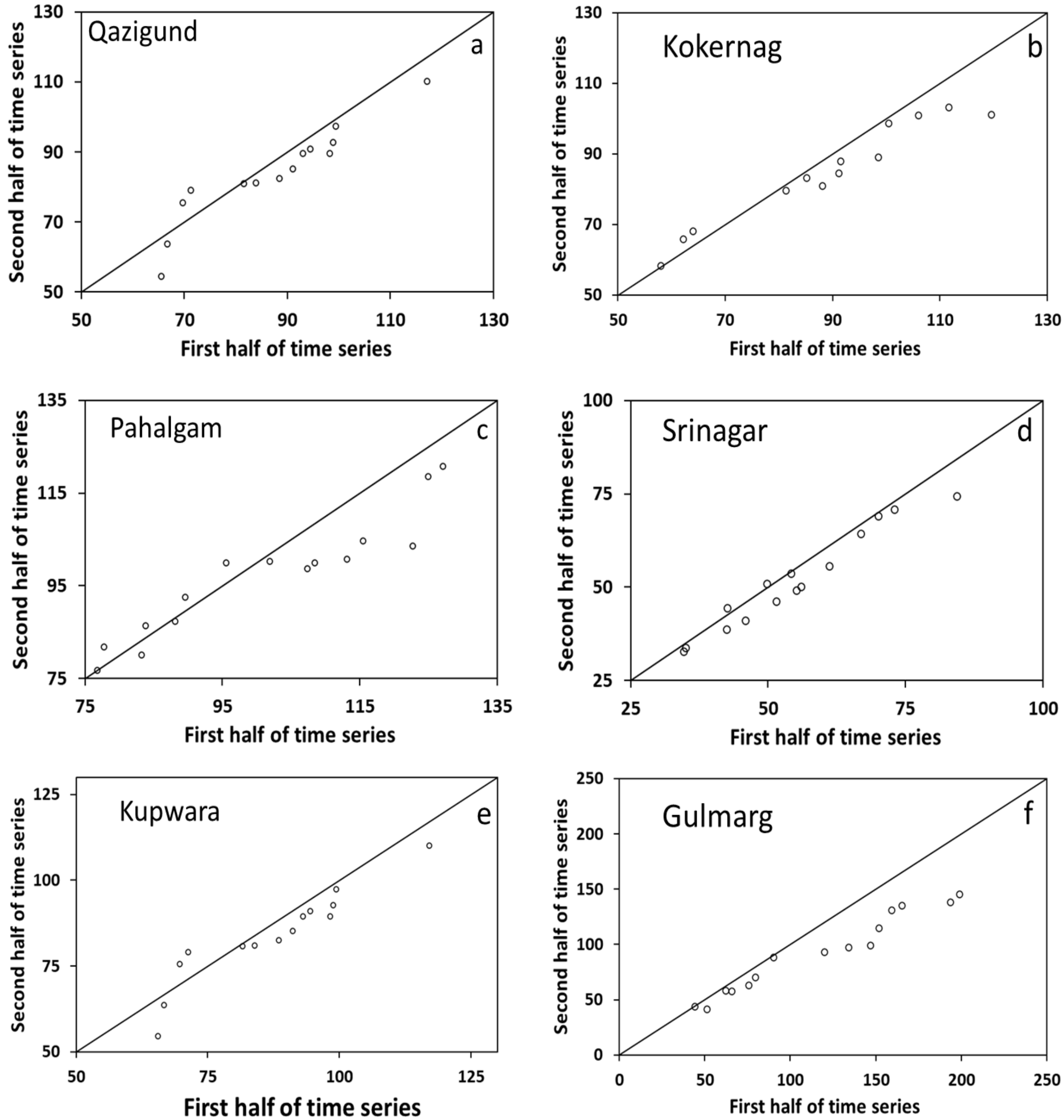

Fig. 4 a-f Trend of annual average rainfall for ITA at six meteorological stations

Discharge

Table 4 and 5 represents results of ITA, MK and Sen's slope for annual maximum and annual average discharge at different hydrometeorological stations. A perusal of Table 4 and 5 divulges a significant increase in annual maximum discharge and a significant decrease in annual average discharge at all stations.

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 annual rate of decrease -18.87 mm/year, and for the M-K test annual rate of decrease was -15.36mm/year in table 5. Figure 5a shows a non-monotonic trend of annual maximum discharge with low magnitude discharges 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 recent 2014 flood maximum discharge was recorded at Sangam (Ramshoo et al. 2017; Alam et al. 2018; Umar et al. 2020). Figure 6a shows the non-monotonic trend for annual maximum discharge in which low magnitude discharge shows increasing trend while medium and high annual maximum discharge is showing a declining trend, as a result of which overall trend for average annual discharge is declining.

Padshahi Bagh

The increasing trend was observed in annual maximum discharge for ITA with annual increasing rate of 35.24 mm/year and 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, annual average discharge has presented decreasing trend for ITA and was statistically significant with decreasing annual rate of -42.63 mm/year and for M-K annual rate of decrease was -37.11 mm/year 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 overall trend is declining for annual average discharges.

Ram Munshi Bagh

Annual maximum time series of discharge shows an increasing trend for ITA with annual increasing rate of 31.57 mm/year and was statistically significant and for M-K annual increasing rate was 28.76 mm/year table 4. The annual average discharge represents decreasing trend for both MK and ITA tests but was proved statistically significant for ITA with annual decreasing rate of -19.55 mm/year and M-K was -16.01 mm/year 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 leads to a general trend of Ram Munshi Bagh declining.

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 was proved statistically significant for ITA with 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 decreasing trend for all stations Shadipora, Asham, Sopore, and Baramullah, and for ITA was proved to be statically significant with decreasing rate of -26.25, -32.09, -39.50, and -52.08 mm/year respectively in table 5. The Shadipora show a nonmonotonic trend as observed in Fig. 5d for the annual maximum annual discharges with low magnitude discharges shows 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 trend, while 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 that there is a decrease in discharge in the upper Jhelum River basin because of decreasing rate of rainfall and 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; Khattak et al. 2011). 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 which leads to more floods in the region (Bhat et al. 2019; Umar et al. 2021). UL Shafiq et al. (2020) carried out a study, concluded that there was a decreasing trend in precipitation and stream runoff in the Jhelum River basin using MK and Sen’s slope test.

Table 4 Results at various gauging stations for annual maximum discharge

Sites	M-K		ITA				
	Z	Sen's slope	$\bar{Y}_1$	$\bar{Y}_2$	σ	S	Critical slope
Sangam	1.01	34.94	717.57	1299.54	674.74	38.79	8.89
Padshahi Bagh	0.96	31.25	470.11	998.76	490.96	35.24	7.12
Ram Munshi Bagh	1.41	28.76	508.78	982.13	419.7	31.57	4.63
Shadipora	1.53	17.23	597.77	871.41	354.85	18.24	3.12
Asham	1.60	25.85	454.92	863.25	383.85	27.22	2.55
Sopore	1.23	22.71	519.74	876.89	263.35	24.01	1.86
Baramullah	1.73	37.29	614.08	918.83	358.43	20.31	1.90

Table 5 Results at various gauging stations for annual average discharge

Sites	M-K		ITA				
	Z	Sen's slope	$\bar{Y}_1$	$\bar{Y}_2$	σ	S	Critical slope
Sangam	-1.04	-15.36	1659.48	1376.29	1491.45	-18.87	9.03
Padshahi Bagh	-1.05	-37.11	1107.70	368.18	639.20	-42.63	8.50
Ram Munshi Bagh	-1.17	-16.01	1284.37	991.06	1249.89	-19.55	8.45
Shadipora	-1.22	-24.09	744.14	350.35	320.99	-26.25	3.03
Asham	-1.18	-30.73	2282.59	1801.09	1489.79	-32.09	9.64
Sopore	-1.07	-32.02	1712.81	1120.22	1185.90	-39.50	5.69
Baramullah	-1.43	-41.67	1751.06	969.81	1272.21	-52.08	9.23

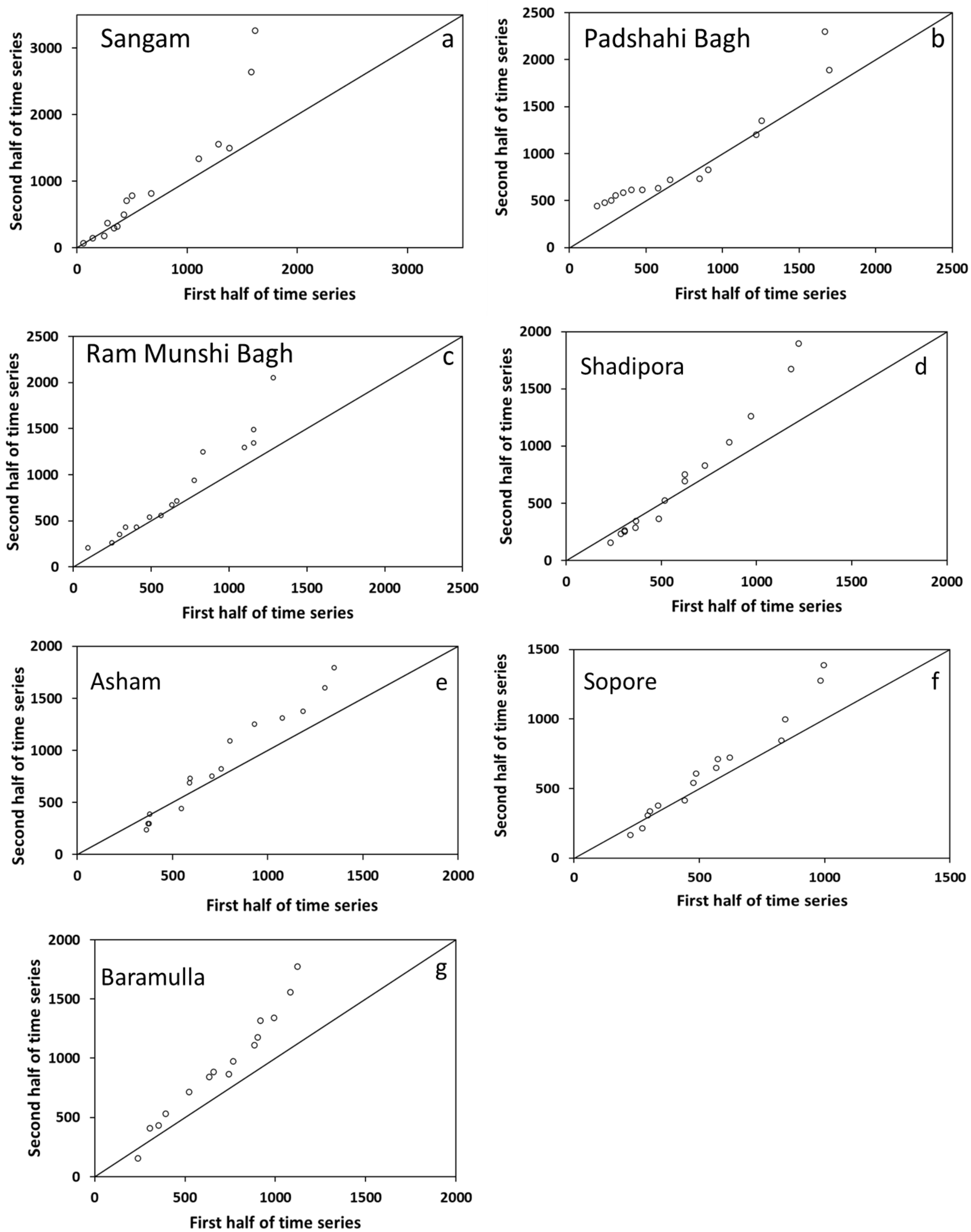

Fig 5 a-g Trend of annual average discharge for ITA at 7 gauging stations

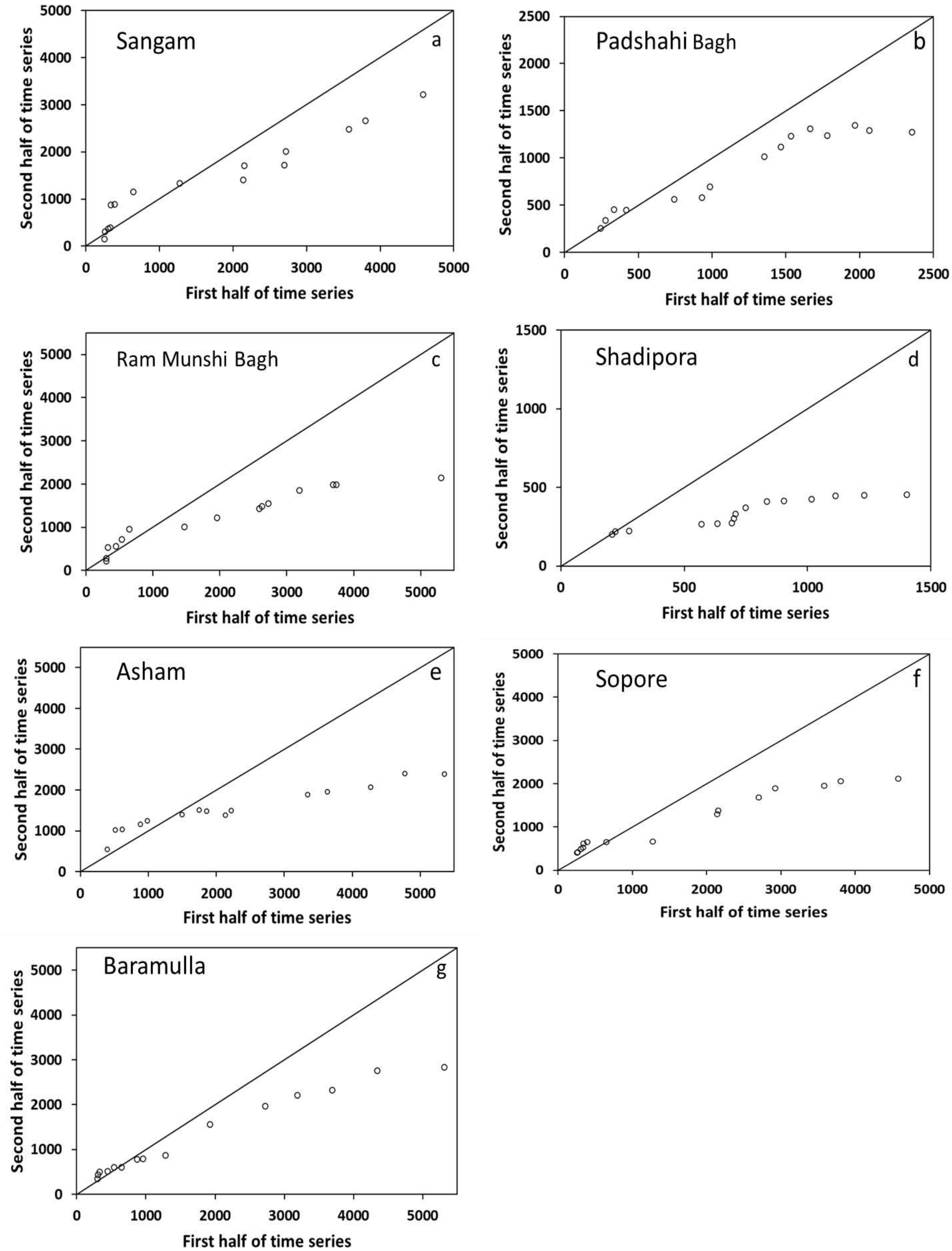

Fig 6 a-g Trend of annual average discharge for ITA at 7 gauging stations

Conclusion

The study involves trend analysis of Hydro-meteorological data was carried out 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, Sen's slope, and ITA test were used, 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 trend 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 which makes the Jhelum River basin more prone to the floods, as several previous studies as discussed above reveal that torrential rainfall events are the main cause of floods in the Jhelum River. The analysis also shows a significant decrease in the average annual discharge which would have an adverse impact on water resources in the future.

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Availability of data and materials 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.

Author contribution Sheikh umar: data acquisition, trend analysis of hydrometereological 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

Declarations

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