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Evaluating rainfall trend in four key stations of the Northwestern Himalayan region, Uttarakhand: utilizing innovative graphical approaches for trend assessment

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सार – स्थानिक एवं कालिक आयाम दोनों तरह से वर्षा के प्रतिरूप को समझना एक बहुआयामी प्रयास है। इन आयामों की जानकारी पाने के लिए वर्षा के टाइम सीरीज़ डेटा की प्रवृति की बारीकी से जांच करना ज़रूरी है। इस अन्वेषण का मुख्य फोकस उत्तराखंड के कोसी नदी बेसिन (KRB) में सालाना और मौसमी वर्षा की अभिलक्षणिकता में बदलाव का मूल्यांकन करना है, जिसके लिए दुनिया भर में सुझाए गए तरीकों जैसे कि इनोवेटिव ट्रेंड एनालिसिस (ITA), मान-केंडल (MK) टेस्ट और लीनियर रिग्रेशन (LR) विश्लेषण का इस्तेमाल किया जाता है। ITA के ज़रिए क्रमिक सहसंबंध, डेटासेट का आकार या वितरण विशेषताओं पर ध्यान दिए बिना एक्दिष्ट और अएक्दिष्ट दोनों तरह की प्रवृति का पता लगाया गया। यह तकनीक वर्षा के डेटा में अलग-अलग प्रवृति की पहचान करने में अहम साबित होती है। MK टेस्ट के मुकाबले, ITA ने प्रवृति का पता लगाने में अधिक प्रभावकारिता दिखाई जिससे अलग-अलग मौसमों में अलग-अलग नतीजे मिले। उदाहरण के लिए, मॉनसून ऋतु में MK टेस्ट प्रवृति का पता लगाने में असफल हो गया जबकि ITA ने उन्हें सफलतापूर्वक पहचान लिया। इसके विपरित, मॉनसून पश्चात प्रवृति की पहचान तीनों विधियों का इस्तेमाल करके की गई। कुल मिलाकर, वर्षा डेटा में प्रवृति की पहचान के लिए ITA एक ज़्यादा भरोसेमंद तरीका बनकर उभरा है। यह जानकारी सस्टेनेबल वॉटर रिसोर्स मैनेजमेंट के लिए रणनीतियाँ बनाने और जलवायु परिवर्तन से पानी की उपलब्धता पर आने वाली संभावित चुनौतियों से निपटने में मददगार हो सकती है। इस अध्ययन के नतीजे मौजूदा जलवायु परिवर्तन नीतियों खासकर उत्तराखंड में पहाड़ी कृषि और दुनिया के दूसरे हिस्सों के लिए भी बहुत ज़रूरी हैं।

ABSTRACT. Comprehending rainfall patterns is a multifaceted endeavor, both in terms of spatial and temporal dimensions. Gaining insight into these patterns necessitates a close examination of trends within rainfall time series data. The main focus of this research is to evaluate the variations in annual and seasonal precipitation characteristics within the Kosi River Basin (KRB) of Uttarakhand using globally recommended method such as., Innovative Trend Analysis (ITA), Mann-Kendall (MK) test and linear regression (LR) analysis. Through ITA, both monotonic and non-monotonic trends were discerned, irrespective of serial correlation, dataset size, or distribution characteristics. This technique proves valuable in identifying diverse trends in rainfall data. In contrast to MK tests, ITA exhibited greater efficacy in trend detection, yielding distinct results across various seasons. For instance, during the monsoon season, MK tests failed to detect trends, while ITA successfully identified them. Conversely, post-monsoon season trends were identified using all three techniques. In sum, ITA emerged as a more dependable method for trend identification in rainfall data. This insight can be instrumental in formulating strategies for sustainable water resource management and addressing potential challenges posed by climate change on water availability. The findings of this study hold significant relevance for ongoing climate change policies, particularly in the context of hill agriculture in Uttarakhand and other parts of the globe.

Key words – Climate variability, Climate trend, Kosi river basin, Trend analysis, Graphical trend methods.

1. Introduction

The hydro-meteorological process is continuously affected by climate change and anthropogenic factors, leading to trends or sudden jumps that have adverse impacts (Şen 2012). While anthropogenic activities (direct or indirect) over a long period are responsible for climate variability. In the recent time, abrupt changes are becoming significant and are expected to be more frequent in the future (Wang *et al*. 2017). In its fifth assessment in 2013, the Intergovernmental Panel on Climate Change (IPCC) reported a global rise in average surface temperature of 0.89 °C between 1901 and 2012. While the increase in minimum and maximum temperatures over land surfaces has been observed since 1950 on a global scale, the magnitude of this change varies over space and time. As per the IPCC, the rise in temperature, combined with a decrease in precipitation and an increase in evapotranspiration, can result in droughts. The hydrological cycle's dynamic parameter, rainfall, undergoes spatial and temporal variations due to the increasing concentration of atmospheric gases. Understanding the spatio-temporal distribution of rainfall is crucial for sustainable utilization of water resources, control of floods and droughts, and accurate modelling of flood control and surface water storage. Rainfall distribution plays a crucial role in the occurrence of floods and droughts, and affects the distribution of runoff, soil moisture, and groundwater reserves in both space and time. Hence, it is crucial to identify trends in rainfall variation at different spatial and temporal scales globally. In recent years, various statistical tests (Mann-Kendall (MK) test, Spearman's Rho (SR) test, regression analysis, and wavelet analysis) have been employed to detect trends in hydrological and meteorological time series data, and several studies have been conducted in this regard. Conversely, the trend analysis methods outlined earlier are purely statistical techniques that lack the capability to simultaneously identify trends across low, moderate, and high values in a single computational process. Several studies have been conducted all over the world, including in India. The findings of these investigations have been employed to examine the diversity of rainfall and other climate parameters over space and time, a vital step in comprehending and reducing the effects of climate change on water resources and related fields. Various statistical tests have been employed in multiple studies to identify trends in meteorological and hydrological data over diverse regions. Certain investigations employed ArcGIS to study trends' spatial patterns. For instance, Chakraborty *et al*. (2013) used the Thiessen polygon method to investigate the trend in rainfall in Seonath basin, while Pingale *et al*. (2014) used Mann-Kendall and Thiel-Sen's slope tests to detect the trend in temperature and rainfall in 33 urban centers of Rajasthan, India. Gajbhiye *et al*. (2016) interpolated the spatial pattern of trend magnitude in the Sindh river basin, India using a kriging technique. Phuong *et al*. (2018) found an upward trend in seasonal and annual rainfall over a period of 37 years in 14 weather stations in Ho Chi Minh City, Vietnam, with the dry season showing statistically significant trends and an increase in rainfall compared to the rainy season in most stations. Various statistical tests have been developed to detect trends in rainfall time series data. These include linear regression analysis, Mann-Kendall test, Spearman's rho test, Theil-Sen approach, and seasonal Kendall methods. The MK test is the most commonly used method globally. Some of the research that has utilized these methods are by Becker *et al*. (2006), Tabari *et al*. (2011), Gemmer *et al*. (2011), Sonali and Kumar (2013), Sang *et al*. (2014), Kumar *et al*. (2023), Asadi *et al*. (2015), Esterby (2015), Wang *et al*. (2016), and Sun *et al*. (2016).

The Kosi River Basin (KRB) is a major river basin in Kumaon division Uttarakhand, characterized by high population density and rapid urbanization in recent years (Fig. 1). The Digital Eleveation model of KRB is shown in figure 2. However, the region is prone to frequent and devastating floods due to the uneven spatial-temporal distribution of rainfall. The water of Kosi River Basin (KRB) is being used for various purposes such as drinking, washing and bathing, fishing, waste dumping like solid waste, domestic waste, industrial waste, cremation waste, etc. Despite numerous studies on rainfall changes in the Kosi River Basin, including those by Kumar *et al*. (2021), Jain and Kumar, (2012), and Kumar *et al*. (2023), few have investigated temporal variations for different rainfall stations, specifically focusing for KRB using innovative trend test.

This study aimed to analyse the rainfall dynamics of seasonal, and annual rainfall time-series data from Hawalbagh, Mukteshwar, Almora and Ramnagar stations

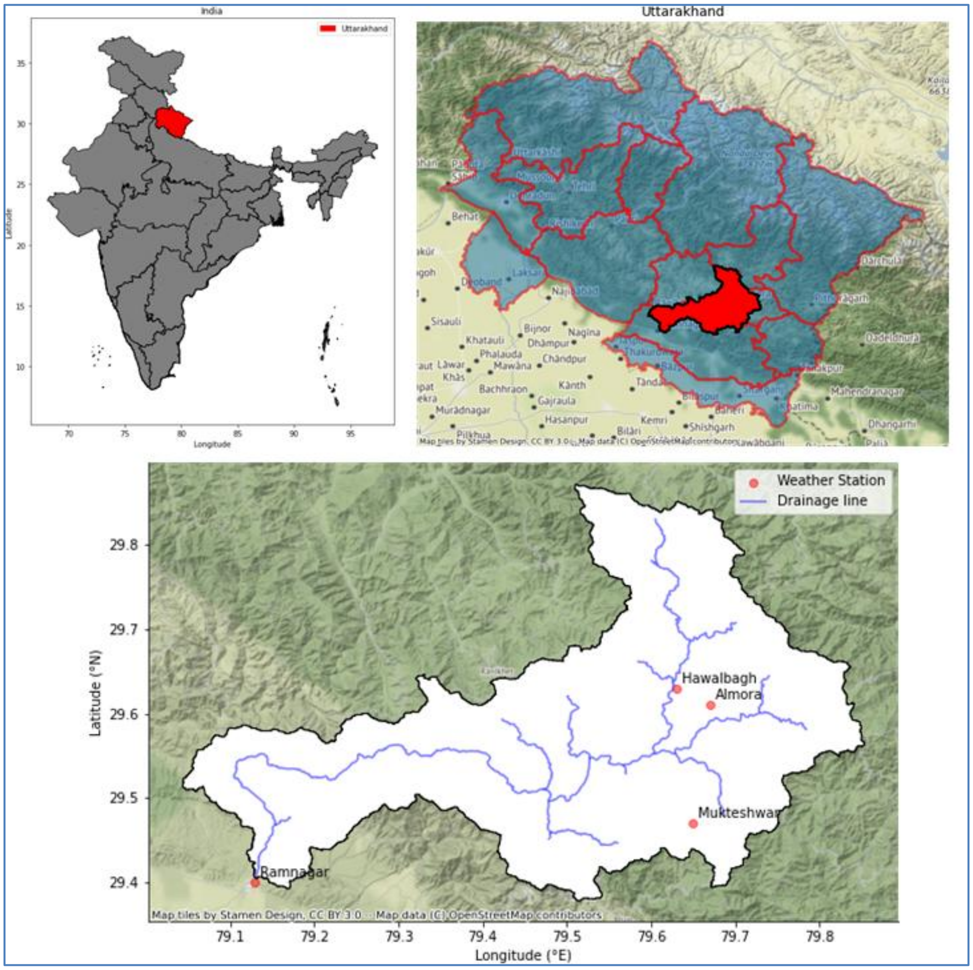


Fig.1. Location map of Kosi River Basin along with geographical information of weather stations

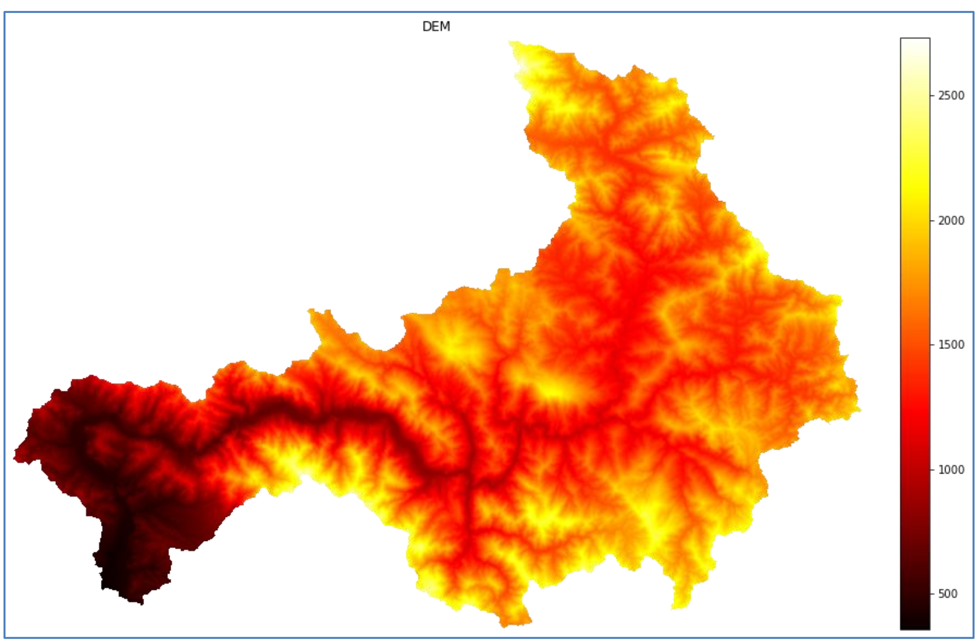


Fig.2. Elevation map of Kosi River Basin

TABLE 1

Geographical information of weather stations and record period of precipitation

Station	Location		Period	Elevation(m)
	Latitude	Longitude		
Hawalabgh(ICAR-VPKAS)	29°37'11.4"N	79°37'48.1"E	1964-2019	1250 m
Mukteswar (IMD)	29°27'25.4"N	79°39'16.2"E	1980-2019	2286 m
Almora(ICAR-VPKAS)	29°35'39.1"N	79°39'14.01"E	1980-2019	1672 m
Ramnagar	29°23'41.1"N	79°7'35.41"E	1998-2022	353 m

using Innovative trend analysis (ITA), Mann-Kendall (MK), Sen-slope (SS), and Linear regression analysis (LRA) techniques to identify patterns and magnitude of trends. The novelty of this research is the graphical comparison of results between the ITA technique and the conventional MK method at a 5% level of significance The analysis of rainfall trends and characteristics in the Kosi River Basin is crucial for mitigating climate change-related hazards and vulnerability. It will also aid in predicting future climate scenarios for effective planning of water resource development and management, which will guide future economic development. This study utilizes the ITA method, Mann-Kendall (MK) test, and Sen's slope estimator test methods to understand rainfall trends and variability that could affect the availability and sustainability of water resources. The study aims to (1) explore the spatial distribution and variability of seasonal and annual rainfall in selected stations of KRB, (2) examine temporal trends and their spatial patterns of seasonal and annual rainfall using the Mann-Kendall test (MK), Sen's slope estimator, and ITA methods, and (3) compare the results of MK trend test and ITA method.

2. Data and methodology

2.1 *Data used*

The monthly meteorological data of precipitation from the four weather station located within the KRB was utilized for this study (Fig.1). These meteorological stations are located at different elevation in the study area. The detailed description of 4 stations with their location and data period is given in Table 1. The meteorological data were collected from the India Meteorological Department (IMD), ICAR-VPKAS (Vivekananda Parvatiya Krishi Anusandhan Sansthan), Almora, Uttarakhand, state government agency. There are four distinct seasons that occur in the study area throughout the year, namely pre-monsoon (MAM: March to May), monsoon (JJAS: June to September), post-monsoon (ON: October to November), and winter (DJF: December to February).

2.2. *Method*

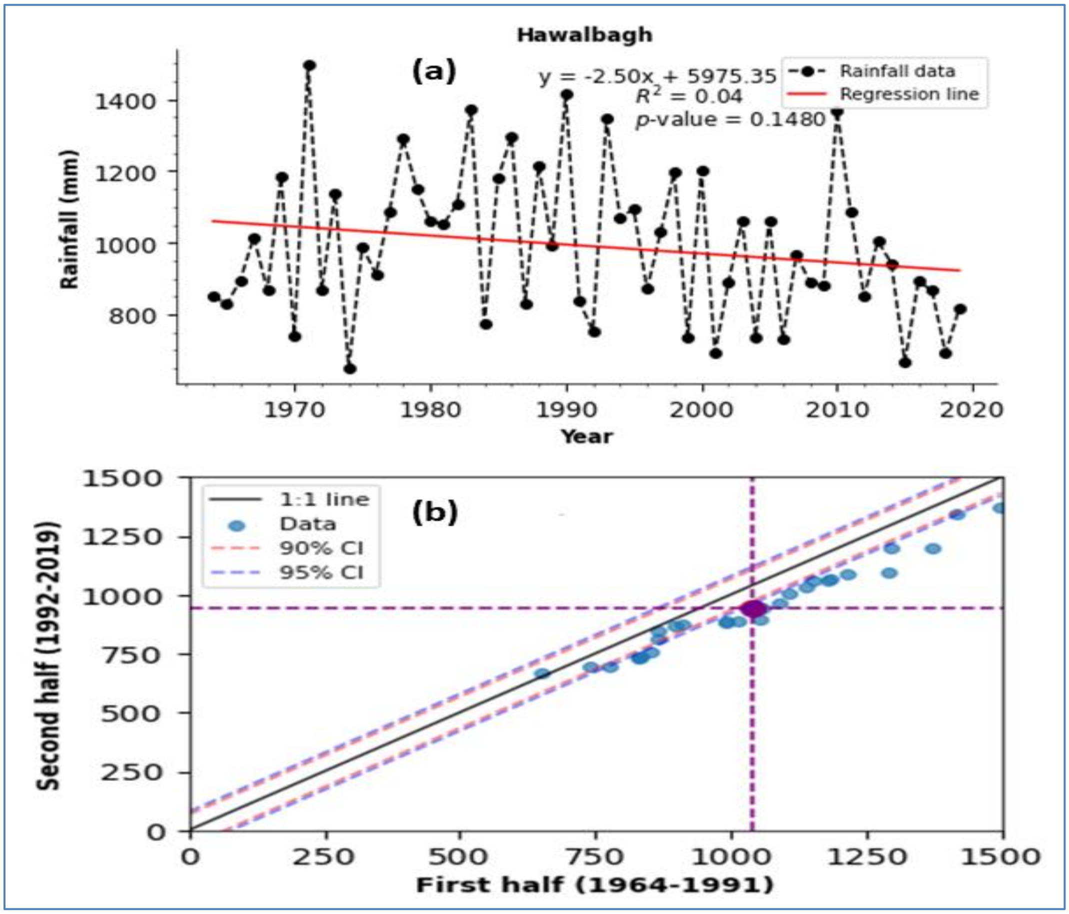
The study uses the ITA method to identify trends in annual and seasonal rainfall and compares them with Theil-Sen approach (TSA) and MK methods. This provides an evaluation of the magnitude and significance of the trends detected by the ITA method, which is an innovative approach to trend analysis.

2.2.1. *Innovative trend analysis test*

To detect trends in hydro-meteorological time series, Şen (2012) introduced the ITA method which entails splitting the series into two equal parts and sorting each of them in ascending order. The first half series ($\bar{y}_1$) is plotted on the horizontal axis and the second half series ($\bar{y}_2$) on the vertical axis of a Cartesian coordinate system, as illustrated in. In order to investigate the trend in hydro-meteorological time series data, scatter plots are used with the data points plotted against a 1:1 line. This line serves as a reference to identify the no-trend line, which separates increasing and decreasing trends. If the scatter points are predominantly above or below the no-trend line, then the time series exhibits a consistent increasing or decreasing trend, respectively. This technique is a simple and effective way to visually inspect the trend in the data. This can help detect trends in rainfall for different clusters, which can have important implications for predicting flooding or drought conditions. The straight-line trend slope (s) plotted by the ITA can be calculated according to the following expression (Şen, 2017).

$$s = \frac{2(\bar{y}_2 - \bar{y}_1)}{n} \tag{1}$$

where $\bar{y}_1$ and $\bar{y}_2$ are the arithmetic averages of the first and second half of the dependent variable, and n is the number of data. As shown in Fig. 3 (a), annual rainfall at Hawalbagh is taken as an application of this proposed method. The substitution of the numerical values as n=56 and the arithmetic averages from Fig. 3(b) as y_1=1039.54 and y_2=943.13 into Eq. (1), yields s=2×(943.13–1039.54)/56=-1.72. According to Şen (2017), it can be



Figs. 3 (a&b). (a) Deterministic and (b) innovative trend plots of annual rainfall at Hawalbagh station (1964–2019)

acceptable within 5% relative error between innovative trend plot and deterministic trend (Fig. 3 (a,b)). To test the significance of the trend slope value, *s*, the null hypothesis, H_o, implies that there is not significant trend if the calculated slope value, *s*, is below a critical value, s_{cr} (Şen, 2017). Otherwise, an alternative hypothesis, H_a, is valid when $s > s_{cr}$. As for the trend slope parameter, Eq. (1) shows that the stochastic property of *s* is a function of the first and second half time series arithmetic average values. Because y_1 and y_2 are also stochastic variables, the first-order moment (expectation) of the slope can be computed by taking the expectation of both sides:

$$E(s) = \frac{2}{n}[E(\bar{y}_2) - E(\bar{y}_1)] \quad (2)$$

In case of no trend, the centroid point falls on the 1:1 line and $E(\bar{y}_2)$= $E(\bar{y}_1)$, and therefore, $E(s)$. Otherwise, the difference between the expectations of both sides gives the variance of slope:

$$\sigma_s^2 = E(s^2) - E^2(s) = \frac{4}{n^2}[E(\bar{y}_2^2) - 2E(\bar{y}_2\bar{y}_1)] + E(\bar{y}_1^2) \quad (3)$$

As $E(\bar{y}_1^2) = E(\bar{y}_2^2)$, the above relationship is written in the following form:

$$\sigma_s^2 = \frac{8}{n^2}[E(\bar{y}_2^2) - E(\bar{y}_2\bar{y}_1)] \quad (4)$$

The final relationship is obtained as follows by substitution of the numerator of correlation coefficient into Eq. 4 and considering $\sigma_{y_2} = \sigma_{y_1} = \sigma/\sqrt{n}$:

$$\sigma_x^2 = \frac{8}{n^2}\frac{\sigma^2}{n}\left(1 - \rho_{\bar{y}_1\bar{y}_2}\right) \quad (5)$$

where $\rho_{\bar{y}_1\bar{y}_2}$ is the correlation coefficient between the two mean values in stochastic processes:

$$\rho_{y_1y_2} = \frac{E(\bar{y}_1\bar{y}_2) - E(\bar{y}_1)E(\bar{y}_2)}{\sigma_{\bar{y}_1}\sigma_{\bar{y}_2}} \quad (6)$$

Finally, the confidence limits (CL) of a standard normal probability distribution function (PDF) with zero mean and standard deviation are s_{cri}, then the confidence limits (CL) of the trend slope is given as

$$CL_{(1-\alpha)} = 0 \pm s_{cri} \times \sigma_s \quad (7)$$

where α is the significance level and σ_s is standard deviation of the slope:

$$\sigma_s = \frac{2\sqrt{2}}{n\sqrt{n}}\sigma\sqrt{1-\rho_{\bar{y}_1\bar{y}_2}} \quad (8)$$

The slope, s, of time series is statistically significant if it falls outside the confidence limits. Because all the odd-order moments of the slope variable are equal to zero, the PDF of slope follows a Gaussian PDF with zero mean and the standard deviation given in Eq. (8). More information can be found in Şen (2017).

2.2.2 *The mann-kendall test*

The non-parametric Mann-Kendall (MK) test, originally proposed by Kendall and Mann, is widely used to detect trends in hydro-meteorological time series due to its ability to handle non-normally distributed data and low sensitivity to outliers. The test assumes that the data are independent and randomly ordered, with no significant trend (null hypothesis H_0). The MK test involves two parameters: Z and β.

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S < 0 \end{cases} \quad (9)$$

$$S = \sum_{i=2}^{n}\sum_{j=1}^{i-1} \mathrm{sign}(x_i x_j) \quad (10)$$

$$\mathrm{sign}(x_i - x_j) = \begin{cases} -1 \text{ for } (x_i - x_j) < 0 \\ 0 \text{ for } (x_i - x_j) = 0 \\ 1 \text{ for } (x_i - x_j) > 0 \end{cases} \quad (11)$$

$$\mathrm{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{k-1}^{l} t_k(t_k-1)(2t_k+5)}{18} \quad (12)$$

To obtain the parameter β, which indicates the variation rate within the time series, the method proposed by Sen (1968) can be used.

$$\beta = \mathrm{Median}\left[\frac{x_i - x_i}{i-j}\right] \text{ for all } j < i \quad (13)$$

where x_i and x_j are data value at times *j* and *k*(*j*>*k*) respectively

2.2.3. *Linear Regression Analysis (LRA)*

This method constructs a one variable linear regression equation of the hydro meteorological variables, x and time, t. It is a simple and commonly used parametric method for detecting monotonic trend in time series (Kumar and Singh 2023). The advantage of parametric method is their simplicity. The LRA method has been widely used for detecting long-term variation trends of hydrological and meteorological variables. The regression coefficients can reflect the rate of change in the hydro meteorological variables; their positive and negative values indicate an increase or decrease in the variables, respectively. The significance of the regression coefficient can be determined by the t-test.

3. Results and discussion

The study analysed the trend in rainfall time series of a specific study area using daily rainfall data from 4 rain gauge stations over the KRB.

3.1. *Long-term mean rainfall of KRB*

Fig. 4 displays the linear plots of annual rainfall amount over different stations in KRB. The precipitation in the region is mostly concentrated in monsoon season (June to September), which account for more than 80% of the total annual precipitation. Figs. 5 (a-d) presents a time series of the seasonal rainfall trend estimated through linear regression analysis. Table 2 shows the descriptive statistics for annual and seasonal precipitation for different stations over the KRB for the study period, indicating that all stations had an increasing trend in precipitation.

3.2 *Spatiotemporal variation of annual and seasonal precipitation trend based on MK and ITA test*

The spatiotemporal variation of annual trend based on MK and ITA test is presented in Fig. 6. The result showed that 3 out 4 station indicates a decreasing trend in annual rainfall which are located in mid Himalayan and Tarai zone of study area. The station located in high hills *i.e.*, Mukteshwar showed increasing trend. Both MK and ITA test showed similar results for all the station. Fig. 7 and figure 8 represents the seasonal trend using MK and

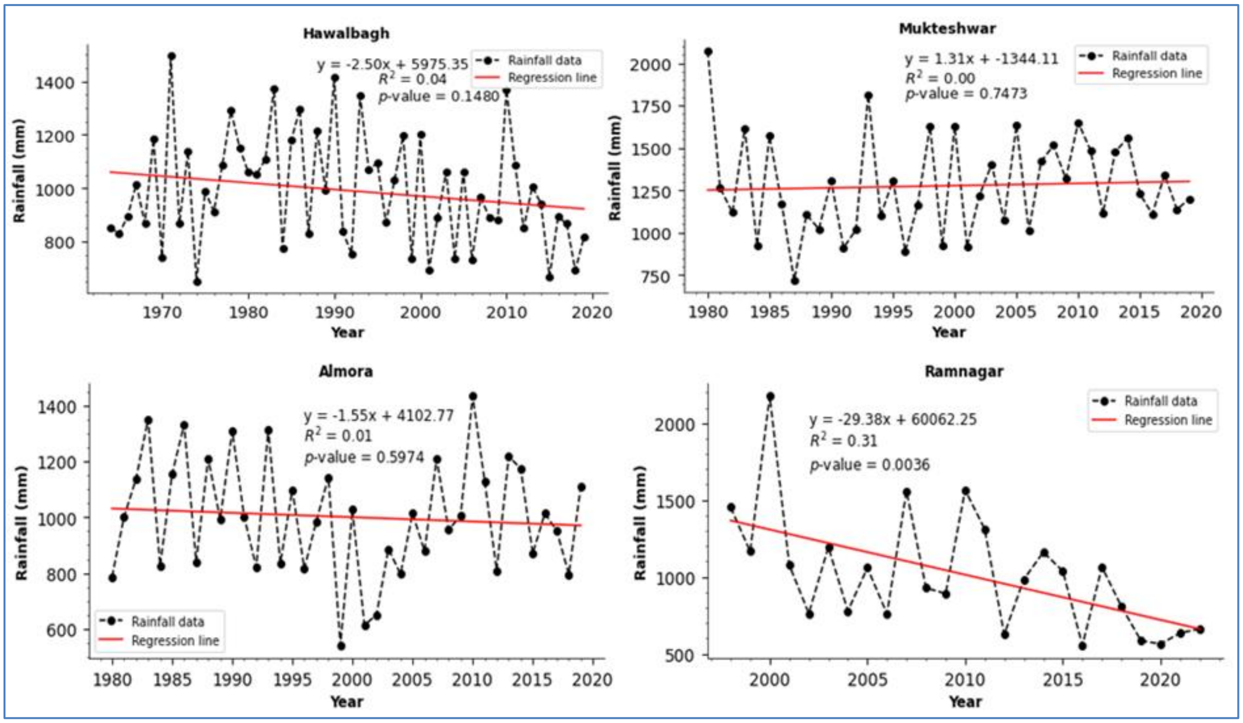


Fig. 4. Linear plots of annual precipitation amount over different station in the Kosi River Basin

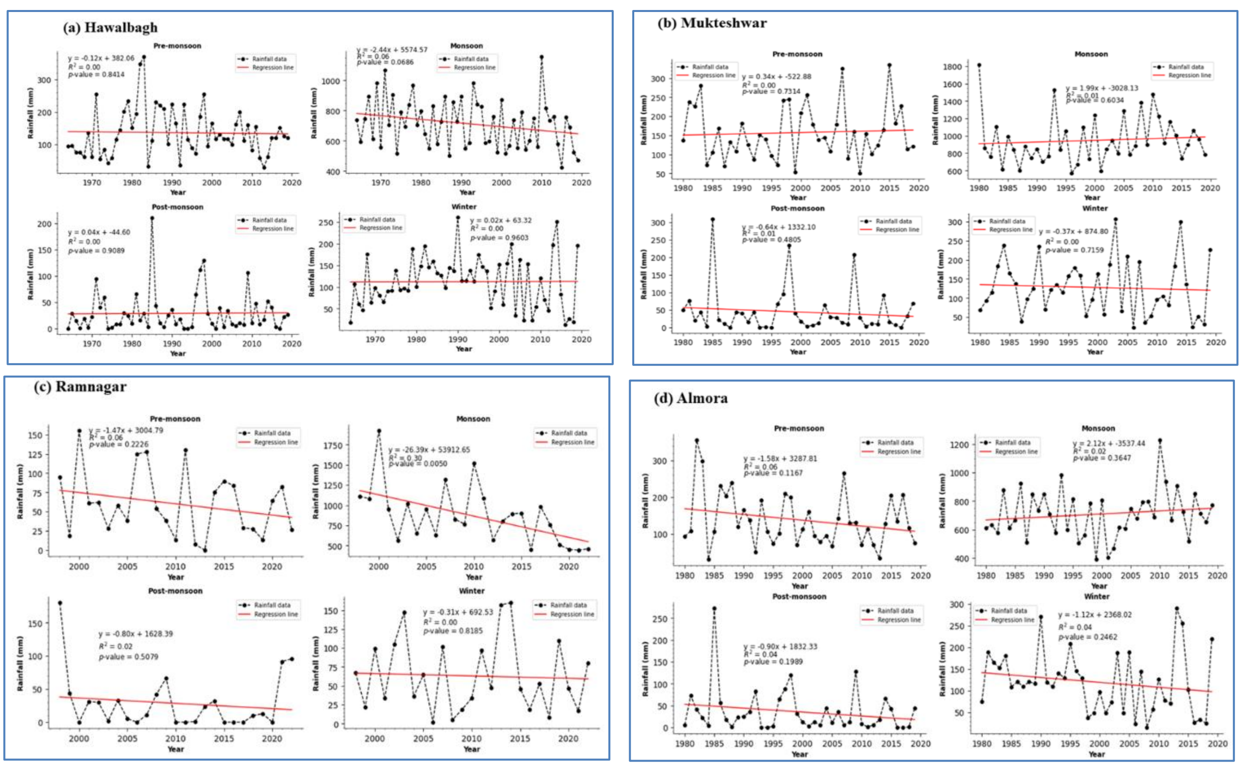


Fig. 5. Linear plots of seasonal precipitation over different station in the Kosi River Basin: (a) Hawalbagh, (b) Mukteshwar, (c) Ramnagar, and (d) Almora.

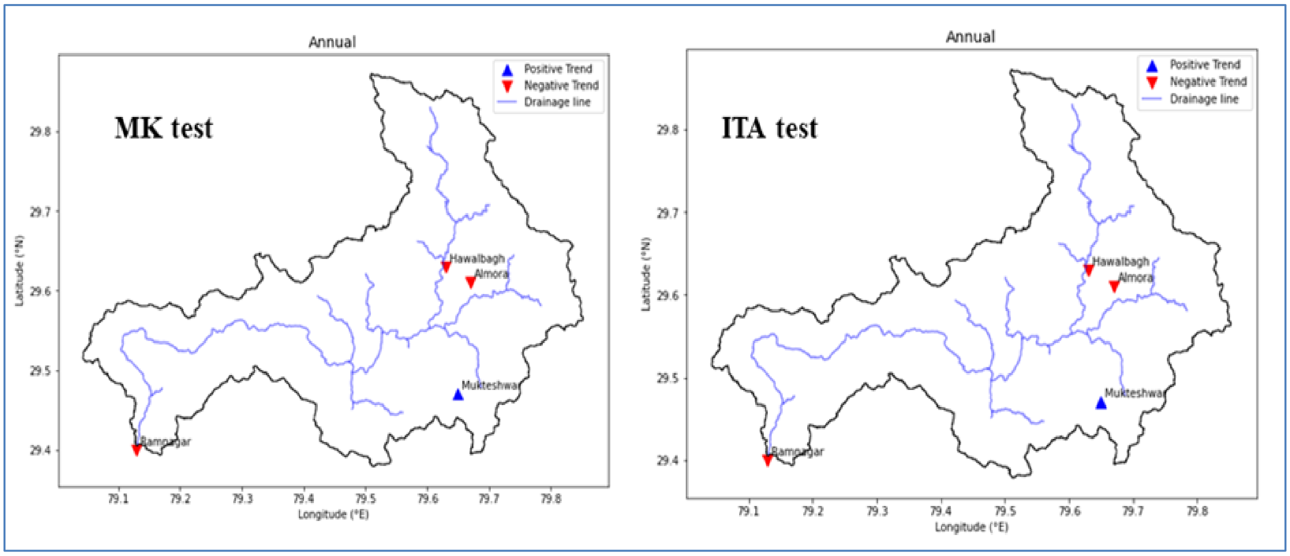


Fig.6. Spatio-temporal variation of annual precipitation trend at different station in KRB using MK and ITA test

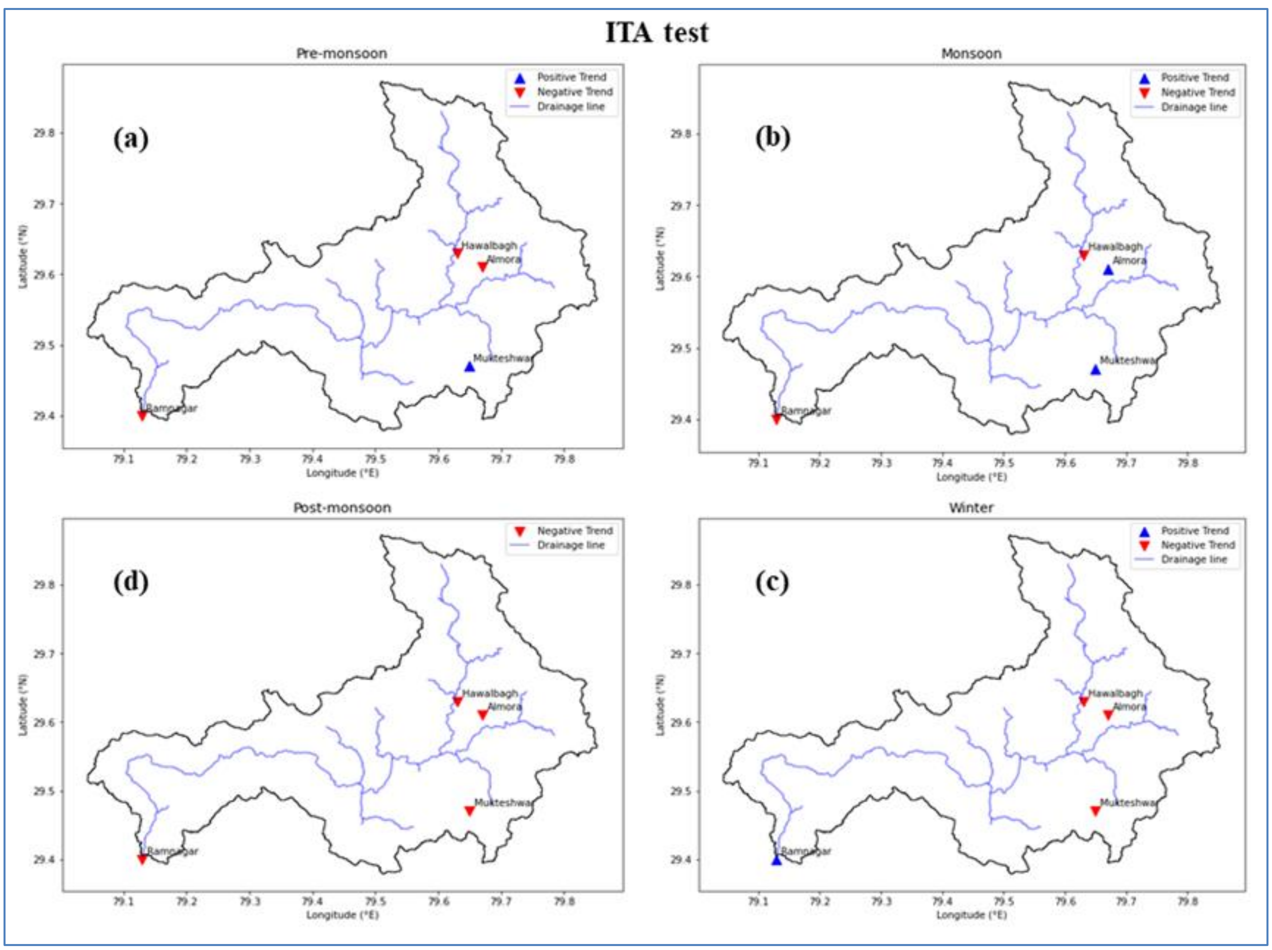


Fig. 7. Spatio-temporal variation of seasonal precipitation trend at different station in KRB using ITA test

TABLE 2

Descriptive statistics of seasonal and annual precipitation at different stations

Season		Hawalbagh 1964-2019	Almora 1980-2019	Mukteshwar 1980-2019	Ramnagar 1998-2021
Annual	Mean	991.34	1000.97	1276.79	1030.81
	Std	208.42	210.68	191.49	384.78
	Min	650.80	541.30	718.30	554.00
	Max	1496.00	1434.00	2070.00	2176.00
	CV	0.21	0.21	0.15	0.37
Pre-monsoon	Mean	135.86	138.04	157.19	61.53
	Std	73.72	73.07	70.98	42.96
	Min	29.00	31.00	50.40	0.00
	Max	369.50	355.60	335.40	155.00
	CV	0.54	0.53	0.45	0.70
Monsoon	Mean	714.22	708.32	947.51	881.27
	Std	162.35	168.61	274.46	354.89
	Min	424.20	391.20	570.20	443.40
	Max	1156.50	1228.20	1816.70	1922.00
	CV	0.23	0.24	0.29	0.40
Post-monsoon	Mean	28.97	35.44	44.20	25.63
	Std	38.35	50.63	65.57	40.65
	Min	0.00	0.00	0.00	0.00
	Max	210.40	272.20	308.30	180.00
	CV	1.32	1.43	1.48	1.59
Winter	Mean	112.27	119.95	127.89	62.37
	Std	58.87	70.03	73.54	48.55
	Min	13.00	15.60	23.00	2.00
	Max	261.10	290.00	306.60	159.20
	CV	0.52	0.58	0.58	0.78

ITA test respectively. For pre-monsoon season Hawalbagh, Almora, and Ramnagar showed decreasing trend while Mukteshwar showed increasing trend using ITA test. For the same season, Hwalbagh and Ramnagar showed decreasing trend while Almora and Mukteshwar showed increasing trend based on MK test. Similarly, for monsoon season Hwalbagh and Ramnagar showed decreasing trend while Almora and Mukteshwar showed increasing trend using ITA test while Hwalbagh and Almora showed decreasing trend while Ramnagar and Mukteshwar showed increasing trend based on MK test. Using ITA test for post-monsoon all stations showed decreasing trend while using MK test all station showed decreasing trend except Mukteshwar. During winter season except Ramnagar all stations showed decreasing trend using ITA test while all station showed decreasing trend except Almora using MK test. This study has revealed some discrepancies in the results obtained from the ITA method and the Mann-Kendall test, highlighting some advantages of Şen's method over the MK trend test.

3.3. *Result of ITA*

Fig. 9 displays the results of ITA at an annual scale, for all stations over the KRB. Further, Figure 9 shows the

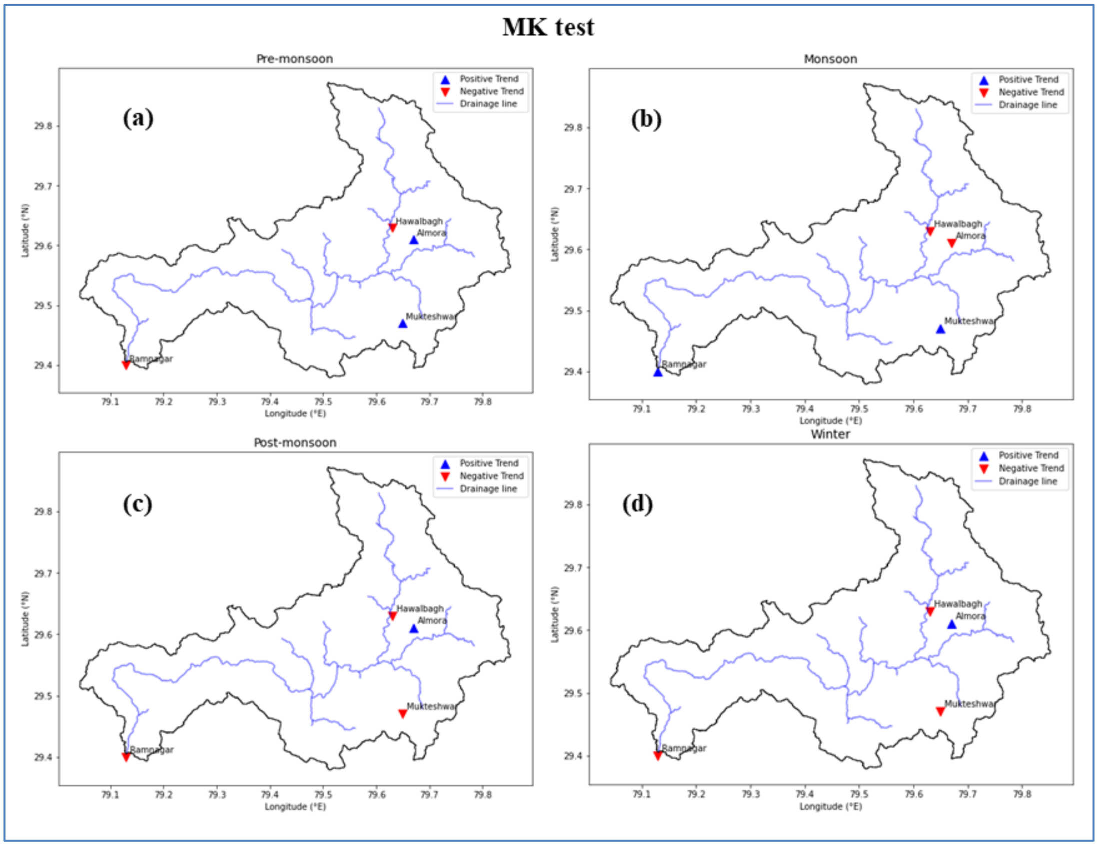


Fig. 8. Spatio-temporal variation of seasonal precipitation trend at different station in KRB using MK test

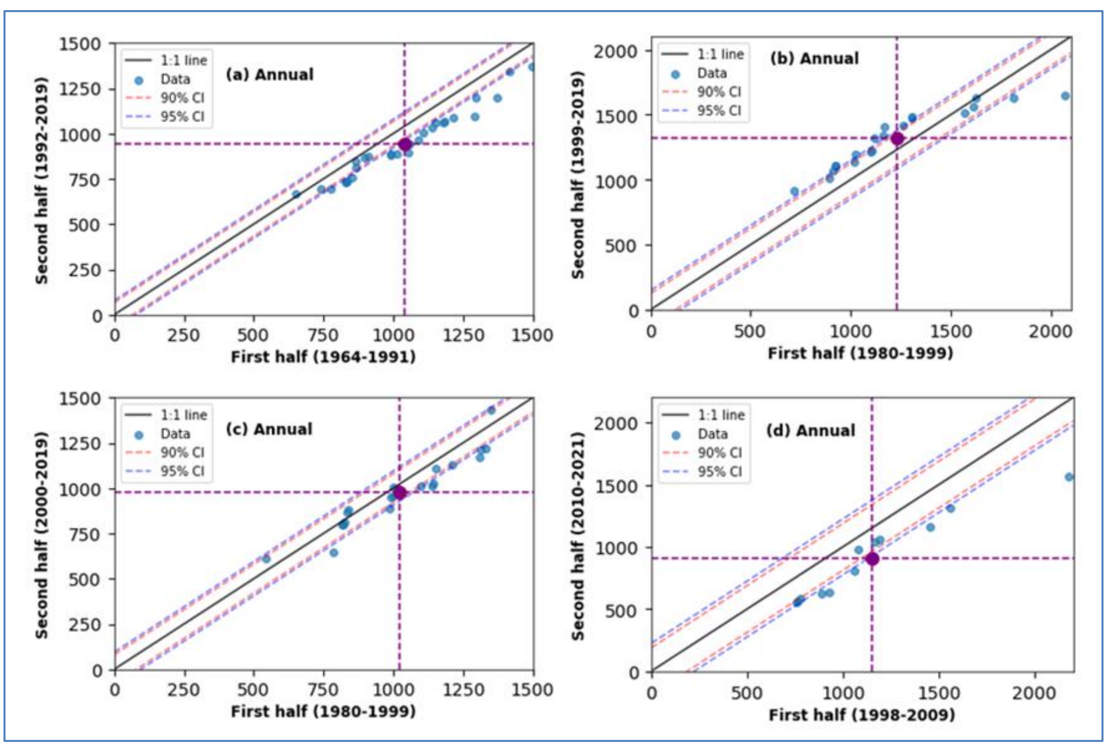


Fig. 9. Graphical results of ITA for annual precipitation at a) Hawalbagh b) Mukteshwar c) Almora and d) Ramnagar

TABLE 3

Results for ITA test (Slope s) for annual and seasonal rainfall in KRB

Season	Station	Slope (s)	95% Threshold	Significant at 95%?	Trend Direction
Annual	Hawalbagh	-3.44	±0.36	Yes	Decreasing
	Almora	-2.38	±0.99	Yes	Decreasing
	Mukteshwar	4.49	±1.62	Yes	Increasing
	Ramnagar	-19.8	±3.53	Yes	Decreasing
Pre-monsoon	Hawalbagh	-0.85	±0.17	Yes	Decreasing
	Almora	-1.64	±0.27	Yes	Decreasing
	Mukteshwar	1.05	±0.32	Yes	Increasing
	Ramnagar	-1.7	±0.50	Yes	Decreasing
Monsoon	Hawalbagh	-2.24	±0.41	Yes	Decreasing
	Almora	2.01	±0.85	Yes	Increasing
	Mukteshwar	4.68	±1.53	Yes	Increasing
	Ramnagar	-16.84	±2.20	Yes	Decreasing
Post-monsoon	Hawalbagh	-0.01	±0.15	No	Decreasing
	Almora	-1.27	±0.11	Yes	Decreasing
	Mukteshwar	-1.13	±0.29	Yes	Decreasing
	Ramnagar	-1.89	±0.28	Yes	Decreasing
Winter	Hawalbagh	-0.33	±0.15	Yes	Decreasing
	Almora	-1.4	±0.37	Yes	Decreasing
	Mukteshwar	-0.12	±0.23	No	Decreasing
	Ramnagar	0.63	±0.52	Yes	Increasing

graphical representations of the ITA results for all 4 stations. The visual display provides primary insights into observing changes i.e. increasing, decreasing or no trend for different stations. In the Figure 9, a confidence bounds of 0.10 has been added as the distance from the line 1:1 to visualize the distance of the points from the no-trend line but without any statistical meaning (Caloiero *et al*., 2011). Rainfall points located between the ±10% lines indicates insignificant variations and may be attributed to natural variability or randomness. Points generally located below the −10% line indicate a downward trend while points located above the +10% indicate upward trend. Hawalbagh, Almora and Ramnagar showed decreasing trend while Mukteshwar showed increasing trend as depicted from Figure 9 (a-d). The result found in this studies supported by different studies such as; Kisi (2015) showed that ITA's graphical plots can reveal more hidden trends, especially in pan evaporation, than MK and SR tests. Dabanlı *et al*. (2016) found ITA to be more practical than the MK test for identifying trends in hydro-meteorological data. Wu and Qian (2017) further highlighted that ITA offers significant advantages over both linear regression and MK tests in detecting trends.

The results indicate that there are obvious regional differences in the variation in annual precipitation. The north-eastern and south-western part of the study area has a decreasing trend, while the south-eastern part has an increasing trend. The annual variation trend of total precipitation obtained using the ITA method is consistent with that obtained using other methods in previous studies (Wang *et al*.2014).

3.4. *Comparison of MK and ITA test*

To compare the two trend analysis methods, values of ITA and Z values of MK of all annual and seasonal series were given in Table 3 and Table 4 respectively. This study demonstrates that there is some agreement between the outcomes obtained by conventional trend

TABLE 4

Results of Theil-Sen approach (TSA) and Mann-Kendall (MK) test of seasonal and annual rainfall in KRB

Season	Station	TSA (Slope)	Z Value	p Value	Significant Trend?	Trend Direction
Annual	Hawalbagh	-2.58	-1.39	0.161	No	Decreasing
	Almora	-0.97	-0.47	0.63	No	Decreasing
	Mukteshwar	3.11	0.73	0.46	No	Increasing
	Ramnagar	-25.86	-2.6	0.009	Yes	Decreasing
Pre-monsoon	Hawalbagh	0.18	0.3	0.76	No	Increasing
	Almora	-1.14	-1.08	0.27	No	Decreasing
	Mukteshwar	0.34	0.29	0.77	No	Increasing
	Ramnagar	-1.28	-0.96	0.33	No	Decreasing
Monsoon	Hawalbagh	-2.82	-1.95	0.05	Borderline	Decreasing
	Almora	2.07	0.82	0.4	No	Increasing
	Mukteshwar	4.19	1.29	0.19	No	Increasing
	Ramnagar	-23.84	-2.75	0.005	Yes	Decreasing
Post-monsoon	Hawalbagh	0.05	0.57	0.56	No	Increasing
	Almora	-0.37	-1.17	0.23	No	Decreasing
	Mukteshwar	-0.29	-0.8	0.42	No	Decreasing
	Ramnagar	-0.26	-1.26	0.2	No	Decreasing
Winter	Hawalbagh	0.23	0.35	0.72	No	Increasing
	Almora	-1.93	-1.85	0.06	No	Decreasing
	Mukteshwar	-0.53	-0.61	0.53	No	Decreasing
	Ramnagar	-0.32	-0.29	0.76	No	Decreasing

tests (MK) and non-traditional (ITA) test. This is consistent with prior research by Haktanir and Citakoglu (2014) and Sonali and Kumar (2013). Nevertheless, the IT test was found to be more responsive to variations in annual rainfall events and demonstrated a significant trend in the rainfall, in contrast to otherstatistical trend tests that revealed no significant trend. Kisi and Ay (2014) obtained similar results while assessing trends in the water-quality parameters of Kizilirmak River in Turkey. It is important to note that the ITA test has several benefits, including its sensitivity to data variations and the lack of any pre-assumptions (such as serial correlation or skewness). It indicates that the ITA method can be used as a simplemethod to visually detect the trend, and particularly to find the trend of high, medium and low values.

3.5. *Discussion and comparison of trend analysis methods*

In this study, 20 seasonal and annual rainfall time series were examined using both the Mann-Kendall (MK) and Innovative Trend Analysis (ITA) methods at a 5% significance level. As detailed in Table 3 and 4, the MK test detected significant positive or negative trends in only 2 series, whereas the ITA method identified significant trends in 18 series-demonstrating its substantially higher sensitivity. Importantly, all significant trends revealed by the MK test were also captured by ITA, which further uncovered numerous hidden trends overlooked by MK. This enhanced detection capability makes ITA particularly valuable for accurately characterizing subtle variations in rainfall trends within the study region. Moreover, the ITA method offers the advantage of graphical visualization on a Cartesian coordinate system, enabling intuitive visual interpretation alongside quantitative analysis (Şen, 2017).

Its simplicity, coupled with independence from assumptions regarding data distribution, serial correlation, or seasonal cycles, further underscores its robustness and practicality in hydro-meteorological studies (Cui *et al.*, 2017; Şen, 2017; Zhou *et al.*, 2018). Overall, the findings firmly establish ITA as a superior and more comprehensive tool than the MK test for detecting both overt and hidden trends in rainfall data across the region.

4. Conclusions

The ITA method was used in this study to analyse the changes in annual and seasonal rainfall in the Kosi River Basin in Uttarakhand, India. To confirm the accuracy of the ITA, two other methods were also employed, namely linear regression analysis and the Mann-Kendall test, to assess the trends. The ITA approach provides a visual representation of the results and enables trends in different categories to be easily identified. The results showed significant negative trends of annual rainfall for three stations using both the test. The ITA method was found to be more reliable than the MK method. It produced useful scientific information, with the identification of monthly shift and trend behaviour of rainfall data at different stations. Some stations showed an increasing trend and others showed decreasing behaviour. The study's findings could aid water managers and local stakeholders in understanding the threats and vulnerabilities associated with climate change and anthropogenic parameters in the study region.

Data Availability

The authors confirm that the data supporting the findings of this study are available within the article.

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