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Statistical analysis of climate change over Hanumangarh district

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ABSTRACT

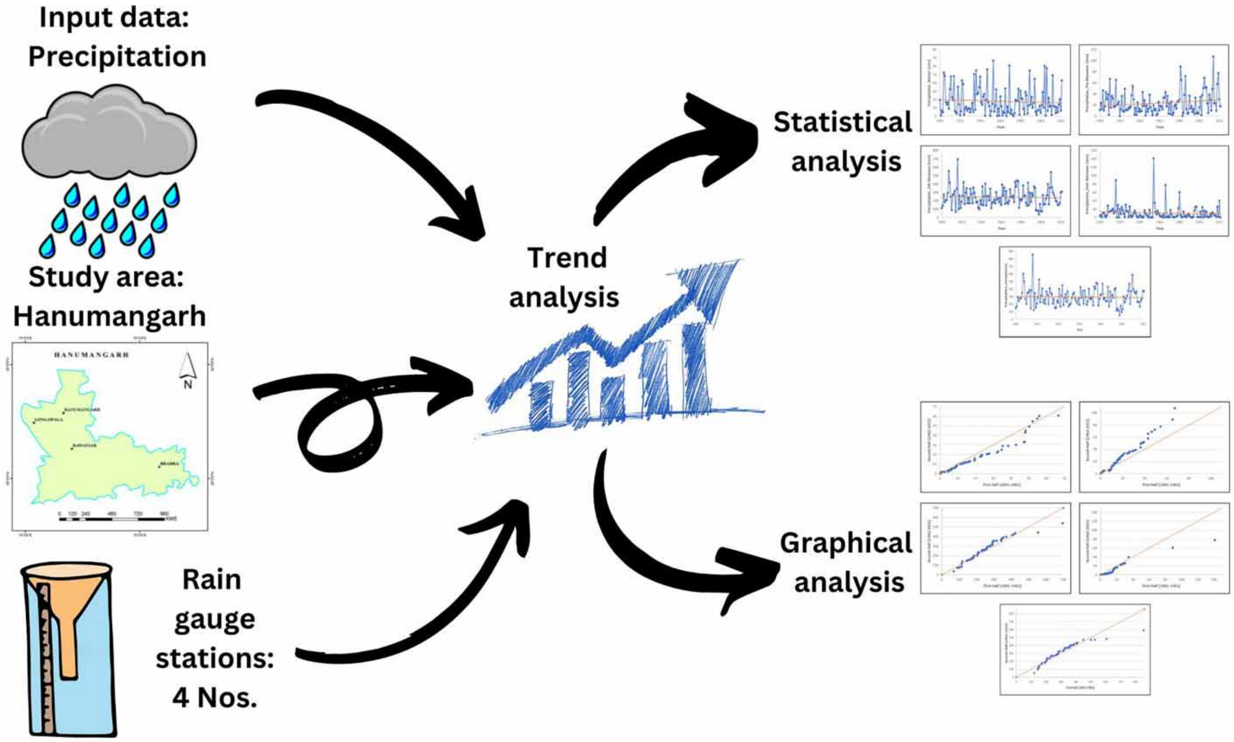
Precipitation is the most critical element of the hydrological cycle that might influence the frequency of floods or drought. Therefore, for drought and flood forecasting, knowing the precipitation pattern and its trend is mandatory. The research aims to estimate the monthly, seasonal, and annual precipitation trend using statistical (Mann Kendall test & Sen's Slope estimator) and graphical (Innovative Trend Analysis method) for the Hanumangarh district of N-E Rajasthan. The mean monthly precipitation data were gathered from the India-WRIS from 1901 to 2022 (122 years). Seasonal and annual precipitation trend variations were examined by statistical methods and compared with the graphical method. The study results conclude that precipitation trends showed variability for the SW monsoon season from the graphical to the statistical method. For the SW monsoon season, the decreasing trend was seen using statistical methods. In contrast, the graphical method revealed an increasing trend. During the annual precipitation, increasing trends were seen using statistical and graphical methods. It is found that the ITA method is more efficient in finding trends because it does not assume any assumptions like that of the MK test. This study will help water resources engineers and local people with sustainable management, planning, and development of water resources in the Hanumangarh district.

Key words: graphical method, Hanumangarh district, precipitation, statistical method, trend analysis

HIGHLIGHTS

- Trends in seasonal and annual precipitation time series are assessed using both statistical and graphical methods and then results are compared.
- The results of the statistical method are well-matched with the graphical method.
- The ITA method is easier to apply for finding trends.
- The ITA method is more accurate because it does not consider any assumptions.

GRAPHICAL ABSTRACT



INTRODUCTION

In recent years, the earth's climate change is a major issue because it is not only increasing the mean temperature of a particular region; it also disturbs the occurrence and severity of various hydrological events such as floods and drought (Tirkey *et al.* 2021). An increase in greenhouse gases (GHGs), owing to anthropological activities, has exacerbated the earth's climate system and led to significant climate change over the world (Solomon *et al.* 2007). Due to global system variation, climatic variables are continuously changing and may have a notable impact on regional water resources (Nistor *et al.* 2020; Azamathulla 2013). Currently, the rising climate is resulting in higher mean temperatures and less mean precipitation (Chattopadhyay & Hulme 1997; Parry *et al.* 2004). Climate change hurts human beings, regional agriculture, water resources, and food security (Goyal & Surampalli 2018). As per Shaver *et al.* (2000), due to climate change earth's weather is changed. As a result, the regional climate is also changed, particularly in terms of temperature and precipitation (Shan *et al.* 2015).

Climate change also affects the long-term trend of precipitation which has led to various hazards, i.e., flood, drought, etc. (Surendran *et al.* 2017; Azamathulla *et al.* 2011). Precipitation is a vital meteorological variable because its intensity and amount can affect the frequency of a drought or flood (Shaikh *et al.* 2022). In this context, arid or semi-arid regions are given higher importance because precipitation occurrences are very irregular, insufficient, and unpredictable (Das *et al.* 2020). Groundwater and surface waters could be adversely affected by low precipitation and high temperatures (Azamathulla & Jarrett 2013; Azamathulla *et al.* 2008). According to Aher & Yadav (2021), precipitation is a crucial element of the hydrological cycle, and variations in its intensity across time can affect the agriculture sector. Dhar *et al.* (1979) noted that there is a significant fluctuation in precipitation distribution in India from one region to another, from time to time, as well as year to year in the same location.

Precipitation data analysis provides valuable information that can be utilized to enhance water management practices, protect the environment, schedule agricultural production, or effects on a region's economic development (Jain *et al.* 2013). In India and East Asia, extremely wet or dry events throughout the monsoon season have increased (Nistor *et al.* 2020). Therefore, the assessment of precipitation trends is crucial for better planning, development, and management of water resources. The procedure of analyzing previous and present trends to forecast future trends is known as trend analysis (Jain *et al.* 2013). Precipitation trend analysis helps in a clearer understanding of issues related to floods, droughts, and the availability of water for future climate scenarios. Precipitation trend analysis assists in the sustainable management of water resources. Hence, to take necessary precautions to prevent future drought and flood-like conditions, it is crucial to understand the precipitation characteristics, the magnitude of change, the nature of the trend, and variations in monthly, seasonal, and annual precipitation. Additionally, it is significant from a socioeconomic perspective (Aher & Yadav 2021).

Various researchers from different disciplines have studied the effects of precipitation changes (Umar *et al.* 2022; Wang *et al.* 2020; Mehta *et al.* 2022). Numerous scientists throughout the world have studied and examined the precipitation trends in recent years (Thomas & Prasannakumar 2016; Caloiero 2020; Aher & Yadav 2021; Bouklikha *et al.* 2021; Mehta & Yadav 2021a, 2021b, 2022a, 2022b; Seenu & Jayakumar 2021; Pastagia & Mehta 2022). Thomas & Prasannakumar (2016), Meshram *et al.* (2018), Das *et al.* (2020), Aher & Yadav (2021), Mehta & Yadav (2021a, 2021b, 2022a, 2022b), and Halder *et al.* (2022), Zakwan & Ara (2019), and Perera *et al.* (2020) used various statistical methods to detect trends in precipitation time series. Broadly, the MK test (Mann 1945) is adopted for trend detection along with the SS estimator (Sen 1968). Kumar *et al.* (2010) assessed the long-term trends of precipitation in India by applying statistical methods (MK test and SS estimator). Yildirim & Rahman (2022) applied statistical methods (MK test and SS estimator) to detect precipitation trends over 45 stations located in Australia between Victoria and New South Wales states. Jain & Kumar (2012) also carried out trend analysis of precipitation and temperature using statistical methods (MK test and SS estimator) across India. However, the MK test required that the precipitation time series should be free from the effects of autocorrelation.

To avoid these problems in precipitation time series, Şen (2012) proposed a new graphical (ITA method). Using the ITA method, trend analysis of precipitation is carried out by various researchers (Caloiero *et al.* 2018; Caloiero 2020; Güçlü *et al.* 2020; Marak *et al.* 2020; Aher & Yadav 2021; Bouklikha *et al.* 2021; Pastagia & Mehta 2022; Zakwan 2021; Zakwan & Niazkar 2022). Pastagia & Mehta (2022) used the graphical (ITA method) to find seasonal and annual trends of precipitation over the Rajsamand district of Rajasthan and revealed that the ITA method is simple, effective, as well as very useful for finding trends in precipitation time series. Zakwan *et al.* (2022) employed the MK test, the ITA method, and the Revised Innovative Trend Analysis (RITA) method to identify the trend in discharge and sediment load at two gauging sites of the lower Drava River Basin and noticed that the ITA method provided greater visualization of the trend of the different magnitude of discharges and sediment load as compared to the MK test. Achite *et al.* (2022) used and compared the results of the statistical method (Theil-Sen (TS) estimator and MK test) with the results of the graphical method (ITA) and found that the results of the statistical method are slightly different from the results of the graphical method. Zena Besha *et al.* (2022) adopted the MK test and ITA method to find long-term trends of precipitation. They also compared the results of both methods and observed that the ITA method allows some advantages as compared to the MK test. Sonali & Kumar (2013) used 11 methods to estimate changes in temperature in India and found that, in comparison to results obtained from other methods, the result of the ITA method matched the trends well.

Thus, the objective of the research is given as follows:

- To determine the long-term trends of precipitation for monthly, annual, and seasonal times series using statistical methods (MK test) and graphical methods (ITA).
- To estimate the magnitude of the trend using the SS estimator test.
- To compare precipitation trends between statistical and graphical methods.

The comparative trend analysis of precipitation results attained from the statistical method with the results of the graphical method is an innovation in this research work.

Study area

In this research, the Hanumangarh district of North-East Rajasthan is selected as the study area. The district is situated among north latitudes of 28°46′25.0″ to 29°57′26.90″ and east longitudes of 73°47′41.74″ to 75°31′58.70″. The district's geographical area is 9,929.3 km^2 which is around 2.90% of the state. According to the census 2011, the district's population is 1,774,692. However, the district's population density is 184 persons/km^2. It was split from Ganganagar district on 12 July 1994, and before that it was one of the Tehsil of Sri Ganganagar districts.

The district's average annual precipitation is 333.27 mm. The climate of the district is varying from arid to semi-arid. The district receives most of the precipitation during the SW monsoon season which is from June to the middle of September. The cold season is between December and February, while pre-monsoon is the season from March to June. The post-monsoon season is between October and the end of November. The mean maximum daily temperature of the district is varying from 20.5 to 42.2 °C from January to June, respectively, whereas the mean minimum daily temperature is 4.7 °C during January and 28.1 °C during July. The recurrence interval of mild or normal drought in the district is once in 2 years. The most extreme drought occurred once in the district in 1969 at Sangaria. Generally, the district contains yellow-brown soil, black soil, and red loam type of soil. The location of the Hanumangarh district is displayed in Figure 1.

Data collection

For effective trend analysis, adequate and reliable periods of precipitation data need to be considered. The precipitation record of a shorter period would not give reliable results. The longer the period of record, the trend analysis will give better, more reliable, and more accurate results. According to the Indian Meteorological Department (IMD), India is divided into 36 sub-divisions. Precipitation data for the Hanumangarh district (4 rain gauge stations) was collected through IWRIS-Indian Water Resource Information (indiawris.gov.in). The mean monthly data of precipitation is collected from 1901 to 2022 (122 years).

METHODOLOGY

For the precipitation trend analysis, four seasons were taken into consideration according to IMD. i.e., winter from January to February, pre-monsoon from March to May, SW monsoon from June to September, and post-monsoon from October to December. Analysis of monthly, seasonal, and annual precipitation time series were carried out for the years 1901–2022 (122 years).

In the current research, the precipitation trend is assessed using three different methods. Firstly, the statistical (MK test) is applied to detect the presence of rising or falling trends. After that, to find the proper slope of a linear trend, the SS estimator test is used. In the last, a graphical (ITA method) is adopted to find trends in precipitation data with or without considering

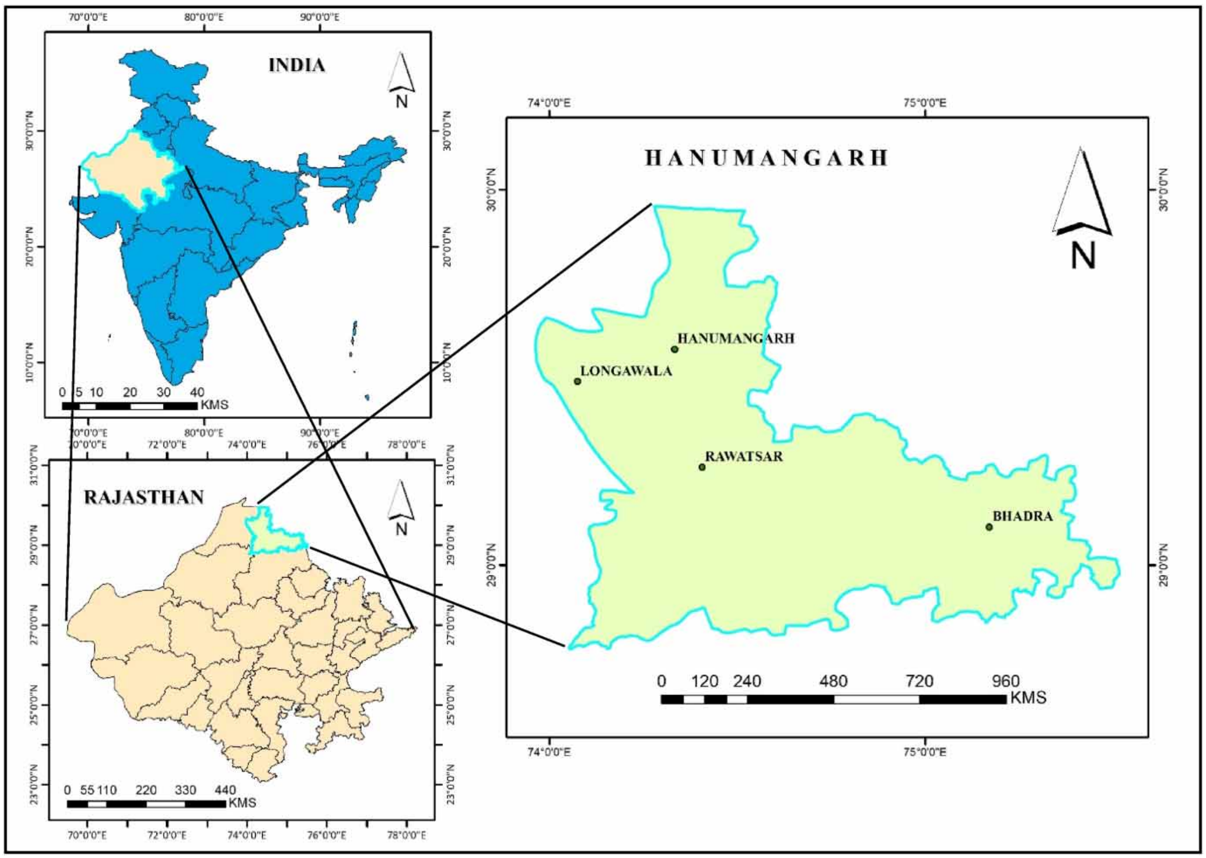


Figure 1 | Location map of Hanumangarh district.

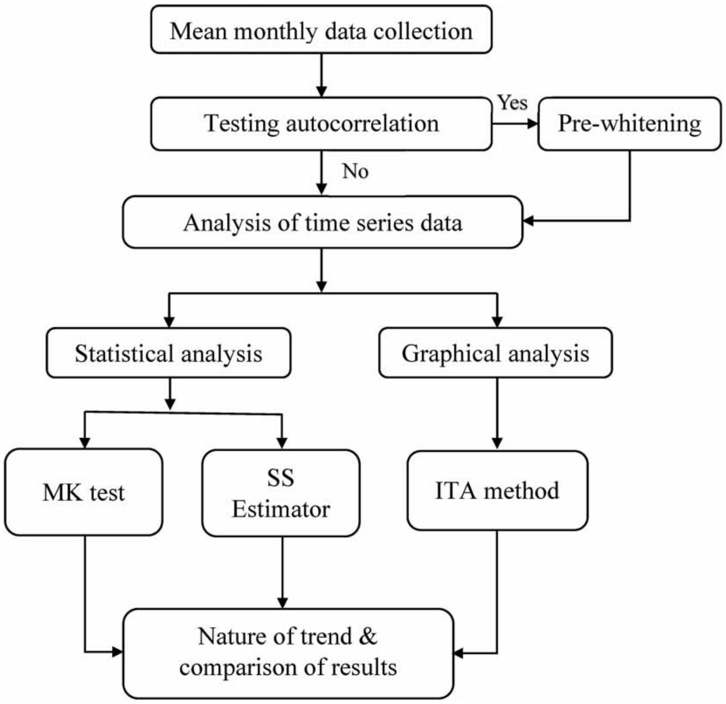


Figure 2 | Outline of methodology.

the effects of autocorrelation, size of the dataset, and distributions. Figure 2 shows the outline of the methodology adopted for the analysis.

Testing autocorrelation

The effect of autocorrelation is a major problem in the trend analysis of precipitation data (Halder *et al.* 2022). The results of trend analysis are underestimated if any negative or positive autocorrelation exists in the data (Hamed & Rao 1998). Even if there is no trend at all, non-parametric tests show a significant trend if there is a positive autocorrelation and vice versa (Halder *et al.* 2022). Thus, it is necessary to eliminate the existence of autocorrelation from the precipitation time series. The lag-1 autocorrelation coefficient (r_1) is used at a 5% significance level to check the existence of autocorrelation in the precipitation time series. It was estimated using the following equations:

$$r_1 = \frac{\frac{1}{n-1}\sum_{\text{i}=1}^{n-1}[X_i - E_{(x_i)}] \times [X_{(i+1)} - E_{(x_i)}]}{\frac{1}{n}\sum_{\text{i}=1}^{n} X_i - E(X_i)2} \quad (1)$$

$$\sum(x_i) = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (2)$$

where $\sum x_i$ indicates the average of sample data and n indicates sample size.

To check the existence of autocorrelation, the (r_1) is checked at a 95% confidence interval using the following equation:

$$r_1[95\%] = \frac{-1 \pm 1.96\sqrt{n-2}}{n-1} \quad (3)$$

The data are considered serially independent when r_1 is concentrated within the confidence interval; otherwise, a pre-whitening approach is used to eliminate autocorrelation when there is a significant correlation (Yue *et al.* 2002).

MK test

In this research, the MK test is adopted to determine trends over precipitation time series values at a 5% significant level. It is one of the consistently used statistical (non-parametric rank-based) tests (Mann 1945). It is usually applied to discover trends in the precipitation time series, whether it is linear or not (Hamed 2008). XLSTAT 2022 was used to conduct the MK test.

The equation gives the MK test statistic (S):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sign}\ (x_j - x_k) \tag{4}$$

where x_j and x_k represent precipitation time series data (years) and n represents the length of data. The value of S reveals a decreasing trend when it is negative and vice versa. The sign function is given as:

$$\text{sign}\ (x_j - x_k) \begin{cases} 1, & (x_j > x_k) \\ 0, & (x_j = x_k) \\ -1, & (x_j < x_k) \end{cases} \tag{5}$$

To calculate the variance (ρ), the following equation is used:

$$\rho = \frac{S\ (n-1)\ (2n+5) - \sum_{i=1}^{q} t\ (t-1)\ (2t+5)}{18} \tag{6}$$

where q represents the tied group and t means the number of observations. The following equation is applied to determine the standard statistic (Z) value:

$$Z_{\text{MK}} = \begin{cases} \dfrac{s-1}{\sqrt{\rho}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \dfrac{s+1}{\sqrt{\rho}}, & \text{if } S < 0 \end{cases} \tag{7}$$

To determine whether a significant trend is present or not, the predicted Z_{MK} value is compared to a typical normal distribution using two-tailed significant levels. The null hypothesis (H_0) is accepted at a 5% significant level. There is an increasing or positive trend in the data, if the value of Z_{MK} is more than zero ($Z_{\text{MK}} > 0$). Similarly, when the Z_{MK} value is less than zero ($Z_{\text{MK}} < 0$), it shows a decreasing or negative trend exists in the data. However, if Z_{MK} is equal to zero ($Z_{\text{MK}} = 0$), the trend is interpreted as no trend.

SS estimator method

The MK test is not able to compute the magnitude of trend changes. Therefore, the SS estimator (Sen 1968) is applied to calculate the slope of a linear trend in the precipitation data. It can be evaluated by applying Equation (8):

$$\beta_i = \text{median} \frac{x_i - x_j}{(i-j)},\ j < i \tag{8}$$

where β_i means slope, x means variables, i and j are indices. If $\beta_i > 0$, it indicates upward trends in a time series data. Otherwise, the data series shows a downward trend during the period, when $\beta_i < 0$.

ITA method

The ITA method (graphical method), used to find trends in hydro-meteorological variables, was developed by Şen (2012). The main benefit of the ITA method compared to other trend analysis methods is that it is free from all assumptions like autocorrelation, normality, and number of observations. To assess trends in the precipitation data, firstly, the data of a precipitation time series are separated into two equivalent parts and then they are independently ranked in ascending (or descending) order (Wu & Qian 2017). Further, by plotting the 1:1 (45°) axis of no trend, the diagram is divided into two different triangles. The area above the 1:1 line is called an upper triangle and the area below the 1:1 line is called a lower triangle. When the data are found in the upper triangle portion, they reveal an increasing trend (Şen 2012). Whereas it shows a decreasing trend when the data are found in a lower triangle (Aher & Yadav 2021). The scatter diagram is split into three parts, i.e., low, medium, and high, to make a detailed interpretation (Pastagia & Mehta 2022).

RESULTS AND DISCUSSION

In this research, the monthly, seasonal, and annual trends of precipitation are calculated using statistical methods (MK test and SS estimator). The graphical method (ITA) is also applied for annual and seasonal precipitation for the period 1901–2022 (122 years). The statistical method (MK test and SS estimator) results are compared to those obtained from the graphical (ITA method).

Autocorrelation in precipitation time series

The seasonal and annual precipitation time series of the Hanumangarh district were checked by applying a lag-1 autocorrelation coefficient (r_1) at a 5% significance level. By performing the test, −0.06981, 0.201715, 0.147105, 0.029664, and 0.14013 values of autocorrelation coefficient were obtained for the winter, pre-monsoon, SW monsoon, post-monsoon, and annual season, respectively. The results revealed that neither seasonal nor annual precipitation series showed any significant autocorrelation since their value was found within the allowable limit ($-1.17818 < r_1 > 1.17818$). Therefore, the MK test is applied directly to the precipitation time series without any pre-whitening.

Precipitation trend analysis using the statistical method (MK test and SS estimator)

The long-term trend of precipitation for the Hanumangarh district is assessed using the MK test and SS estimator method and the results of the test are shown in Table 1. The results of the MK test revealed a positive trend for pre-monsoon and annual seasons with values of Z_{MK} (0.06 and 0.014), respectively. Whereas it shows a negative trend for winter, SW monsoon, and post-monsoon season with Z_{MK} values (−0.044, −0.006, and −0.097), respectively. The results of the MK test also show that most of the months are observed with a positive trend followed by a negative trend. Out of all 12 months, 8 months (February, March, April, May, June, July, September, and November) are observed with positive trends with values of Z_{MK} (0.008, 0.002,

Table 1 | MK test results for monthly, seasonal, and annual precipitation time series from 1901 to 2022 over Hanumangarh district

Precipitation duration	Kendall Z_{MK} value	Trend result	MK test *p*-value (two-tailed test)	Test result	Sen's Slope (SS)	Trend result
January	−0.072	Falling	0.239	Insignificant	−0.012	Decreasing
February	0.008	Rising	0.893	Insignificant	0	No trend
March	0.002	Rising	0.974	Insignificant	0	No trend
April	0.058	Rising	0.345	Insignificant	0.003	Increasing
May	0.14	Rising	0.022	Significant	0.035	Increasing
June	0.116	Rising	0.059	Insignificant	0.097	Increasing
July	0.009	Rising	0.887	Insignificant	0.019	Increasing
August	−0.063	Falling	0.303	Insignificant	−0.134	Decreasing
September	0.025	Rising	0.686	Insignificant	0.024	Increasing
October	−0.003	Falling	0.968	Insignificant	0	No trend
November	0.164	Rising	0.013	Significant	0	No trend
December	−0.123	Falling	0.051	Insignificant	−0.001	Decreasing
Winter	−0.044	Falling	0.471	Insignificant	−0.022	Decreasing
Pre-monsoon	0.06	Rising	0.328	Insignificant	0.041	Increasing
SW monsoon	−0.006	Falling	0.919	Insignificant	−0.039	Decreasing
Post-monsoon	−0.097	Falling	0.115	Insignificant	−0.024	Decreasing
Annual	0.014	Rising	0.815	Insignificant	0.064	Increasing

0.058, 0.14, 0.116, 0.009, 0.025, and 0.164), respectively. While the rest of the months (January, August, October, and December) show a negative trend with the value of Z_{MK} (−0.072, −0.063, −0.003, and −0.123), respectively. The results of the SS estimator agreed with the results of those obtained from the MK test. SS estimator results show that a significant trend is reported for May and November months, while the rest of the months are observed with an insignificant trend. Also, it is observed that in some of the months, there is no trend. Figure 3(a)–3(d) shows a graphical representation of seasonal precipitation times series (1901–2022) during winter, pre-monsoon, SW monsoon, and post-monsoon, respectively, while Figure 4 shows a graphical representation of the annual precipitation time series during 1901–2022. The orange line shows the trend line of the precipitation time series.

Precipitation trend analysis using graphical (ITA method)

The first half-times series versus the second half-times series graph is plotted and shown in Figure 5. ITA plots for different season precipitation times series, i.e., winter, pre-monsoon, SW monsoon, and post-monsoon are represented in Figure 5(a)–5(d), respectively. However, Figure 6 illustrates the ITA plot of annual precipitation during 1901–2022. The ITA results indicate that the winter and post-monsoon season precipitation trends are negative in all three regimes, whereas the pre-monsoon and annual seasons show positive precipitation trends in the medium and high regimes. Also, the results indicate that for the SW monsoon season, negative and positive precipitation trends are observed for the low regime and high regime, respectively. No trend is observed for the SW monsoon season in the medium regime. The low regime observed the most decreasing trend in comparison to the medium and high regimes. Table 2 illustrates the results of the ITA method for all different regimes.

Comparison of results of trend analysis between the statistical and graphical methods

In this research, the statistical and graphical methods are used to assess the precipitation trend of different seasons. In the statistical method, the MK test and SS estimator were used. While for the graphical method, the ITA method is used. Table 3 represents the comparison of results between these three methods. During the annual precipitation time series, increasing trends are detected equally for the MK test, SS estimator, as well as ITA method. In the winter season, using the MK test and SS estimator method, a decreasing trend is detected. The ITA method also detected a decreasing trend

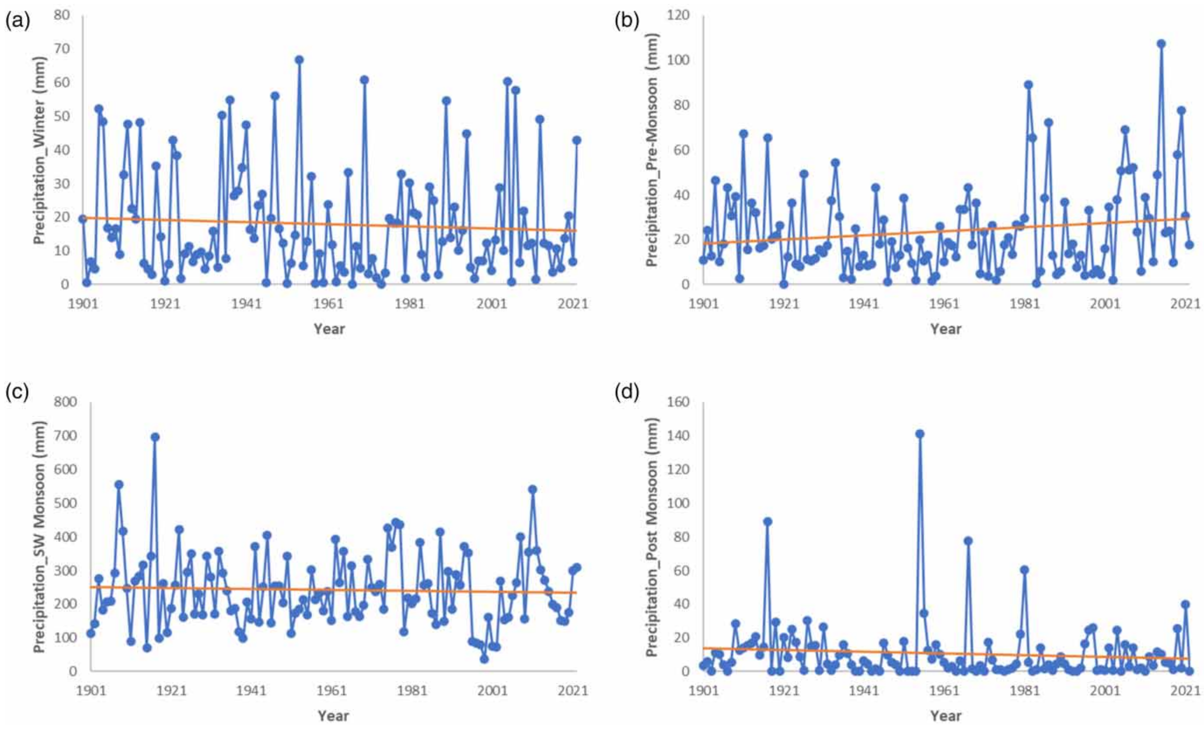


Figure 3 | Time series of precipitation for (a) winter, (b) pre-monsoon, (c) SW monsoon, and (d) post-monsoon (1901–2022) over Hanumangarh district.

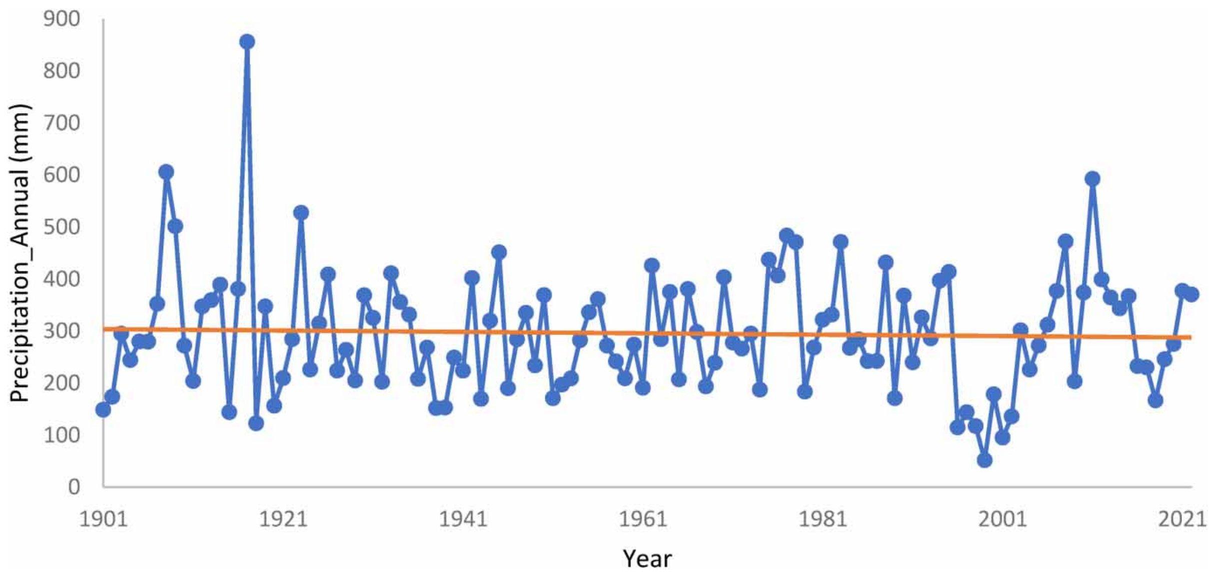


Figure 4 | Annual precipitation time series (1901–2022) over Hanumangarh district. Please refer to the online version of this paper to see this figure in colour: https://dx.doi.org/10.2166/wcc.2023.227.

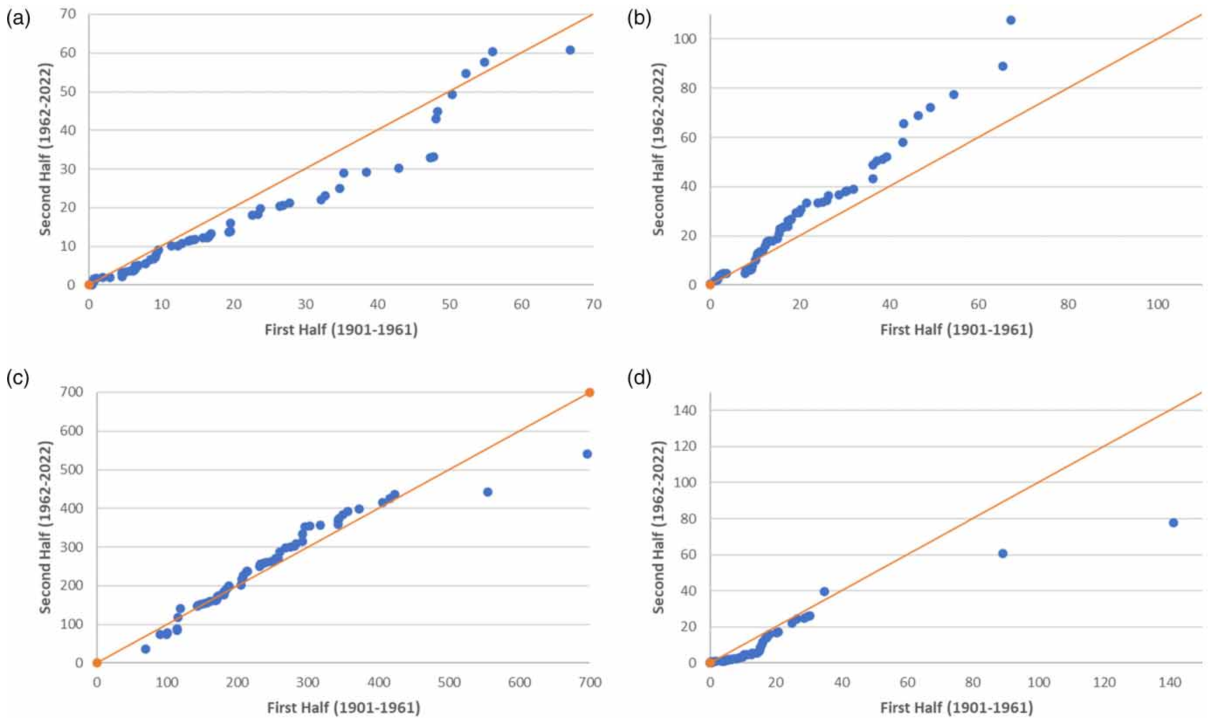


Figure 5 | ITA plot for (a) winter, (b) pre-monsoon, (c) SW monsoon, and (d) post-monsoon seasons (1901–2022) over Hanumangarh district.

during the winter season. Similarly, for the post-monsoon season, a decreasing trend is observed using all three (MK test, SS estimator, and ITA) methods.

During the pre-monsoon season, the increasing trend is noticed for all seasons under the MK test and SS estimator. Correspondingly, an increasing trend is observed by applying the ITA method. For the SW monsoon season, the MK test and SS estimator revealed a decreasing trend, which is highlighted in bold in Table 3. Meanwhile, the ITA method represents an

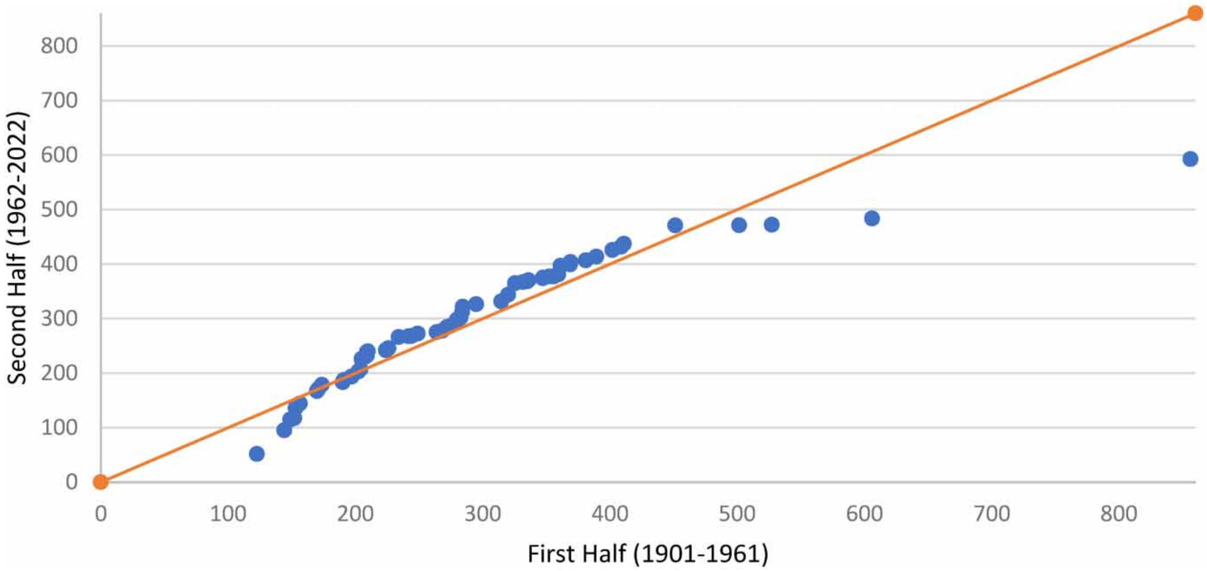


Figure 6 | ITA plot of annual precipitation (1901–2022) over Hanumangarh district.

Table 2 | Summary of the ITA method for annual and seasonal precipitation of Hanumangarh district

Season	Low	Medium	High
Winter	Decreasing	Decreasing	Decreasing
Pre-monsoon	Decreasing	Increasing	Increasing
SW monsoon	Decreasing	No trend	Increasing
Post-monsoon	Decreasing	Decreasing	Decreasing
Annual	Decreasing	Increasing	Increasing

Table 3 | Comparison of results of trend analysis between statistical (MK test and SS estimator) and graphical (ITA method)

Seasons	MK test	SS estimator	ITA method
Winter	Decreasing	Decreasing	Decreasing
Pre-monsoon	Increasing	Increasing	Increasing
SW monsoon	Decreasing	Decreasing	**Increasing**
Post-monsoon	Decreasing	Decreasing	Decreasing
Annual	Increasing	Increasing	Increasing

increasing trend for the SW monsoon season. So, from the above results, it is concluded that the graphical method (ITA) showed a tendency to detect the same trends compared to the statistical method (MK test and SS estimator) without any assumptions.

CONCLUSION

In this study, statistical (MK test & SS estimator) as well as graphical (ITA) methods are adopted to find trends in monthly, seasonal, and annual precipitation time series for the period of 122 years (1901–2022). The graphical (ITA method) has been used and compared with statistical methods (MK test & SS estimator) for the Hanumangarh district of N-E Rajasthan. For the pre-monsoon and annual precipitation time series, the increasing trend is detected using both statistical (MK test & SS estimator) as well as graphical (ITA method). However, for the winter season and post-monsoon season, using statistical (MK test & SS estimator) and graphical (ITA method) decreasing trend is detected. On the other hand, the SW monsoon season represents the decreasing trend for the statistical method (MK test & SS estimator). Meanwhile, the graphical (ITA method) detected an increasing trend. During the SW monsoon, decreasing precipitation can affect the availability of water in the Hanumangarh district. It can also lead to short-term meteorological droughts, which have a severe effect on the agriculture sector. To reduce this risk, it is recommended to adopt the rainwater harvesting system and proper management of water in the future.

Except for the SW monsoon season, the results of the graphical method (ITA) agrees with the result of the statistical method (MK test & SS estimator). Also, it was found that the graphical method (ITA method), which compares two ascending (descending) ordered time series, is easier to use than the statistical method (MK test & SS estimator). Because, like the MK test, the ITA method does not take into account any prior conditions. Therefore, the graphical (ITA method) is more suitable for identifying trends in precipitation time series. This study of precipitation trend analysis and its comparison along two methods (statistical and graphical) will help water resources engineers and local people in sustainable management, planning as well as the development of water resources in the study region. The outcomes of this study will help to determine the suitable methodology for the assessment of drought in future studies. It will also help to decide the future strategies for drought mitigation.

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AUTHOR'S CONTRIBUTION

S.P. has carried out the work using various techniques and prepared the manuscript and D.M. has verified the analysis work and compiled the manuscript with proper corrections.

DATA AVAILABILITY STATEMENT

All relevant data are available from https://drive.google.com/file/d/124iVw9cfObGMKkXcvKlR5AajvttjAwyr/view?usp=sharing.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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