International Journal of Environment and Climate Change

Volume 14, Issue 2, Page 590-600, 2024; Article no.IJECC.112343
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Evaluation of Historic Trends for Monthly, Seasonal, and Annual Rainfall Series of Tenkasi, Tamil Nadu, India

M. Manikandan [a*], M. Nagarajan [b] and N. Anandaraj [c]

[a] Agricultural Research Station, Tamil Nadu Agricultural University, Kovilpatti, India.
[b] Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur, India.
[c] Agricultural College & Research Institute, Tamil Nadu Agricultural University, Eachangkottai, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2024/v14i23974

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/112343

Original Research Article

Received: 03/12/2023
Accepted: 08/02/2024
Published: 17/02/2024

ABSTRACT

Analyzing the variability and trends of rainfall plays a major role in water resource planning and management. Changes in rainfall patterns significantly influence the water availability in the irrigation structures and agronomical practices of crops. This study aimed to investigate the trends and estimate the magnitudes of monthly, seasonal, and annual rainfall series in Tenkasi, Tamil Nadu, India, using 49 years of rainfall data from 1971 to 2019. Sen's Innovative trend analysis (ITA) method, Mann-Kendall (MK), and Simple Linear Regression (SLR) test were applied to assess the trends at 5 and 10 % significance levels. Trend magnitudes were estimated by Sen's slope estimator (SSE) and SLR method. Changes in rainfall magnitude with mean values in percentage were estimated for all three slope estimation methods. The results revealed that the ITA method detected more significant trends of rainfall series over other methods. Significant downward trends were exhibited by October and north east monsoon (NEM) rainfall series had a trend magnitude of -0.43 mm/year and -0.04 mm/year. The percentage change in magnitude of the trend from mean

**Corresponding author: E-mail: manikandan.m@tnau.ac.in;*

values for October and the NEM series was -11.5% and -0.39%. Sub-trends within the October and NEM rainfall series showed that the low rainfall sub-series exhibited no trend, medium and high rainfall sub-series showed a downward trend. This study concluded that, in comparison to traditional trend analysis methods, the ITA method demonstrated a more rigorous investigation of trends. The significant decrease in rainfall during the NEM necessitates greater attention to water resources planning and management, serving as valuable scientific information for both crop planning and water resource management.

Keywords: Innovative trend analysis (ITA); Mann-Kendall; rainfall; regression; slope; trend.

1. INTRODUCTION

As per the report of IPCC, 2018 [1], climate change develops a significant impact on extreme climate events such as heat waves, floods, and drought. Extreme climate events influence the rainfall-runoff processes attributable to increasing or decreasing trends in hydro-meteorological time series [2]. Rainfall, one of the important components of the hydrologic cycle varies temporally and spatially due to the effect of green gas emissions and global warming [3]. Understanding the patterns of rainfall variability in agriculture and information of historic rainfall trends is essential for the planning and management of water resources [4].

The importance of trend analysis of rainfall can be understood by viewing the number of hydro-meteorological studies in different parts of the world [5,6]. Trends of hydro-meteorological variables can be detected using parametric (simple linear regression) and non-parametric (Kendall rank correlation, Spearman's rho, Mann-Kendall, modified Mann-Kendall, Thiel-Sen's slope) tests [7,8,9,10]. These methods require some assumptions about the time series such as independence from autocorrelation and normality of the distribution [11].

Recently, Şen's, 2012 [2] innovative trend analysis (ITA), has gained more attention for detecting trends of hydro-meteorological variables. This method provides a graphical solution of trends without any assumptions on time series data [6,12]. Malik [3] investigated the spatial and temporal trends of seasonal and annual rainfall series (1966–2015) at 13 stations located in the Uttarakhand State of India. Marak [13] studied the use of Innovative trend analysis for assessing the spatial and temporal rainfall variations in the Umiam and Umtru watersheds in Meghalaya, India. Wang [6] used the innovative trend analysis (ITA) method with a significant test for rainfall trend detection at 14 stations in the Yangtze River Delta, eastern China during 1961–2016. Singh [4] analyzed the spatio-temporal trends of rainfall during the last 119 years (1901 to 2019) in different meteorological sub-divisions of India using Innovative trend analysis (ITA) and compared with traditional Mann-Kendall and linear regression analysis (LRA). Pastagia [14] applied innovative trend analysis on rainfall time series from 1902-2021 over the Rajsamand district of Rajasthan state and they detected the patterns in rainfall time series data such as 'low,' 'medium,' and 'high. These studies showed the importance and advantages of the ITA method for identifying the trends. With this understanding, this study was formulated with the objective of (i) to identify the significant upward and downward trends of monthly, seasonal, and annual rainfall series by MK, SLR test, and ITA method, (ii) to estimate the magnitudes of trends by SSE, SLR and ITA method, and (iii) to calculate the percentage changes in the magnitude of rainfall trend from mean values of rainfall series.

2. MATERIALS AND METHODS

2.1 Study area and data used

This study was conducted for Tenkasi taluk, the district headquarters of the southern part of Tamil Nadu, India (Fig. 1). It is located at 08°57'35" and 77°18'24" with an elevation of 184 m. The total area of the Tenkasi taluk is around 65 sq km. The maximum temperature recorded was 31.3°C and the minimum temperature was 23.6°C. Tenkasi is categorized as the southern agroclimatic zone of Tamil Nadu with a rainfall total of 857 mm. Tenkasi is surrounded by the Western Ghats in three sides. Parts of areas of Tenkasi adjacent to the Western Ghats are enjoying a subtropical climate that is conducive to the cultivation of most of the spices, subtropical fruits, plantation crops, and production of off-season mango. In some parts of areas the vegetables are growing. Paddy is cultivated mainly in Tenkasi Taluk. Tenkasi

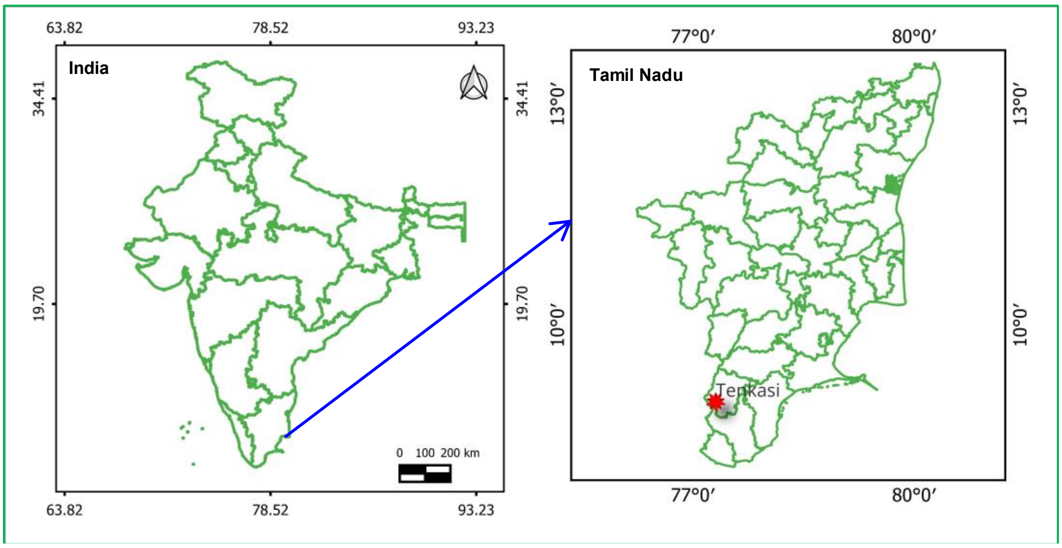

Fig. 1. Location of study area

is drained mainly by Chittar and its tributaries. Chittar originates near Courtallam hills and flows through Tenkasi and confluences with Tamarabarani. Agriculture flourishes in this area so more than 65% of the population is engaged in agriculture and related activities.

Monthly rainfall data of Tenkasi rain-gauge station for the period from 1971 to 2019 were collected from State Ground and Surface Water Resources Data Center, Public Works Department, Water Resources Organisation, Chennai for this study. The monthly rainfall series was further arranged into seasonal rainfall series as South West Monsoon (SWM) from June to September, North East Monsoon (NEM) from October to December, winter season from January & February, summer season from March to May, and annual rainfall series for analysis purpose.

2.2 Statistical Properties of Monthly, Seasonal, and Annual Rainfall

The statistical properties viz. mean, maximum, minimum, standard deviation, coefficient of variation, coefficient of skewness, and kurtosis were calculated for monthly, seasonal, and annual rainfall series of Tenkasi to understand the rainfall behaviors on a statistical basis. The analysis was conducted using Microsoft Excel.

2.3 Analysis of Rainfall Trends

In this study, trends of monthly, seasonal, and annual rainfall series of Tenkasi were detected by the non-parametric Mann-Kendall (MK) test, parametric Simple linear regression (SLR) analysis, and Sen's Innovative Trend Analysis (ITA) method. Magnitude or slope of the trend was estimated by Sen's slope estimator (SSE), SLR, and ITA method. The detailed computational procedures are described below.

2.3.1 Mann-kendal test

It is a non-parametric test commonly used to explore the trends in hydrometeorological data. Trends in the time series detected by this test are monotonic but not necessarily linear. Mann [15] originally used this test and Kendall [16] subsequently derived the test-statistic distribution. The null hypothesis in this test is independent and randomly ordered data. This test does not require any assumption of normality and only indicates the direction but not the magnitude of significant trends [5,15,16].

The MK Test statistic *S* is calculated by the formula $S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn(x_j - x_i)$:, where x_j and x_i are the annual/seasonal/monthly values in years *j* and *i, j*>*i* respectively, and N is the number of data points. S statistics indicate the number of positive differences minus the number of negative differences for all the differences considered.

The value of $sgn(x_j - x_i)$ is computed by: $sgn(x_j - x_i) = \begin{cases} 1\ if(x_j - x_i) > 0 \\ 0\ if(x_j - x_i) = 0 \\ -1\ if(x_j - x_i) < 0 \end{cases}$ For large samples (N>10), the test is conducted using a normal approximation (Z statistics) with the mean $E[S] = 0$

and the variance as: $Var(S)=\frac{1}{18}[N(N-1)(2N+5)-\sum_{p=1}^{q}t_p(t_p-1)(2t_p+5)]$ where q is the number of tied (zero difference between compared values) groups, and t_p is the number of data values in the p^{ath} group.

The test statistic can be calculated by Z: $Z=\begin{cases}\frac{S-1}{\sqrt{Var(S)}} if S>0\\ 0 \quad if S=0\\ \frac{S+1}{\sqrt{Var(S)}} if S<0\end{cases}$ A positive/negative value of Z indicates an upward/downward trend. The statistic Z follows a normal distribution. To test for statistical significance, the calculated Z value is compared with critical values obtained from the standard normal distribution tables at two significance levels (α = 5% and α = 10%). The null hypothesis H_0 of no trend is rejected if the calculated value of Z is greater than the table value of $Z_{1-\alpha/2}$.

2.3.2 Simple linear regression analysis

Simple linear regression (SLR) analysis is a parametric model extensively used for detecting the monotonic long-term trend in the monthly, seasonal, and annual rainfall time series. SLR analysis derives the relationship between any two variables. The positive slope shows an upward trend whereas the negative slope indicates a downward trend. The main advantage of using SLR analysis is that it gives a measure of significance on the basis of the hypothesis test on the slope and also provides the magnitude of the rate of change. The calculation procedure of SLR analysis is detailed in [17,18] was adopted in this study.

2.3.3 Sen's slope estimator

The magnitude of the trend in the monthly, seasonal, and annual time series was determined using a non-parametric method known as Sen's estimator [19]. Sen's slope estimator requires equally spaced data in a time series [20]. The main advantage of Sen's slope estimator over the SLR is that it is not much affected by the whole data errors and outliers [21] and also is resistant/robust to extreme observations. This method can be applied in cases where the trend line can be assumed to be linear.

To get the slope estimate Q, the slopes of all data value pairs are first calculated using the equation: $Q_i=median\frac{x_j-x_k}{j-k}$; where x_j and x_k are data values at time j and k ($j>k$) respectively. If there are n data values $x_j$in the time series there will be as many as $N = n(n-1)/2$ slope estimates Q_i. Sen's slope estimator is the median of these N values of Q_i. The N values of Q_i are ranked from the smallest to the largest and Sen's estimator is $=Q_{\left[\frac{(N+1)}{2}\right]}$, if N isodd or $Q=\frac{1}{2}\left(Q_{\left[\frac{N}{2}\right]}+Q_{\left[\frac{(N+2)}{2}\right]}\right)$, if N is even. The positive value of the Q denotes the slope of the upward trend and the negative value for the downward trend. A zero value of Q indicates that there is no trend in the time series.

2.3.4 The innovative trend analysis method

The innovative trend analysis (ITA) method has been successfully applied for the detection of trends in the hydro-meteorological parameters [22,23]. This method is quite simple, easy to identify the trend, and visibly shows the trends of high, medium, and low data in the trend line. Not like any non-parametric trend identification test, this method does not require any restrictive assumptions, such as the independent structure of the data series, normality, and data length [24]. By this method, all the data points of the time series are located in a Cartesian coordinate system and compared with the diagonal straight 1:1 line [25]. The ITA construction procedure is provided below.

- Monthly, annual, and seasonal rainfall time series is equally divided into two half series. Each half series is arranged in ascending order. The first half of the time series is placed on X axis and the other half of the time series is placed on Y axis, rainfall series is plotted in a scatter diagram.
- Draw a (1:1) 45° straight line diagonally in the scattered graph; divide the plot into upper and lower half triangles.
- If the scattered points perfectly lie on a 45° straight line, the series does not have a trend. When the scattered points lie on the upper half triangle, the rainfall series is said to be increasing trend. When the scattered points lie on the lower half triangle, the rainfall series are said to be decreasing trend.
- A time series is considered as monotonic trend if all the scattered points are lies above or below the upper or lower half triangles: non-monotonic trend occurs if some of the scattered points are located on an upper half triangle and the

remaining points are located in the lower half triangles [2].

- The trend of low, medium, and high values can be spotted in the scatted graph.
- To test the significance of the trend, it is considered that the null hypothesis (H_0): there is no significant trend if the calculated slope value (S) is below the critical value (S_{cri}), the alternative hypothesis (H_a): there is a significant trend when S >S_{cri}. The slope (S) of the trend can be computed by the formula [23]: $S = \frac{2(\bar{y}_2 - \bar{y}_1)}{n}$; Where, $\bar{y}_1$ and $\bar{y}_2$ = mean of first and second half of the rainfall time series and n = the number of data in the rainfall time series.
- The slope standard deviation is computed as follows The standard deviation (σs) of the trend slope is calculated by the formula [23]: $\sigma_S = \frac{2\sqrt{2}}{n\sqrt{n}}\sigma\sqrt{1-\rho_{\bar{y}_1\bar{y}_2}}$; where (σ)=standard deviation, cross-correlation coefficient between the means of the two half series. By using the confidence limits (S_{cri}) for a standard normal probability density function, the confidence limits of the trend slope are calculated at the significance level of α from the formula [23]: $CL_{(1-\alpha)} = 0 \pm S_{cri}\sigma_S$. If slope value (s) lies outside the lower/upper confidence limits, then the null hypothesis of no significant trend is rejected at α significance level.

2.4 Change of Magnitude from Mean Rainfall in Percentage

The change of rainfall magnitude in percentage was calculated using the slope values estimated by SSE, SLR, and ITA methods using the following expression [26].

$$PC = \frac{n \times S}{\bar{x}} \times 100$$

Where PC is the change of rainfall in percentage (%), n is the length of rainfall series (years), S is the magnitude of the trend, and $\bar{x}$ is the mean value of the rainfall series.

3. RESULTS AND DISCUSSION

3.1 Statistical Analysis of Rainfall

Statistical properties of the monthly, seasonal, and annual rainfall series of Tenkasi are presented in Table 1. The seasonal and annual distribution of rainfall is presented in Fig. 2. The average annual rainfall of Tenkasi for the period of 1971-2019 was 992.7 mm. The maximum rainfall of 1909.3 mm has recorded in 1972 and the minimum rainfall of 384.1 mm has recorded in 2016. Regarding the seasonal rainfall, NEM recorded higher rainfall of 49.8 percent of annual rainfall. SWM, Winter, and summer rainfall registered 22.8, 5.7, and 21.7 percent of annual rainfall, respectively. Among the monthly rainfall series, November and October month recorded higher rainfall. The coefficient of variation (CV) of the annual rainfall was 36.13 which indicates there is not much variation in the total amount of rainfall between times. The rainfall series of April, October, November, SWM, and NEM showed minimum CV values (50<CV>70) over the other rainfall series. Skewness and kurtosis were computed to understand whether the rainfall series follow a normal distribution. Skewness measures the lack of symmetry of rainfall series. Positive values of the skewness for all rainfall series indicate that data are skewed to the right, and found lack of symmetry. Kurtosis measures the peakness or flatness of rainfall series. Positive kurtosis of annual rainfall series indicates a peaked distribution. Negative kurtosis of SWM and winter rainfall series indicates a flat distribution.

3.2 Trend Results of MK and SLR Methods

The trends of monthly, seasonal, and annual rainfall series and the magnitude of trends calculated by MK and SLR methods are given in Table 2. The results of Z statistics conducted for the MK test revealed that July month rainfall exhibited a significant downward trend at 5 % significance level. Other rainfall series did not exhibit a significant trend. The results of test for the SLR method showed that a significant downward trend was noticed in April month at 10% significance level and July month at 5 % significance level. Annual rainfall series exhibited a significant downward trend at 10% significance level.

3.3 Trend Results of ITA Method

The trend parameters calculated by the ITA method for the monthly, seasonal, and annual rainfall of Tenkasi at the 5% and 10% significant levels are detailed in Table 3. The graphical representation of ITA for the identification of monotonic trends and sub-trend of rainfall is presented in Fig. 3. The results of the ITA

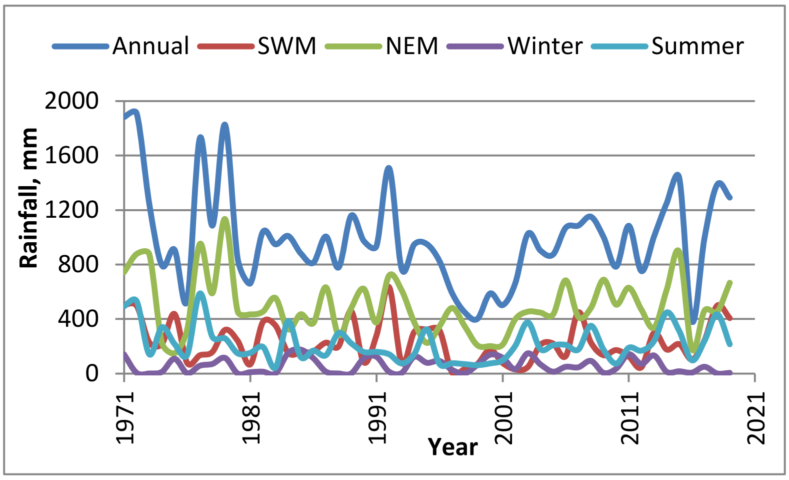

Fig. 2. Distribution of seasonal and annual rainfall series of Tenkasi

Table 1. Statistical properties of monthly, seasonal, and annual rainfall series of Tenkasi

Time series	Mean	Maximum	Minimum	Standard deviation	Coefficient of variation	Skewness	Kurtosis
Jan	23.09	152.00	0.00	36.39	157.58	2.15	4.51
Feb	33.81	146.25	0.00	43.90	129.83	1.20	0.14
Mar	71.52	299.50	0.00	70.90	99.13	1.57	2.60
Apl	80.96	228.00	0.00	56.04	69.22	0.80	0.32
May	63.16	430.40	0.00	77.82	123.21	2.89	10.61
Jun	69.24	266.00	0.00	58.73	84.82	1.23	1.78
Jul	57.61	199.10	0.00	52.21	90.63	1.17	0.64
Aug	47.04	197.50	0.00	42.80	90.99	1.60	3.19
Sep	55.25	199.00	0.00	51.21	92.70	0.99	0.25
Oct	179.46	544.00	23.00	122.00	67.98	0.82	0.48
Nov	220.93	710.00	47.00	126.10	57.08	1.61	3.78
Dec	93.89	403.50	0.00	79.68	84.86	1.81	4.40
Annual	992.70	1909.30	384.10	358.70	36.13	0.81	0.80
SWM	225.87	635.50	6.00	148.63	65.80	0.75	-0.02
NEM	494.28	1134.20	147.30	216.34	43.77	0.79	0.60
Winter	56.91	175.00	0.00	54.38	95.56	0.54	-1.16
Summer	215.64	587.20	42.00	129.70	60.15	1.08	0.74

Table 2. Result of MK and SLR test and slope values and percentage change in magnitude of SSE and SLR

Time series	MK Z test	SLR t test	Mean RF	SSE		SLR	
				Slope (Q)	PC	Slope (β)	PC
Jan	0.63	-0.52	23.09	0.00	0.00	-0.19	-39.50
Feb	0.51	0.10	33.81	0.00	0.00	0.04	5.68
Mar	-0.71	-0.04	71.52	-0.35	-23.49	-0.03	-2.01
Apl	-0.06	-0.14*	80.96	-0.03	-1.78	-0.08	-4.74
May	-0.28	-1.41	63.16	-0.13	-9.88	-1.10	-83.60
Jun	-0.37	-0.78	69.24	-0.21	-14.56	-0.46	-31.89
Jul	-2.19**	-2.05**	57.61	-0.86	-71.65	-1.05	-87.48
Aug	-0.73	0.56	47.04	-0.25	-25.51	0.24	24.49
Sep	-0.19	-0.75	55.25	-0.05	-4.34	-0.39	-33.88
Oct	0.25	0.02	179.46	0.28	7.49	0.02	0.53
Nov	-0.73	-0.91	220.93	-0.73	-15.86	-1.16	-25.20
Dec	-0.36	-1.28	93.89	-0.23	-11.76	-1.03	-52.66

Time series	MK	SLR	Mean		SSE		SLR
Annual	-0.44	-1.45*	992.70	-1.27	-6.14	-5.18	-25.05
SWM	-0.98	-1.11	225.87	-1.29	-27.41	-1.66	-35.28
NEM	-0.18	-0.99	494.28	-0.45	-4.37	-2.16	-20.98
Winter	0.19	-0.27	56.91	0.01	0.84	-0.15	-12.65
Summer	-0.17	-0.92	215.64	-0.27	-6.01	-1.21	-26.93

PC = Per cent change of magnitude from mean rainfall

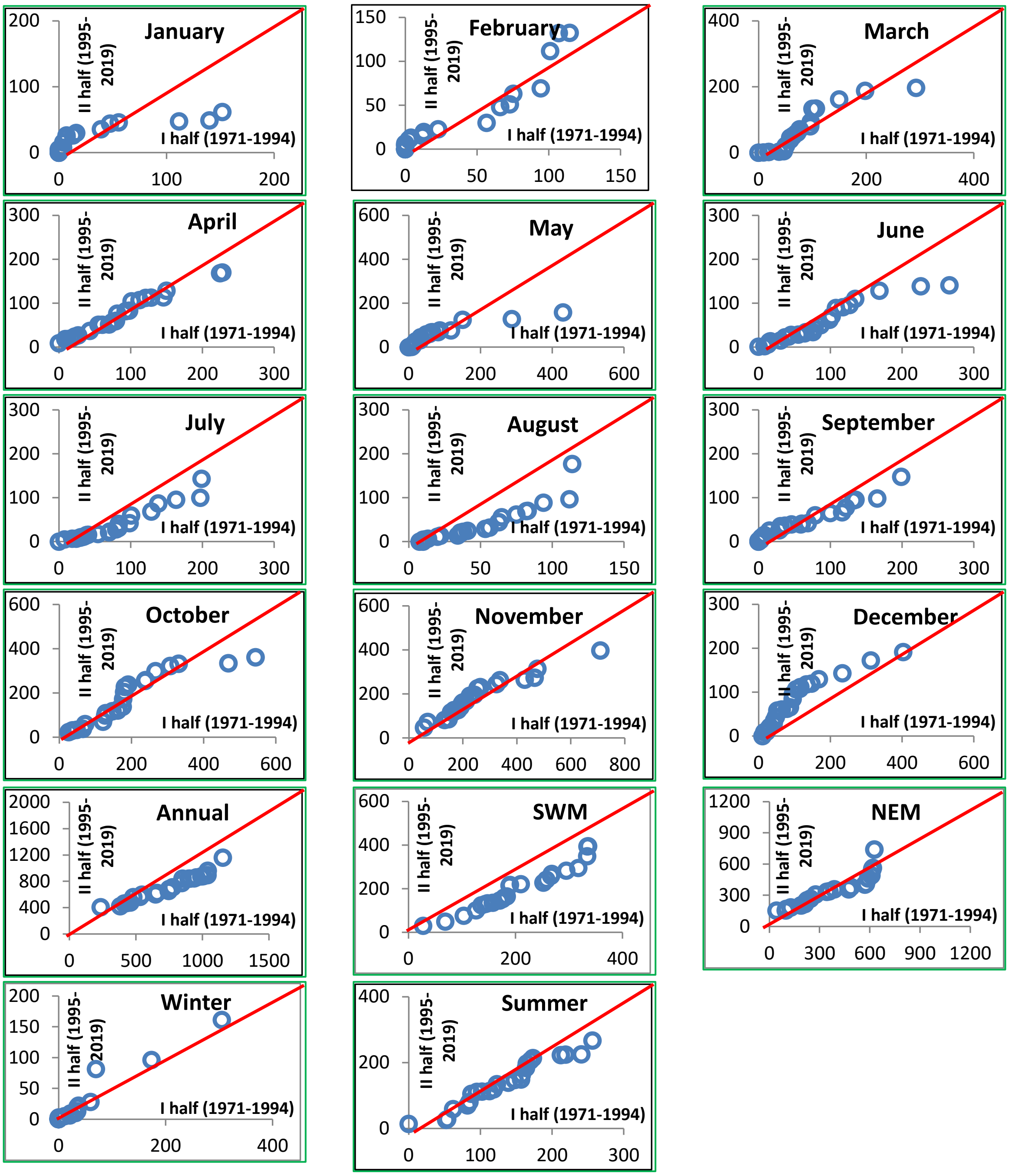

Fig. 3. Results of ITA method for different rainfall series of Tenkasi

Table 3. Results of innovative trend analysis of different rainfall series for Tenkasi

Time series	Slope	σ	ρ_{y1y2}	σ_s	Lower and Upper CL		Decision	PC
					SL@5%	SL@10 %		
Jan	-0.15	34.94	0.86	0.11	±0.18	±0.21	-Ha**	-31.18
Feb	0.19	41.15	0.95	0.07	±0.12	±0.14	Ha**	26.97
Mar	-0.23	63.29	0.92	0.14	±0.24	±0.28	-Ha**	-15.44
Apl	-0.30	54.11	0.99	0.05	±0.09	±0.11	Ho	-17.79
May	-0.58	75.9	0.89	0.21	±0.34	±0.41	Ho	-44.08
Jun	-1.07	58.37	0.96	0.09	±0.15	±0.18	Ho	-74.18
Jul	-1.36	51.23	0.97	0.08	±0.13	±0.15	Ho	-113.31
Aug	-0.15	37.15	0.92	0.08	±0.14	±0.17	-Ha*	-15.31
Sep	-0.48	49.48	0.98	0.05	±0.09	±0.11	Ho	-41.70
Oct	-0.43	120.29	0.92	0.28	±0.46	±0.55	-Ha**	-11.50
Nov	-2.46	123.25	0.96	0.21	±0.35	±0.41	Ho	-53.45
Dec	-0.87	77.62	0.92	0.18	±0.29	±0.35	Ho	-44.48
Annual	0.25	224.55	0.97	0.29	±0.48	±0.58	Ho	1.21
SWM	0.16	92.04	0.97	0.12	±0.20	±0.24	Ho	3.40
NEM	-0.04	177.59	0.93	0.39	±0.64	±0.76	-Ha**	-0.39
Winter	-0.38	55.91	0.97	0.08	±0.13	±0.16	Ho	-32.05
Summer	0.52	66.24	0.97	0.09	±0.15	±0.18	Ha**	11.57

σ=standard deviation, σs = standard deviation of the trend slope, ρ_{y1y2} = Correlation, PC = Per cent change of magnitude from mean rainfall, CL= confidence limits of the trend slope , SL= significance level, Ho=null hypothesis, Ha = alternative hypothesis

method showed that seven out of seventeen rainfall series exhibited the alternate hypothesis of existing trends as the estimated slope values are located outside the lower and upper confidence level limits ($S>S_{CL}$). February and Summer rainfall series showed significant upward trends at 5 % significance level. January, March, October and NEM rainfall exhibited significant downward trends at 5 % significance level. August month rainfall series showed downward trends at 10 % significance level, but the series failed at 5 % significance level. Slope values estimated by the ITA method for other rainfall series fall within the critical levels. Hence these series failed the significance test so the null hypothesis of no significant trend is accepted. One of the noteworthy points in this Table 3 is that there is a close cross-correlation value between two half series because they are estimated depending on the ascending ordered sequence in each half series.

A scattered graph was drawn between the first half of the rainfall series (1971-1994) and the second half of the rainfall series (1995-2019) to identify the monotonic trend and sub-trends (Fig. 2). A 45° straight line was drawn between two half series and hence the scattered graph was divided into two triangles. If all the data points lie in a straight line, it is said to be no trend. If all data points are located in the upper triangle, it is referred as a monotonic upward trend; data on the lower triangle is referred as a monotonic downward trend. Further 45° straight lines on the scatter plot on are divided into three vertical columns as low, medium, and high rainfall within a series. All the rainfall series of Tenkasi showed non-monotonic trends. However within the series as divided into low, medium, and high rainfall, sub-trends were explored. The rainfall series which exhibited significant trends are further discussed for sub-trends. Significant upward trends identified for February and Summer rainfall series showed non-monotonic tend. For February, the medium rainfall subseries exhibited a downward trend whereas the high rainfall subseries showed an upward trend. For summer, the medium rainfall subseries showed an upward trend. August rainfall series clearly showed a monotonic downward trend, however medium and high rainfall subseries showed an upward trend. October and NEM rainfall series showed a non-monotonic downward trend, low rainfall subseries exhibited no trend, and medium and high rainfall subseries showed a downward trend. January and March month rainfall values are concentrated only at the lower zone of a straight line. High rainfall sub-series of January and March exhibited a downward trend.

It is clearly visible that the trends detected by the ITA method are generally more significant than trend detected by MK and SLR test for all the rainfall time series. ITA method detected trend that was not detected by other method, by showing its ability to identify the hidden trends in time series [6]. The ITA method was found to be more effective for assessing trends of hydro-meteorological variables [14]. Many scientists have reported the similar merits of ITA and its ability to identify trends more effectively in hydro-meteorological variables as compared to the traditional trend detection methods in corroboration with our study [3,4,6,13,14].

3.4 Estimation of Trend Slope

The magnitudes of trends of monthly, seasonal, and annual rainfall time series for Tenkasi were estimated by Sen's slope estimator (SSE) and SLR slope, and the summary of the results are presented in Table 2. It is seen from Table 2 that the magnitudes of rainfall trends of different rainfall time series showed large variations between SSE and SLR slope. In both cases, most of the rainfall series showed insignificant negative magnitudes.

SSE method showed that July month showed a significant downward trend at the rate of -0.86 mm/year. SLR method explored the significant downward trend with the magnitude at the rate of -0.08 mm/year for April rainfall and -1.05 mm/year for July rainfall series. The annual rainfall series showed a significant downward trend with slope values of -5.18 mm/year.

The slope values estimated by the ITA method for the rainfall series are presented in Table 3. From the table, it can be seen that February and Summer rainfall series showed significant upward trends with slope value of 0.19 and 0.52 mm /year. Significant downward trends were exhibited by January, March, August, and October and NEM rainfall series had slope values of -0.15,-0.23, -0.15, -0.43 and -0.04 mm/year, respectively. Some rainfall series showed higher slope values but they are not significant.

3.5 Change of Rainfall Magnitude

The percentage change of rainfall magnitude from mean values over the study period for the rainfall series of monthly, seasonal, and annual rainfall data was worked out using the SSE, SLR, and ITA slope, and the results are presented in Tables 2 and 3. From Table 2, it can be seen that the percentage change of rainfall calculated from the slope values was the lowest negative in the July rainfall series by SSE method (-71.65%) and SLR (-87.48 %). By ITA method, February and Summer had the values of positive percent chance of rainfall. July (-113.31 %) and November (-53.45 %) had the lowest percent change of rainfall.

4. CONCLUSION

In the present study, the statistically significant trends of monthly, seasonal, and annual rainfall time series were investigated in Tenkasi using Mann-Kendall (MK) and Simple Linear Regression (SLR) along with Sen's innovative trend analysis (ITA) method. The Sen's Slope Estimator (SSE) and SLR method was applied for calculating the slope of the rainfall trend line. The results of MK test revealed that July month rainfall exhibited a significant downward trend at 5 % significance level with slope values of -0.86 mm/year. The results of SLR method showed that a significant downward trend was noticed in the Annual rainfall series at 10% significance level with slope values of -5.18 mm/year and July month at 5 % significance level with slope values of -1.05 mm/year. The results of ITA method indicated that February and Summer rainfall series showed significant upward trends with the slope value of 0.19 and 0.52 mm /year. Significant downward trends were exhibited by January, March, August, and October and NEM rainfall series had the slope values of -0.15,-0.23, -0.15, -0.43 and -0.04 mm/year, respectively. The ITA method identified more significant trends in rainfall series compared to other methods. The graphical representation of the ITA method aids in detecting sub-trends of low, medium, and high rainfall within sub-series. The findings presented in the study are valuable for decision-making regarding crop planning and water resource management.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. IPCC. Summary for policymakers. In: Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and

related global greenhouse gas emission pathways, in the context of strengthening the global response to. World Meteorol. Organ. Geneva, Switzerland. 2018;106:32.
2. Şen Z. Innovative trend analysis methodology. J Hydrol Eng. 2012; 17:1042–1046.
3. Malik A, Kumar A, Guhathakurta P, Kisi O. Spatial-temporal trend analysis of seasonal and annual rainfall (1966–2015) using innovative trend analysis method with significance test. Arabian Journal of Geosciences. 2019;12:328.
4. Singh RN, Sah S, Das B, Potekar S, Chaudhary A, Pathak H. Innovative trend analysis of spatio-temporal variations of rainfall in India during 1901–2019. Theoretical and Applied Climatology. 2021;145:821–838.
5. Sonali P, Nageshkumar D. Review of trend detection methods and their application to detect temperature changes in India. Journal of Hydrology. 2013;476:212–227.
6. Wang Y, Xu Y, Tabari H, Wang J, Wang Q, Song S, Hu Z. Innovative trend analysis of annual and seasonal rainfall in the Yangtze River Delta, eastern China. Atmospheric Research. 2020; 231:104673.
7. Gajbhiye S, Meshram C, Mirabbasi R, Sharma SK. Trend analysis of rainfall time series for Sindh river basin in India. Theoretical and Applied Climatology. 2015;125: 593–608.
8. Dinpashoh Y, Singh VP, Biazar SM, Kavehka S. Impact of climate change on streamflow timing (case study: Guilan Province). Theoretical and Applied Climatology. 2019.
Available:https://doi.org/10.1007/s00704-019-02810-2
9. Kumar S, Machiwal D, Dayal D. Spatial modelling of rainfall trends using satellite datasets and geographic information system. Hydrol Sci J. 2017;62(10):1–18.
10. Machiwal D, Jha MK. Evaluating persistence and identifying trends and abrupt changes in monthly and annual rainfalls of a semi-arid region in Western India. Theoretical and Applied Climatology. 2017;128: 689–708.
11. Yue S, Pilon P, Phinney B, Cavadias G. The influence of autocorrelation on the ability to detect trend in hydrological series. Hydrol Process. 2002;16:1807–1829.
12. Singh R, Sah S, Das B. Spatio-temporal trends and variability of rainfall in Maharashtra, India: analysis of 118 years. Theoretical and Applied Climatology. 2020.
Available:https://doi.org/10.1007/s00704-020-03452-5
13. Marak JDK, Sarma AK, Bhattacharjya RK. Innovative trend analysis of spatial and temporal rainfall variations in Umiam and Umtru watersheds in Meghalaya, India. Theoretical and Applied Climatology. 2020;142:1397–1412.
14. Pastagia J, Mehta, D. Application of innovative trend analysis on rainfall time series over Rajsamand district of Rajasthan state. Water Supply. 2022;22(9):7189.
DOI: 10.2166/ws.2022.276
15. Mann HB. Non-parametric tests against trend. Econometrica. 1945;13:245–259.
16. Kendall MG. Rank correlation methods. Charles Griffin and Co. Ltd. London, U.K; 1975.
17. Meshram SG, Singh VP, Meshram C. Long-term trend and variability of precipitation in Chhattisgarh State, India. Theoretical and Applied Climatology. 2017;129:729–744.
18. Machiwal D, Gupta A, Jhaand MK, Kamble T. Analysis of trend in temperature and rainfall time series of an Indian arid region: Comparative evaluation of salient techniques. Theoretical and Applied Climatology. 2018;136:301–320.
19. Sen PK. Estimates of the regression coefficient based on Kendall'stau. Journal of American Statistical Association; 1968.
Available:https://doi.org/10.1080/01621459.1968. 10480934
20. Machiwal D, Jha MK. Hydrologic time series analysis: Theory and practice. 1sted. New Delhi, India: Springer, Germany and Capital Publishing Company; 2012.
21. Malik A, Kumar A. Spatio-temporal trend analysis of rainfall using parametric and non-parametric tests: Case study in Uttarakhand, India. Theoretical and Applied Climatology. 2020.
Available:https://doi.org/10.1007/s00704-019-03080-8
22. Sen Z. Trend identification simulation and application. J. Hydrol. Eng. 2014; 19(3):635–642.
23. Sen Z. Innovative trend significance test and applications. Theoretical and Applied Climatology. 2017;127: 939–947.
24. Meena HM, Machiwal D, Santra P, Moharana PC, Singh DV. Trends and

homogeneity of monthly, seasonal, and annual rainfall over arid region of Rajasthan, India. Theoretical and Applied Climatology; 2018.
Available:https://doi.org/10.1007/s00704-018-2510-9

25. Sanikhani H, Kisi O, Mirabbasi R, Meshram SG. Trend analysis of rainfall pattern over the Central India during 1901–2010. Arabian Journal of Geoscience. 2018;11:437.

26. Suryavanshi S, Pandey A, Chaube UC, Joshi N. Long-term historic changes in climatic variables of Betwa Basin, India. Theoretical and Applied Climatology. 2014;117:403–418.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/112343