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Study of trend of rainfall data: A case study of Koraiyar basin, Tamil Nadu

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Rainfall is an vital hydro-climatic element at the helm of that heads the hydrological cycle and water availability in a specific region. In current years, significant deviances have been observed in rainfall patterns on a global as well as local scale. Several analyses have established that any study of hydro-climatic variables must be handled and executed on different micro-scales rather than regional scale because the trends and their effects may differ widely from station to station. In the current investigative study, the urban rainfall variation in the Koraiyar basin between the years 1975-2010 is examined to study the trend of precipitation. The non-parametric test is used in this study because the data outliers can be avoided easily. The Mann-Kendall (M-K) method is adopted to analyze the trend, and Sen's slope is used to estimate the linear trend. To detect the change in trends, the CUSUM test is applied. The coefficient of variance (CV) is applied for variability analysis. From the analysis, it is noted that there is an unpredictable increasing and decreasing trend in the yearly and periodic rainfall patterns in the basin.

[**Keywords**: CUSUM test, Spear Man-Rho test (SR test), Precipitation, Sen's slope estimator test, Trend]

Introduction

Precipitation is an essential element responsible for the availability of freshwater resources. The amount of water available in a specific place depends upon quantum of precipitation and ground collection. Precipitation trend varies with time and place. Forecasting trends using seasonal rainfall time series data is much more complicated than forecasting ambient temperature trends. In recent hydrological studies, top priority has been given to rainfall trend analysis. The trend analysis of precipitation is generally conducted on a macro scale, and the gathered data has helped identify a decreasing trend in the mean yearly rainfall in countries such as India, Russia, Northeast, and North China and along the arid plains of Pakistan. An increasing trend in the mean yearly rainfall has been witnessed in the Chang Jiang valley in China, and Bangladesh in summer season[1]. In earlier studies, global trend analysis was always done with historical rainfall data, which is less useful for local-scale planning of water resources; some analyses showed no significant variation in trend[2,3]. The study of rainfall variability and its trends is a useful tool for policymakers for agricultural planning and hazard mapping[4,5]. The rainfall trends are generally observed to vary from one locality to another. The study of rainfall variability in India is carried on a macro scale. It shows that in the case of peak monsoon season, rainfall variability is high and mostly shows a negative trend, which results in increased frequency and magnitude of monsoon rainfall. The reported yearly rainfall in peninsular India shows no major variation in trends[6,8]. The rainfall data for a period of 40 years from 1971 to 2010 in the river basin of Orissa was used to determine the precipitation trend and to identify the pattern of increasing or decreasing cycles for narrowing attributes[9].

The study of rainfall trends is required for applications like flood frequency analysis, monitoring of drought, and for sustainable management of water resources[10-13]. The oscillating variation in rainfall trends has become a challenging issue for the planning of current and future developmental activities[14].

The exact trends and identification should be made for regional-scale analysis for a particular place. There are different statistical methods to detect a trend in hydrology; these are classified as parametric and non-parametric tests. The parametric test is a more powerful technique that requires data to be distributed both normally and independently which is infrequently seen for hydrological period series data. In the non-parametric method, all data should be independent. The outliers in this method are restored. The frequently used non-parametric tests are the M-K test and Spearman's Rho (SR) method for time series trend. The M-K test is the standard method used in determining hydrological time series trends while the SR test is used in combination with the M-K test for comparison purposes[7].

The present work aims to determine the rainfall trend on the basis of a local scale for the Koraiyar river basin, which is prone to high rainfall variability. In this study, the monthly rainfall data from 1975 to 2010 (35 years) is used for analyzing the trend of monthly variability in the rainfall patterns. The Koraiyar basin is selected for this study because it passes through Tiruchirappalli city which is located in the central part of Tamil Nadu due to deviation of rainfall pattern in the basin. The present study deals with the narration of dataset, a study area, and a description of the methodology. The non-parametric tests M-K test and Sen's slope estimator are used in this study for better interpretation of the trend analysis. The slope is observed by Thiel-Sen's method. The change in rainfall trend is studied using the CUSUM method. The obtained results are reviewed, and rainfall trends are analyzed for different months and seasons. The trend analysis is studied to identify the flood pattern of the basin.

Materials and Methods

Study area and data used

The Koraiyar river originates from the Karuppur Reddiyarpatti hills R.F at an elevation of about 500 m with latitude 10°40′20″ N and longitude 78°39′26″ E. The basin receives water from the catchment areas of Puttanattam, Viralimalai, Malaikudippatti, Tennalur, Illupur, Kalluppatti, Arur, Kulakkattai gudi, Keeranur, and Thuvarankurichi. The catchment area of the river is 1498 sq. km, and the length is 75 km. A large number of tanks cover the entire catchment of the river. The river finally drains into the Uyyokondan channel in the center of Tiruchirappalli city, Tamil Nadu, as shown in Figure 1.

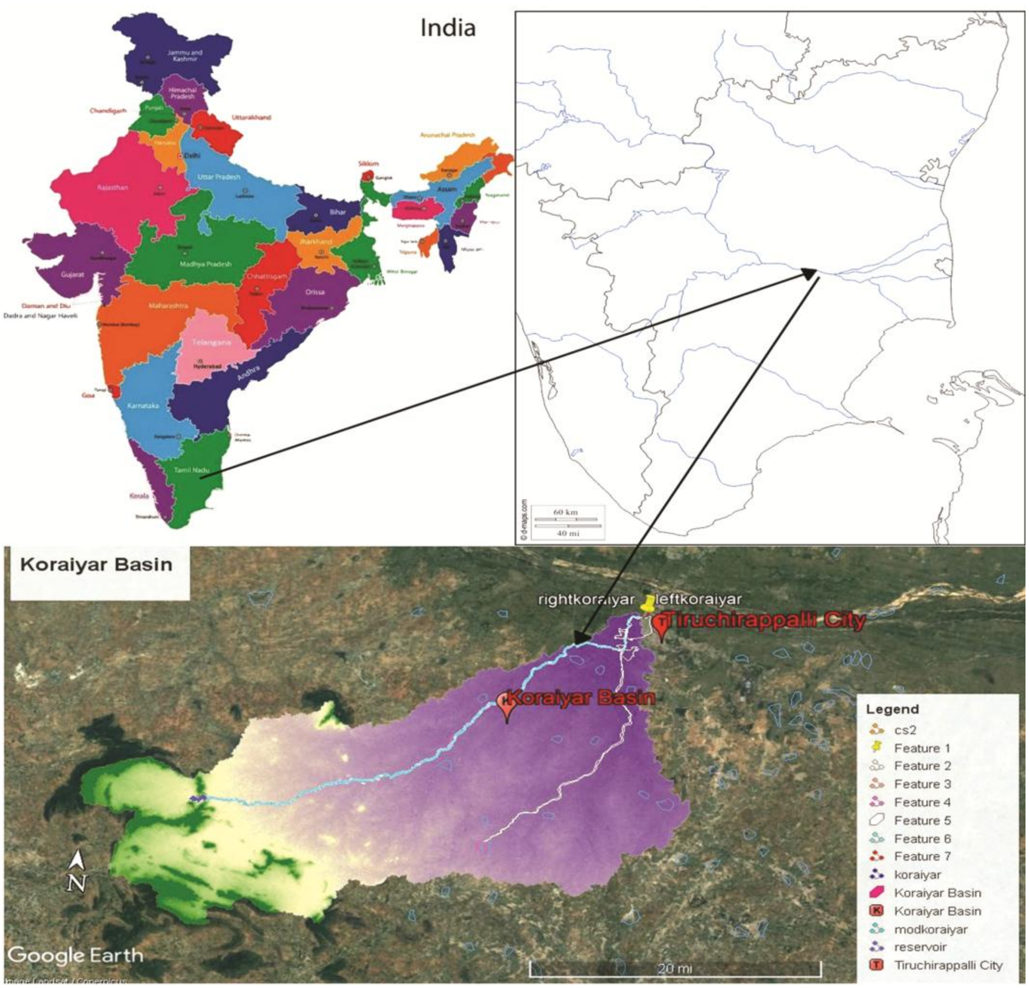

Fig. 1 — Location of study area - Koraiyar basin

Moreover, the surplus water passes through Puthur weir outlet in the left bank of Uyyakondan and traverses Kodamurutty river to a length of 6 km, before finally falling into the Bay of Bengal. The basin experiences a sub-tropical climate, and there is no significant swing in temperature between summer and winter, with summer (March to May) having a maximum temperature of 41 °C and a minimum of 36 °C, and winter (December to February) being warm but pleasant with temperatures ranging from 19 to 22 °C. The rainy season falls between October to December, with good rains obtained mostly from the northeast monsoon. The average rainfall for the basin is around 957.44 to 1062.18 mm. The rain gauge stations in the basin are located at Marungapuri, Manaparai, and Trichy airport. The semi-urban river basin is currently facing rapid urbanization.

Methodology

In the present study, the temporal variability of the rainfall for the Koraiyar basin is analyzed for the period of (1975-2010). The rainfall data is collected from the Indian Water Portal (https://www.indiawaterportal.org) and Irrigation Management Training Institute, Tiruchirappalli. The general characteristics of rainfall in the basin are analyzed by calculation of mean monthly, seasonal, annual standard deviation, and coefficient of variation. In the current work, a non-parametric test is adopted for trend detection in the rainfall time series.

Statistical tests

Non-Parametric

The most commonly used non-parametric test for finding the trend in hydrological variables is the M-K test. The statistically significant trend is detected by using a non-parametric model such as the M-K test, and it is completed with Sen's slope estimation to define the extent of the trend[10].

Mann-Kendall test (M-K test)

The M-K test is used for determining the rainfall trend[1]. It is a non-parametric test and in this, the difficulty data outliers can be evaded easily[8]. The M-K statistic S is given in the following Eq. (1).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \qquad \dots (1)$$

This method is applied to a time series x_i that is ranked from i = 1, 2 … n-1, and xj, which is ranked from j = i+1, 2 …. n. The data point x_i is taken as a location point for comparing with all other data points, x_j so that the statistic S is approximately distributed normally, i.e. shown in Eq. (2).

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

The var(s) is shown in Eq. (3) below:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i\,(i)(i-1)(2i+5)}{18} \qquad \dots (3)$$

Z_{mk} follows a standard normal distribution as shown below in Eq. (4). Hence, if a positive value occurs, it indicates a rising trend, and that of negative values shows a decreasing trend. The significance level α is also used for testing either an upward or downward trend in a two-sided test. The Z_{mk} is bigger than $Z_{\alpha/2}$, where α depicts the significance level; then, the trend is considered to be significant. Generally, Z_{mk} values are 1.645, 1.960 and 2.576 for significance level of 10 %, 5 % and 1 %, respectively[8].

$$z_{mk} = \begin{Bmatrix} \frac{s-1}{\sqrt{var\,(s)}}, S > 0 \\ 0, S = 0 \\ \frac{s+1}{\sqrt{var\,(s)}} \end{Bmatrix} \qquad \dots (4)$$

Sen's slope estimator is the most commonly used method to sense a linear trend[5,6,15]. The slope (T_i) of all data pairs is given in Eq. (5)[8].

$$T_i = \frac{(x_j - x_k)}{j - k} \text{ for i = 1,2,3…. N} \qquad \dots (5)$$

Where, x_i and x_j are considered as data values in time j and k (j > k), respectively. The Sen's estimator of the slope is given by the median of N values of Ti, which is projected as given in Eq. (6), in terms of odd and even values are shown in Eq. (7) and (8).

$$Q_i = \begin{Bmatrix} \frac{T_{N+1}}{2} \\ \frac{1}{2}(T_{\frac{N}{2}} + \frac{T_{N+2}}{2}) \end{Bmatrix} \qquad \dots (6)$$

$$\frac{T_{N+1}}{2} \text{ N is odd} \qquad \dots (7)$$

$$\frac{1}{2}(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}) \text{ N is even} \qquad \dots (8)$$

The positive and negative values of Q_i represent an increasing and decreasing trends, respectively.

Spearman's Rho test

It is a rank-based test for correlation between two variables that can be used to test correlation between time and the data series. It is the usual parametric measure of correlation for trend analysis, in which one variable is taken as the time (years) and the other as the corresponding time series data.

Like the M-K test, the 'n' time series values are substituted by their ranks. The test statistic ρ_s is the correlation coefficient, as shown in Eq. (9). It is obtained in the same way as the usual sample correlation coefficient, by using ranks test statistics [13] and are shown below in Eqs. (10-12).

$$\rho_s = \frac{S_{xy}}{\sqrt{S_x S_y}} \quad \ldots (9)$$

$$S_x = \sum_{i=1}^{n} (X_i - \bar{X})^2 \quad \ldots (10)$$

$$S_y = \sum_{i=1}^{n} (Y_i - \bar{Y})^2 \quad \ldots (11)$$

$$Sxy = \sum_{i=1}^{n} (X_i - \bar{X})^2 (Y_i - \bar{Y})^2 \quad \ldots (12)$$

For large samples, the quantity is almost normally distributed with a mean of 0 and a variance of 1.

CUSUM test

The CUSUM test is used to check the statistically significant changes in trends of rainfall time series data and to identify the year in which the trend begins if it exists. It is explained below in Eq. (13)[3].

$$y_i = (x_i + x_{i-1} + x_{i-2} + \ldots\ldots x_n) - i.\bar{X} \quad \ldots (13)$$

Where, y_i- is the computed CUSUM value at any time i, n- is the sample size, x_i, …, x_n is the original rainfall time series data, and x is the average of the total rainfall time series data.

The plot of y_i versus i normally oscillates around a horizontal axis when the original series (x_i, ..., x_n) is free from a statistically significant change in trends. The deviation from the value shows that there is a change in pattern and changes in the trend beginning from the year of observation.

Coefficient of Variance (Cv)

The C_V is a statistical measure of analyzing the individual data points and their variance from the mean value, as shown in Eq. (14). A higher value of C_V is the indicator of more considerable spatial variability, and vice versa[11].

$$C_v = \frac{SD}{x} * 100 \quad \ldots (14)$$

Where, x is - Mean, and SD- Standard Deviation

Results and Discussion

Rainfall characteristics

The trend analysis of precipitation is shown in Figure 2. It shows the unevenness of the annual precipitation data in the basin for the whole period of study. It is observed that there is a decline in annual mean precipitation during the period of 1975-2010. The rainfall characteristics of the basin are shown in Table 1.

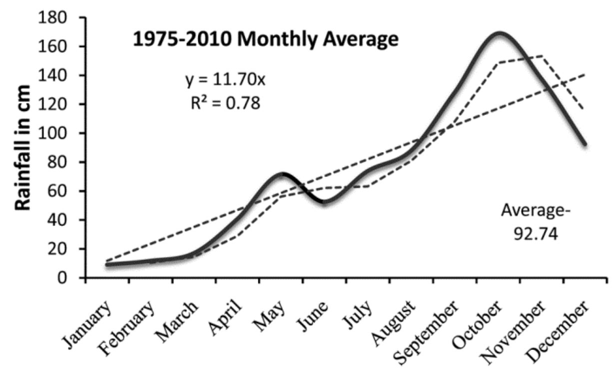

Fig. 2 — Average monthly trend of rainfall pattern in Koraiyar basin

Table 1 — Mean monthly, seasonal and annual rainfall statistics in the Koraiyar basin (1975-2010)

Months	Rainfall (mm)	Standard deviation	Coefficient of Variance	% contribution to annual rainfall
January	9.05	17.71	1.95	
February	11.72	18.40	1.56	1.01
March	17.06	24.74	1.44	1.31
April	40.73	33.33	0.81	1.90
May	71.58	41.40	0.57	4.55
June	52.59	39.64	0.75	7.99
July	73.87	53.87	0.72	5.87
August	88.01	60.79	0.69	8.25
September	128.19	80.21	0.62	9.83
October	169.08	95.21	0.56	14.32
November	137.51	79.82	0.58	18.95
December	92.44	89.71	0.97	15.36
				10.36
		Seasonal		
Winter Jan-March	12.61	20.28	1.65	4.24
Summer April-June	54.96	38.12	0.71	18.48
Pre-monsoon July-September	96.69	64.96	0.68	32.52
Monsoon October-December	133.01	88.25	0.70	44.74
		Annual		
	891.88	52.90	0.94	100

The annual precipitation in the basin is 866.70 mm, with a standard deviation of 52.90 mm based on 35 years of data. The analysis of mean monthly rainfall in the basin shows that rainfall during October is the highest (169.08 mm), which contributes 18.95 % to the annual rainfall followed by November (137.51 mm), September (128.19 mm) and December (92.44 mm). The least amount of rainfall is observed during the months of January (9.05 mm), February (11.72 mm), and March (17.06 mm). The seasonal shift of rainfall is witnessed in the basin.

The Koraiyar basin experiences four distinct seasons, namely, winter (January to March), summer (April to June), pre-monsoon (July to September) and monsoon (October to December). The average winter season rainfall in the basin is 12.61 mm, with a standard deviation of 20.28 mm. The winter rainfall contributes only 4.23 % to the annual rainfall. The average rainfall in summer season is 54.96 mm, with a standard deviation of 38.12 mm, which contributes 18.48 % to the yearly rainfall. The basin receives maximum rainfall during the monsoon season, which contributes 44.74 % to the yearly rainfall. The spatial variability of the rainfall in the basin, expressed by the C_V is calculated using mean monthly and yearly rainfall values. It is noted that the C_V is less throughout the monsoon season, which indicates very less variability whereas the winter season showed high variability of 1.68 %.

The trend analysis for mean monthly, seasonal, and annual rainfall in the Koraiyar basin is carried out with 35 years of rainfall data from 1975-2010. M-K and Sen's Slope estimator are used for the determination of trend. In the non-parametric M-K test, the trend of rainfall is calculated for each month separately with Sen's magnitude of slope (Q). In the M-K test, the Z statistics expose the trend of the series for 35 years of rainfall data for separate months. The trend analysis shows that statistically insignificant (95 % confidence level) negative trends of the mean annual rainfall look as if in almost 9 months, and it shows a statistically significant decreasing trend at 95 % confidence level. The value ranges from -3.03 to -0.29. The maximum decreasing trend is found during March, and the minimum is found during December. Z values for January, May, and November showed an increasing trend.

The values obtained from the analysis using non-parametric methods are shown in Table 2. M-K trend analysis is examined by using M-K equations (1-4). Sen's slope estimators are given in equations (5-8). The trend is detected by Spearman's Rho equation (9). In SR method, a positive and negative trend is almost significant with M-K Test. The substantial change point for this trend is detected by the CUSUM technique.

A significant change is noted in June but the similar trend result of this month is insignificant because trends are calculated for some time after the trend begins. The yearly rainfall for July, October, and November show a significant increasing trend annually. The rainfall during February shows a statistically significant decreasing trend at 95 % confidence level. The rainfall during October shows an increasing trend, which is statistically significant at 95 % confidence level. The rainfall in January and May also showed an increasing trends, but all are statistically insignificant. The rainfall in March, April, June, July; and August, September, November, and December showed insignificant decreasing trends. The comparison between the non-parametric methods is shown in Figure 3.

Increasing rainfall trends, statistically significant at 95 % confidence level, are found only during the monsoon season, all other seasons showed statistically insignificant negative trends, as shown in Table 3.

Table 2 — Mean monthly rainfall analysis by trend and change statistics (1975-2010)

	Trend				Change
Months	MK trend (z)	Spearman's Rho (Z)	Sen's Slope (T)	Trend 95% level of Significance	CUSUM
January	1.39	0.98	-0.57	Increasing	-30.81
February	-1.30	-1.08	-0.90	No trend	-43.54
March	-3.03	-4.08	-0.88	Decreasing	54.22
April	-0.25	-0.99	-2.20	No trend	11.43
May	0.026	-0.36	-4.23	Increase	-47.07
June	-1.04	-1.70	-2.62	No trend	35.17
July	-2.09	-3.18	-4.66	No trend	204.64
August	-0.69	-1.23	0.97	No trend	81.75
September	-1.85	-2.50	-3.88	No trend	149.66
October	0.926	1.7600	-13.24	Increase	268.69
November	-0.61	-1.630	15.68	No trend	80.82
December	-0.29	-0.72	-8.00	Decreasing	-323.07

Table 3 — Seasonal rainfall analysis by trend and change statistics (1975-2010)

Months	MK trend (Z)	Spearman's Rho (Z)	Sen's Slope (T)	Trend 95 % level of Significance	CUSUM
Jan-Mar	-1.76	-2.66	-1.65	No Tend	-6.713
Apr-Jun	-0.04	-0.44	-3.02	No Trend	-0.153
Jul-Sep	-1.79	-2.93	-2.53	No Tend	145.35
Oct-Dec	0.21	-1.26	-11.1	Increasing	8.81

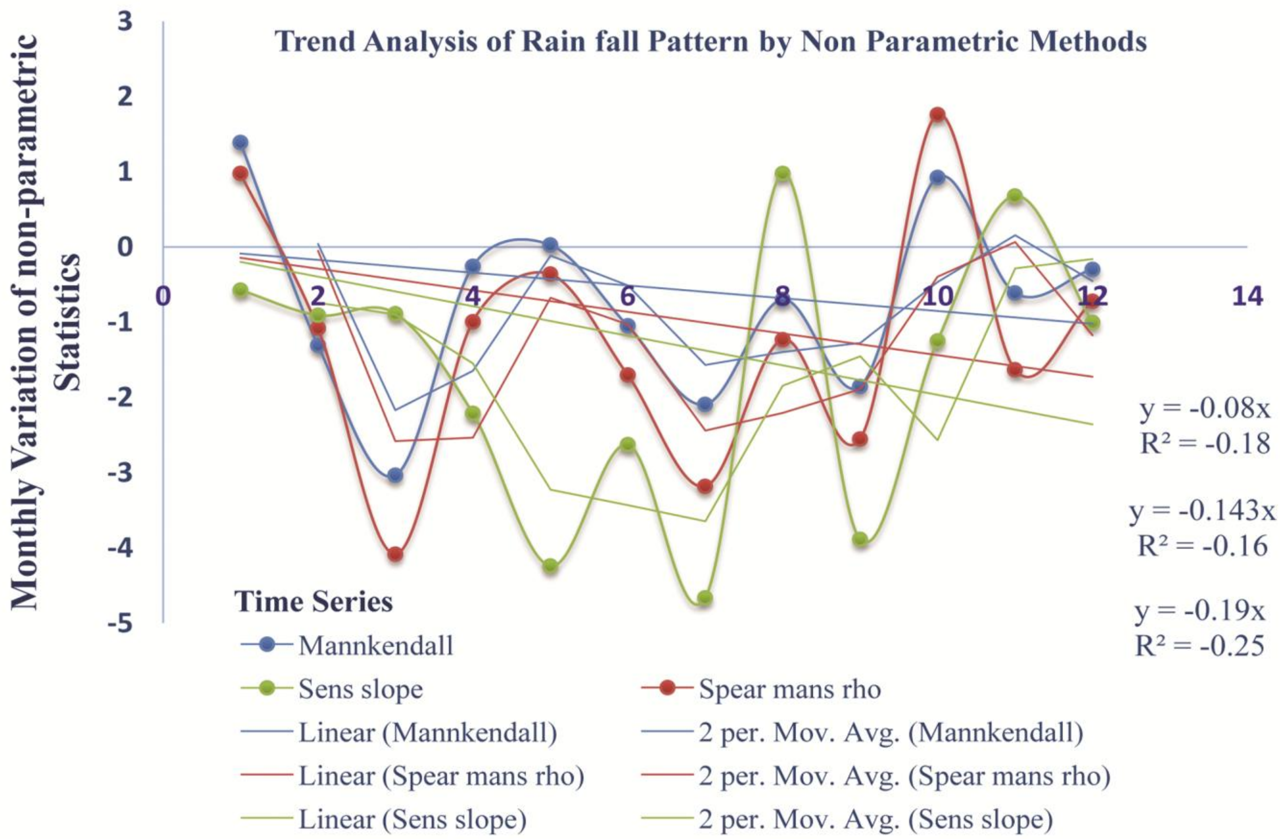

Fig. 3 — Comparison of non-parametric methods

Conclusion

The present explorative study analyzes the temporal variability of rainfall in the selected study area, investigated for 35 years with the help of different statistical techniques. The conclusions gathered from this study can be summarized as follows. The rainfall in the Koraiyar river basin is not uniformly distributed in all seasons and tends to vary. The basin experiences statistically significant decreasing rainfall at 95 % confidence level. Statistically insignificant increasing rainfall trends are noted only for three months, namely, January, February, and March. The rainfall in the basin decreases during March while it increases in October. During the monsoon season (October-November), the basin experiences moderate rainfall. The highest rainfall variability is seen during 1988-1994. The results of the M-K and Sen's Slope statistical tests are quite similar to each other. The trends and variability of rainfall indicate that there is a local climatic change, which can harm the socio-economic development of the study area. Therefore, proper mitigation measures are required to minimize climatic impacts. Practically, the observed trends of rainfall pattern were recomended for designing flood mitigation structures, design of urban storm sewers and drought management in the Koraiyar basin. The results obtained from the analyses will aid in the efficient management of freshwater resources thereby contributing to the economic progress of the region.

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Conflict of Interest

The author declares no conflict of interest.

Author Contributions

The first author NS contributed in this study by data collection, analysis, results and preparation of manuscript. The results and manuscript were reviewed and corrected by second author RN.

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