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Rainfall Trend Analysis using Non-Parametric Test for Raichur Region, Karnataka

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ABSTRACT: The study of rainfall trends is critically important for a country like India whose food security is dependent on the timely availability of water.The purpose of this study is to identify monthly, seasonal and annual rainfall trends, as well as their magnitude, in the Raichur region in Karnataka. Daily rainfall data from 1981 to 2020 was processed using the Mann-Kendall Test, Modified Mann-Kendall Test and the Sen's Slope Estimator to determine trend and slope magnitude. The findings of the trend analysis revealed substantial variations in all seasons. *Zc* readings show a positive trend for ten months and a negative trend for two months. Sen's slope factor reveals a seven-month positive trend, a one-month negative trend and four months of no change in trend. These statistical tests indicated that the region has undergone minor changes overall.

Keywords : Rainfall trend, Precipitation, Mann-Kendall, Modified Mann-Kendall, Sen's Slope estimator.

INTRODUCTION

For more than four decades, trend identification has been a hot topic in hydrology, climatology, water quality, soil moisture, flood predictions, and other natural sciences. Rainfall is the primary supply of water for the world, and it is one of the components of the hydrological cycle. Rainfall in India is highly variable both spatially and temporally. According to Indian Water Resources Society (IWRS, 2016), the annual rainfall averages less than 100 mm in western Rajasthan and more than 2500 mm in the north-eastern region. Between June and September, a substantial portion of India's precipitation is affected by southwest storms, with the exception of Tamil Nadu, which is affected by north-east rainstorms between October and November. In India, agriculture planning and water use are both influenced by monsoon rainfall, which accounts for 75% of total rainfall (Guhathakurta and Rajeevan, 2008; Krishan *et al*., 2015). India receives roughly 4000 billion cubic metres of annual precipitation, according to the Central Water Commission (CWC, 2005). Only 690 BCM and 432 BCM of surface and ground water resources are estimated to be used, respectively. The annual average precipitation was assessed to be 3882.07 BCM in the CWC report of 2008, and the utilisable total surface water and total replenishable ground water were estimated to be 690 BCM and 433 BCM, respectively. As a result, the research indicates that the yearly average rainfall over the country has decreased, indicating a decreasing trend in precipitation. As a result, water availability will fluctuate, and due to the irregularity of rainfall in most regions, water availability will become increasingly challenging. The need to retain river flows during monsoon months is a key stumbling block to fully utilising all available water. In order to store river flows and manage water resources efficiently in a basin during monsoon months, precise data on the basin's spatial, temporal, and rainfall trends is essential. The analysis of rainfall and the determination of yearly maximum daily rainfall will improve the management of water resources applications and the efficient use of water resources (Subudhi, 2007). Changes in land use due to the impact of agricultural and irrigation methods are also contributing to climate change as a result of urbanisation (Kalnay and Cai, 2003). The amount of water available to service diverse demands, such as agricultural, industrial, domestic water supply, and hydroelectric power generation, is determined by the amount of rainfall received in a given location. For trend detection, a variety of parametric and non-parametric approaches have been used. The Mann-Kendall (MK) test (Kwarteng *et al*., 2009; Manikandan and Tamilmani, 2012; Mondal *et al*., 2012; Rahman and Monira 2013; Rani *et al*., 2014; Das *et al.*, 2014; Ganguly *et al*., 2015; Pandit, 2016) is a frequently used non-parametric test for detecting a trend in hydroclimatic data series. Recently, Sridhara *et al.*, (2020) observed that there is an increasing trend in rainfall during winter, monsoon and annual basis and decreasing trend of rainfall during pre and post monsoon season. Shraddha *et al*., (2020) noticed that the trend in rainfall time series is decreasing in the recent decade on annual and seasonal scale. Using Mann-Kendall trend analysis and Sen's slope estimator, the current study attempts to investigate the rainfall distribution and trend in the Raichur region. The trend was studied using R-software and rainfall data spanning 40 years (1981-2020).

MATERIALS AND METHODS

Study Area: The research region is in the northern section of India's Karnataka state. It is positioned between the Krishna and Tungabhadra rivers and is located at 16°20' N latitude and 77°37' E longitude (Deccan Plateau). The location is in the monsoon climatic region, with yearly temperatures ranging from 18 to 45 degrees Celsius and annual rainfall of roughly 658 millimetres. The monsoon season, which runs from June through October, sees the most rainfall. It is rich in deposits from the Krishna and Tungabhadra rivers. Droughts have a significant impact on agricultural activities (Fig. 1).

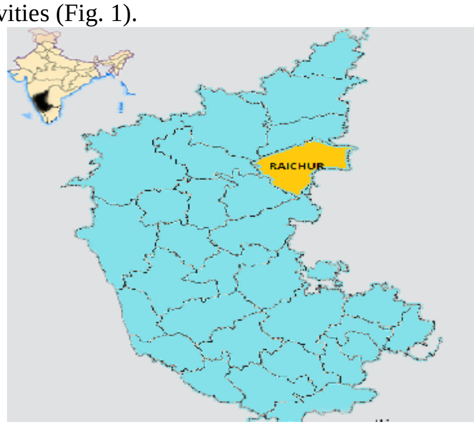

Fig. 1. Location Map of the Raichur region.

Data Collection: The study relied heavily on rainfall data from the Raichur region of Karnataka, which included rainfall durations and intensities. Daily rainfall statistics from the website www.climateengine.com for the years 1981 to 2020. A rainfall analysis was conducted independently for each season and for the entire year. The R-software was used to calculate the rainfall in Raichur on a monthly, seasonal, and annual basis.

Rainfall Trend Analysis: The non-parametric Mann-Kendall test (Mann, 1945; Kendall, 1975) is often used for hydrologic data analysis to discover monotonic but not necessarily linear trends. The independent and randomly arranged data is the null hypothesis in the Mann-Kendall test. The Mann-Kendall test does not assume normality and only identifies the direction of significant trends, not their magnitude. The formula for calculating the Mann-Kendall test statistic S is as follows:

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

The trend test is applied to two time series: x_i, which is ranked from $i = 1,2,\dots,n-1$, and x_j, which is ranked from $j = i+1,2,\dots,n$. Each data point x_i is used as a reference point, and the remainder of the data points x_j are compared to it

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

For all the differences analysed, this statistic represents the number of positive differences minus the number of negative differences. The test is carried out with a normal approximation (Z statistics) for big samples ($N > 10$), with the mean and variance as follows:

$$E[S] = 0 \qquad (3)$$

$$Var(S) = \frac{1}{18}\left[N(N-1)(2N+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \qquad (4)$$

t_p is the number of data values in the pth group, and q is the number of tied (zero difference between compared values) groups. The test statistic Z is calculated using the values of S and Var(S)

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & \text{if } S < 0 \end{cases} \qquad (5)$$

The Z value is used to determine whether a statistically significant trend exists. A positive Z number denotes an upward trend, while a negative value denotes a downward trend.

Rainfall Trend using MMK test: For autocorrelation series trend detection, the Modified Mann-Kendall (MMK) test was used (Hamed and Rao, 1998). After removing the non-parametric Sen's median slope from the data (Mondal *et al.*, 2012), the autocorrelation between the ranks of the observations ρ_k was computed in this study. The variance correction factor n/n^* was calculated and significant values of ρ_k were solely used for that purpose

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)} \times \sum_{k=1}^{n-1} (n-k)(n-k-1)(n-k-2)\,\rho_k \qquad (6)$$

where n is the number of real observations, n^* is the number of effective observations to account for autocorrelation in the data, and ρ_k is the autocorrelation function for the ranks of the observations. After that, the corrected variance is provided as (Hamed and Rao, 1998),

$$Var^*(S) = Var(S) \times \frac{n}{n^*} \qquad (7)$$

where $Var\ (S)$ is from equation (4).

The size of the rainfall trend devised a non-parametric method for estimating the size (slope) of a time series trend (Sen, 1968). This approach presupposes that the time series has a linear trend. The slope Q_i of all data value pairs is determined using this method

$$Q_i = \frac{x_j - x_k}{j-k} \qquad (8)$$

where j is greater than k. If the time series has n values x_j, we get $N = n(n-1)/2$ slope estimates Q_i. The median of these N values of Q_i is Sen's estimator of the slope. The Sen's estimator is used to rank the N values of Q_i from smallest to largest.

$$Q = \begin{cases} Q_{\frac{N+1}{2}}, & \text{if } N \text{ is odd} \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+1}{2}}\right), & \text{if } N \text{ is even} \end{cases} \qquad (9)$$

To obtain the true slope for the non-parametric test in the series (Kwarteng *et al.*, 2009), the two-sided test is performed at $100\ (1-a)$ percent of the confidence interval. The upward (growing) or downward (decreasing) trend is determined as the positive or negative slope Q_i.

RESULTS AND DISCUSSION

Mean Annual Rainfall: Rainfall distribution in the Raichur region has been investigated for the past 40 years (1981-2020). The Raichur region's average annual rainfall is 800.45 mm, based on 40 years of precipitation data (1981-2020).

The maximum annual rainfall was 1288.40 mm in 2020 followed by 1195.28 mm in 2007 and 1116.65 mm in 2005, while the lowest was 536.46 mm in 1982 followed by 539.87 mm in 2003 and 546.21 mm in 1992 (Fig. 2).

Monthly Variation of Rainfall: The rainfall pattern of distinct months during a 40-year period is depicted (Fig. 3).

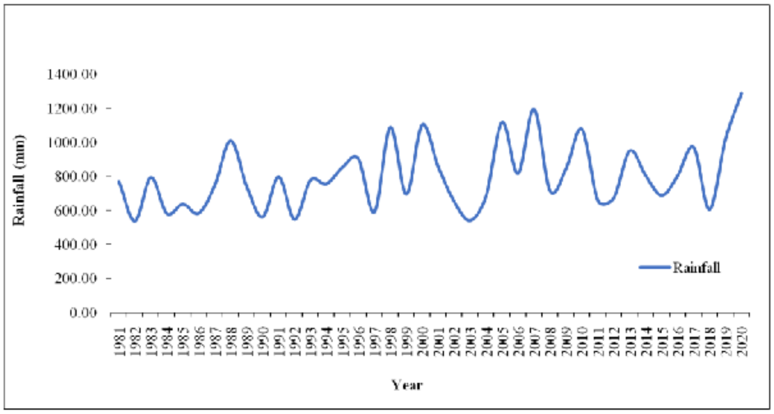

Fig. 2. Mean annual rainfall of the study area (1981-2020).

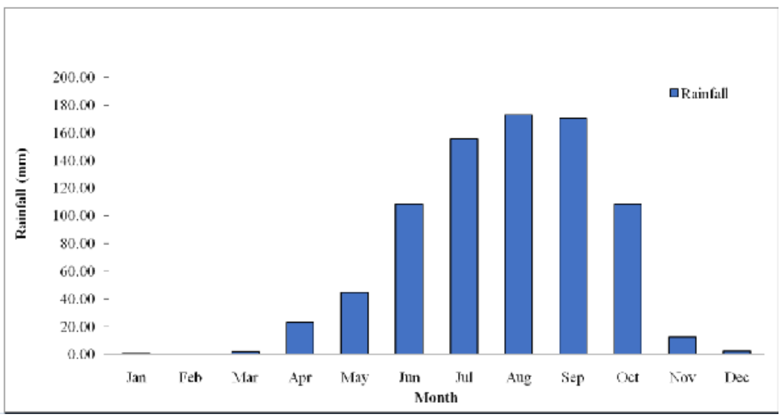

Fig. 3. Average monthly rainfall of the study area (1981-2020).

The month of August has the most rainfall (173.32 mm), followed by September (170.61 mm), and July (159.69 mm). For the past 40 years, the least rainfall received month has been February (0.05 mm), followed by January (0.31 mm) and March (2.04 mm).

Seasonal Variation of Rainfall: The seasonal rainfall distribution over the last 40 years is illustrated (Fig. 4).The results obtained were found in concurrence with the findings of Sridhara *et al*., (2020).

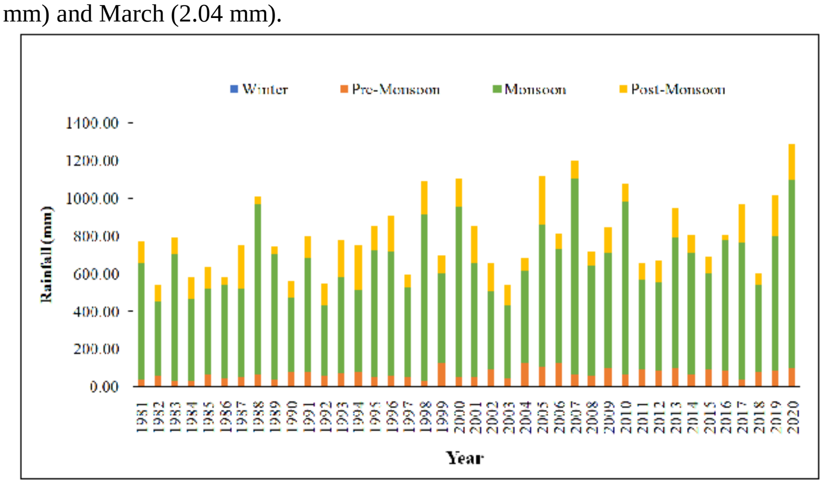

Fig. 4. Seasonal rainfall of the study area (1981-2020).

Monsoon (Jun-Sep) is expected to deliver the most rainfall 607.85 mm (75.94%), followed by Post-Monsoon (Oct-Dec), which will bring 123.09 mm (15.38%), Pre-Monsoon (Mar-May), which will contribute 69.15 mm (8.64%), and Winter (Jan-Feb), which will contribute 0.36 mm (0.05 %).

Mann-Kendall Trend Analysis: The non-parametric Mann-Kendall test was used to calculate the rainfall trend for 40 years from January to December for each month separately, as well as the Sen's slope (Q). The Zc statistics demonstrated the pattern of the series for 40 years for individual 12 months from January to December in the Mann-Kendall test (Fig. 5).

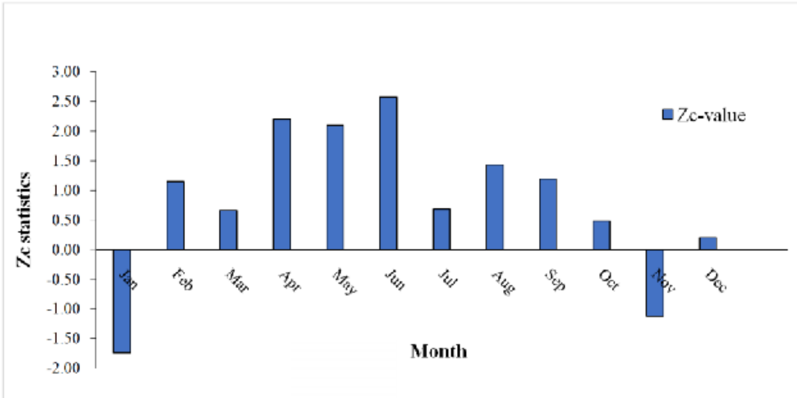

Fig. 5. Trend of Zc for individual months for 40 years.

The month of June has the highest positive trend of 2.58, followed by April, May, August, September, February, July, March, October, and December. The month of January has the biggest negative trend of -1.74, followed by November. Thus, Zc values show a positive trend for ten months and a negative trend for two months, indicating an almost non-significant condition.

Sen's Slope (Q) Estimator: The non-parametric results of rainfall trend by Sen's slope (Q) estimator for 40 years, from January to December is determined (Fig. 6).

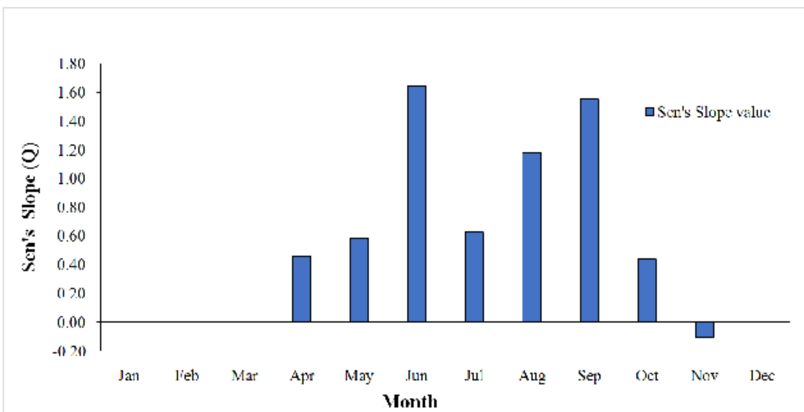

Fig. 6. Trend of Sen's slope (Q) for individual months for 40 years.

For the months of April, May, June, July, August, September, and October, Sen's slope estimator reveals a positive trend. November has a negative trend, while January, February, March, and December have no change in trend.

Table 1 : Result of Mann Kendall and Sen Slope Estimator during 1981-2020.

Month	Zc-value	p-value	S	$Var(S)$	tau	Sen's slope
Jan	-1.74	0.08	-110.00	3902.00	-0.22	0.00
Feb	1.15	0.25	38.00	1038.67	0.16	0.00
Mar	0.67	0.50	46.00	4524.67	0.09	0.00
Apr	2.20	0.03	190.00	7366.67	0.24	0.46
May	2.11	0.03	182.00	7364.67	0.23	0.59
Jun	2.58	0.01	222.00	7364.67	0.28	1.65
Jul	0.69	0.49	60.00	7366.67	0.08	0.63
Aug	1.43	0.15	124.00	7366.67	0.16	1.18
Sep	1.20	0.23	104.00	7366.67	0.13	1.55
Oct	0.48	0.63	42.00	7366.67	0.05	0.44
Nov	-1.12	0.26	-97.00	7349.00	-0.13	-0.10
Dec	0.20	0.84	17.00	6107.00	0.03	0.00

Mann-Kendall's non-parametric tests, as well as a 95 percent confidence bound estimate for the slope for each month from January to December over a 40-year period. For the months of April, May, and June, there is a significant trend at the 5% level of significance, however for the remaining months, there is a non-significant trend.

CONCLUSIONS

The Zc statistics revealed the trend of the series for 40 years (1981-2020) for individual 12 months from January to December, which are -1.74, 1.15, 0.67, 2.20, 2.11, 2.58, 0.69, 1.43, 1.20, 0.48, -1.12, and 0.20, respectively, in the non-parametric Mann-Kendall test. There is evidence of growing rainfall tendency in the months of February, March, April, May, June, July, August, September, October, and December, whereas Zc value is displaying a negative trend in January and November. Similarly, there is a positive trend in Sen's slope estimator for the months of April, May, June, July, August, September, and October. Only the month of November shows a downward trend. The pattern did not change in the four months of January, February, March, and December. Thus, Zc readings for three months demonstrate a significant condition and non-significant condition for the remaining nine months. The rainfall trend study assisted in understanding the Raichur region's monsoon pattern and so anticipating a flood crisis during the monsoon season.

FUTURE SCOPE

The trend analysis of rainfall will be help to develop suitable coping mechanisms for changing climatic conditions during the cropping season. Since rice and cotton are the major kharif crop (May-October) in this region, the increasing trend of rainfall during the month of August may affect the vegetative phase of the crops. The decrease in rainfall during November may create panic situation in sowing of important rabi crop (i.e., wheat) in this region.

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Conflict of Interest. Authors have declared that no conflict of interest exist.

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