Trend Analysis of Rainfall Patterns in Rajnandgaon District, Chhattisgarh, India

ABSTRACT

Climate is a crucial determinant of an area's vegetation, wildlife, and livability, influenced by long-term atmospheric characteristics and fluctuations. Precipitation, particularly rainfall, plays a vital role in the Earth's hydrological cycle, connecting weather, climate, and water resources. This study focuses on Rajnandgaon district in Chhattisgarh, India, with an average annual precipitation of 1274mm. Analyzing trends, we identify changes in certain properties over time. The findings indicate that rainfall variability, measured by the coefficient of variation, is lowest during June to September (CV < 76%). Monsoon rainfall displays the least variability (CV of 30.88%), while pre-monsoon rainfall and winter rainfall exhibit higher variability (CV of 33.83% and 208.48%, respectively). The analysis also reveals a significant decreasing trend in annual, monsoon, and September rainfall. However, May rainfall shows a significant increase at a 5% level of significance. The study utilizes the non-parametric Mann-Kendall and Sen's Slope Estimator tests, employing monthly rainfall data from 1988 to 2018 for Rajnandgaon district, Chhattisgarh.

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Keywords: Climate, Rainfall, Trend Analysis and Non Parametric Test

INTRODUCTION

Climate is the atmospheric condition at a specific location, encompassing information about the types of plants, animals, and suitability for human habitation. It represents a long-term summary of various atmospheric factors and their fluctuations, including solar radiation, temperature, humidity, rainfall, atmospheric pressure, wind, and its direction. Rainfall plays a crucial role in transporting water from the atmosphere to the Earth's surface, connecting weather patterns, climate, and the hydrological cycle. In the case of India, precipitation holds significant importance for regional climate, annual crops, food production, local economy, and has therefore been the subject of numerous studies analyzing long-term trends.

The Indian climate is predominantly influenced by the southwest monsoon, with around 80% of rainfall occurring during the four monsoon months (June-September) and exhibiting substantial spatial and temporal variations across the country. Precipitation in

India primarily takes the form of rainfall. One of the challenges posed by climate variability is identifying and quantifying trends in rainfall, as well as understanding their implications for river flows. Analyzing these trends helps in effective water resource management and the formulation of appropriate adaptation strategies. The scientific community has placed significant attention on rainfall trend analysis in the past century due to the global focus on climate change (IPCC, 1996).

Trend analysis provides insights into whether concentrations of rainfall are increasing or decreasing over time. It serves as a key tool for predicting rainfall patterns and rainy days in a particular area, facilitating planning for agricultural activities based on yearly and monthly rainfall and rainy day data.

STUDY AREA

The study area is Rajnandgaon district, located in the state of Chhattisgarh, India. It was established on 26 January 1973 through the division of Durg district. Rajnandgaon is a large district spanning 8022.55 square kilometers and is situated between 21.10° N Latitude and 81.03° E Longitude. It has an average elevation of 307 meters and receives an annual precipitation of 1274mm. The region is encircled by Kabirdham district in the Northern direction, Bastar district in the Southern direction, Durg district in the Eastern direction, and on the Western side, it shares borders with Gadchiroli and Bhandara districts of Maharashtra state, along with Balaghat district of Madhya Pradesh state.

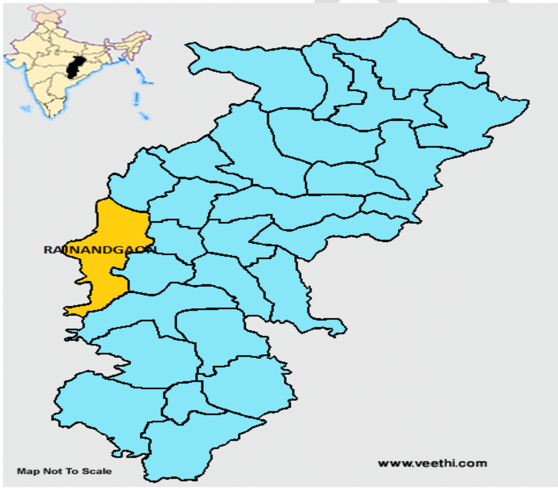

Fig. 1: Map of Rajnandgaon district in Chhattisgarh and India map

Fig. 2: Map of Rajnandgaon District

METHODOLOGY

The study area's meteorological data, focusing on rainfall and rainy days, was examined using non-parametric statistical techniques. These approaches are more appropriate for analyzing data that does not follow a normal distribution, as opposed to parametric statistical test.

The Mann-Kendall (MK) test stands as the prevailing non-parametric statistical method employed to identify trends in hydro-meteorological time series variables, including but not limited to water quality, stream-flow, temperature, and precipitation. This test suite encompasses various assessments: the Mann-Kendall test for recognizing consistent trends, Sen's slope test for gauging slope magnitude, and Wilcoxon Mann-Whitney step trend analysis. These methodologies collectively aid in detecting and quantifying trends within the mentioned variables.

A trend refers to a significant evolution over time observed in a random variable. Typically, the extent of a trend in a time series is determined either through regression analysis (a parametric examination) or the Mann-Kendall test (a non-parametric approach). Both of these techniques assume a linear trend in the time series. In this specific investigation, both linear regression and the Mann-Kendall test were employed. The trend analysis was conducted annually and seasonally. Meteorologically, a year is divided into four seasons: the southwest monsoon season (June-Sep), post-monsoon season (Oct-Dec), winter season (Jan-Feb), and summer season (Mar-May).

Mean rainfall:

The quantity of precipitation gathered in a rain gauge during a 24-hour period is termed "daily rainfall," whereas the cumulative amount measured throughout a year is known as "annual rainfall." The average total rainfall recorded over a span of 31 years in India is referred to as "mean annual rainfall" or "normal annual rainfall."

$$\text{Mean annual rainfall} = \frac{\text{Total rainfall}}{\text{Number of years}}$$

Standard Deviation:

Standard deviation represents the square root of the average of squared differences between rainfall values and their mean, indicating variability or dispersion. Its formula is as follows.

$$\mathrm{SD} = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}}$$

Where,

X_i= rainfall frequency, $\bar{X}$= mean rainfall, n= numbers of year

Variability analysis (Coefficient of variation):

Assessment of rainfall variability using the Coefficient of Variation (CV %) seems straightforward. The CV is calculated by dividing the Standard Deviation by the mean rainfall value, presenting rainfall variability as a percentage.

$$CV = \frac{\sigma}{\bar{X}} \times 100\ \%$$

The higher the coefficient of variation (CV), the lower the reliability of rainfall occurrence. To evaluate the rainfall in a specific region, the Indian Meteorological Department (IMD) employs the subsequent criteria, taking into account the yearly CV.

Normal = - 19 to 19 % of annual normal rainfall.

Deficit = - 20 to - 59 % of annual normal rainfall.

Scarce = - 60 % and above of annual normal rainfall

A trend is a notable change in a random variable over time. Trend magnitude is typically assessed using regression analysis or Mann Kendall's non-parametric test, with the latter being used in this study. The non-parametric tests used are listed below.

NON- PARAMETRIC TREND TEST-

- **Mann-Kendall Analysis :**

Mann-Kendall's test stands as a non-parametric approach that exhibits reduced sensitivity to outliers. Its primary purpose is to assess the presence of a trend within time series data, all the while refraining from mandating that said trend must be either linear or non-linear in nature.

The Mann-Kendall test assesses trends in a dataset without assuming any specific probability distribution. The test statistic (S) is computed as follows:

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

Here, S represents the Mann-Kendall test statistic. The variables xi and xj denote sequential data points from a time series occurring in years i and j, respectively (where j > i). The parameter 'n' corresponds to the length of the time series.

A positive (S) value denotes an upward trend, while a negative value indicates a downward trend in the data series. The sign function is defined as follows:

$$\mathrm{Sgn}(x_j - x_i) = \begin{cases} +1 \text{ if } (x_j - x_i) > 0 \\ 0 \text{ if } (x_j - x_i) = 0 \\ -1 \text{ if } (x_j - x_i) < 0 \end{cases}$$

The variance of S, considering the presence of tied values (i.e., equal values) in the x values, can be calculated using the following formula:

$$V(s) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{g} tp(tp-1)(2tp+5)}{18}$$

Where:

g is the number of tied groups. tp is the number of data values in the pth group.

n represents the number of years of data.

For values of (n) greater than 10, the approximation of the standard normal distribution is computed through the following formula:

$$Z_{mk} = \begin{cases} \frac{S-1}{\sqrt{\text{var}(s)}}; \text{if } S > 0 \\ 0 \quad ; \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{var}(s)}} \; ; \text{if } S < 0 \end{cases}$$

To assess the presence of a statistically significant trend, we examine the Z_{mk}value. A positive or negative value of Z indicates an upward or downward trend. respectively. In a two-sided test for trend, we can accept the null hypothesis H_o

if $Z_{mk}<Z_{(1-\alpha)/2}$ at a given level of significance. $Z_{(1-\alpha)/2}$ represents the critical value of Z_{mk} from the standard normal table.

Sen's slope :

The method employed for estimating the magnitude of the trend slope is as follows. Sen's slope estimator is a non-parametric, linear technique that is particularly effective when applied to data exhibiting monotonic behavior.

Sen's slope method is utilized to ascertain the extent of the trend line. This evaluation calculates both the slope (representing the linear rate of change) and the intercept, employing Sen's approach. Initially, a series of linear slopes is computed using the following formula:

$$\text{Median } (d_k) = \frac{(\mathbf{Xj-Xi})}{(\mathbf{j-i})}, \quad \text{for}(1 \leq i<j \leq n),$$

Where,

d = slope, X = variable, n = number of data , i, j = indices.

Afterwards, Sen's slope is obtained as the median value from all the calculated slopes, represented as: b = median(d_k).

In this context:

b = estimated slope of the trend, and

Xi = the j^{th} observation.

A positive value of b indicates an upward trend, while a negative value represents a downward trend.

Additionally, the intercepts for each timestep "t" are computed as follows:

at = Xt – b × t.

- **Spearman's rho (SR) test :**

After the MK (Mann-Kendall) test gained popularity for evaluating the significance of trends in hydro-meteorological time series, the SR (Spearman's rho) test has become less frequently employed in hydro-meteorological trend analysis.

$$D = 1 - \frac{6\sum_{i=1}^{n}[R(x_i) - i]^2}{n(n^2 - 1)}$$

In this equation, R(xi) represents the rank of the ith observation (xi) in the sample of size n. Under the null hypothesis, the distribution of D tends towards normality, and its mean and variance are given by:

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$$E(D)=0$$

$$V(D) = \frac{1}{n - 1}$$

RESULTS AND DISCUSSION

This section unveils the outcomes of an exhaustive examination performed on rainfall and rainy days data spanning 31 years. The obtained findings will be critically analyzed in connection with pertinent literature, encompassing the subsequent facets.

Table 1: Monthly rainfall statistics for the period (1988-2018) of Rajnandgaon district of Chhattisgarh

Month/ Period	**Mean monthly rainfall (mm) (1988-2018)**		
	Mean (mm)	**CV (%)**	**Contribution (%)**
JAN	2.80	146.55	0.29
FEB	3.26	177.91	0.33
MAR	21.85	65.41	2.25
APR	12.14	88.53	1.25
MAY	18.17	61.48	1.88
JUN	153.58	21.74	15.86
JUL	306.00	28.36	31.60
AUG	223.59	25.37	23.08
SEP	170.15	25.87	17.56
OCT	55.23	82.60	5.70
NOV	0.31	323.84	0.03
DEC	1.35	382.80	0.14
ANNUAL	**968.43**	**32.93**	**100**
MONSOON	**754.98**	**30.88**	**77.95**
PRE-MONSOON	**205.75**	**33.83**	**21.24**
WINTER	**7.74**	**208.48**	**0.80**

The monthly rainfall in Rajnandgaon district, Chhattisgarh, exhibits significant variability as evident from its high standard deviation (SD) and coefficient of variation (CV). The table presents the mean, CV, and percentage contributions of rainfall. Over the 31-year period from 1988 to 2018, the average annual rainfall was recorded at 968.43mm, with a CV of 32.93%. The corresponding percentage contributions were 100% for the overall period.

Analyzing the monthly data, July experienced the highest average rainfall at 306.00 mm, while November had the lowest at 0.31 mm. When considering seasonal patterns, the monsoon season had the highest cumulative rainfall of 754.98 mm, followed by the pre-monsoon season with 205.75 mm, and the winter season with 7.75 mm. The CV values for the seasonal rainfall were 30.88, 33.83, and 208.48, respectively for monsoon, pre-monsoon, and winter. The corresponding percentage contributions were 77.95%, 21.24%, and 0.80%.

The districts receive the majority of their annual rainfall during the monsoon season. The south-west monsoon, which spans from June to September, brings the highest amount of rainfall. Although other months also contribute to the average annual rainfall, their impact is comparatively minimal compared to the substantial rainfall during the monsoon period.

TREND ANALYSIS OF MONTHLY RAINFALL

The rainfall data of Rajnandgaon district spanning from 1988 to 2018 has been categorized into three separate time series. The objective is to examine the rainfall trends in two distinct periods and make a comparative analysis. The time series are as follows: (i) 1988-2018, (ii) 1988-2003, and (iii) 2004-2018. Each time series will be analyzed individually.

Table 2: Trend analysis of monthly rainfall

MONTH/ PERIOD	1988-2018			1988-2003			2004-2018		
	MK	SR	SS	MK	SR	SS	MK	SR	SS
JAN	0.00	0.02	0.00	0.17	0.27	0.00	-0.21	-0.27	0.00
FEB	0.06	0.09	0.00	-0.09	-0.11	-0.01	0.00	0.01	0.00
MAR	0.10	0.14	0.13	0.30	0.39	1.40	-0.02	-0.04	-0.05
APR	0.55	0.05	0.05	-0.16	-0.27	-0.34	-0.03	-0.07	-0.09
MAY	-0.10	-0.16	-0.14	0.06	0.09	0.02	0.06	0.08	0.20
JUN	-0.10	-0.15	-0.58	0.02	0.01	0.33	0.05	0.07	0.35
JUL	-0.03	-0.06	-0.26	-0.02	-0.08	-0.42	-0.25	-0.37	-4.00
AUG	-0.12	-0.16	-0.86	0.30	0.46	5.64	0.17	0.24	1.59
SEP	-0.22	-0.32	-1.62	0.19	0.23	1.79	0.09	0.13	0.43
OCT	0.03	0.01	0.26	-0.13	-0.24	-1.44	-0.08	-0.12	-1.53
NOV	-0.08	-0.10	0.00	0.10	0.11	0.00	-0.27	-0.35	0.00
DEC	0.18	0.23	0.00	0.07	0.08	0.00	0.12	0.14	0.00

Here:

MK= Mann-Kendall test,SR= Spearman's rho test, SS= Sen's slope

Observing the analysis separately, the values from 1988 to 2018 show a negative trend in September but a positive trend in both 1988-2003 and 2004-2018. Similarly, all values in July exhibit a downward trend.

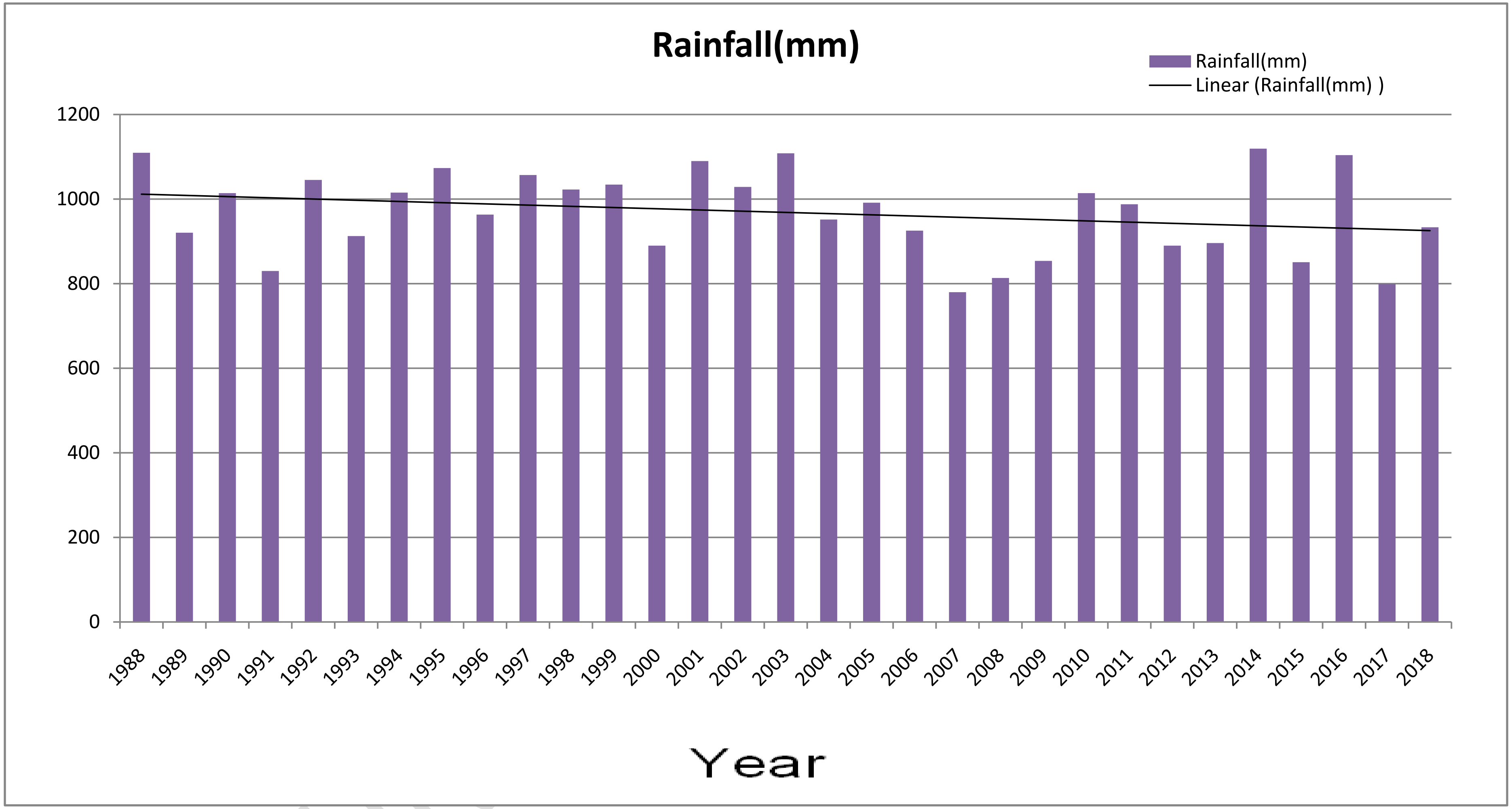

Fig.3: Annual Rainfall trend of Rajnandgaon

Conclusion

The findings of this study reveal interesting patterns in the monthly rainfall data for Rajnandgaon district of Chhattisgarh from 1988 to 2018. After analysis, it has been established that the variability, represented by the coefficient of variation, is quite low in the months of June, July, August, and September (CV < 76%). Notably, the monsoon precipitation demonstrates the least amount of variability, having a coefficient of variation of 30.88%, while the pre-monsoon phase shows slightly higher variability, with a coefficient of variation of 33.83%. Conversely, the winter rainfall experiences the highest variability, with a coefficient of variation of 208.48%.

Utilizing the non-parametric Mann-Kendall and Sen's Slope Estimator tests, a thorough examination was performed on the rainfall data to analyze trends. The findings reveal a noteworthy declining pattern in annual, monsoon, and September rainfall. Nevertheless, it is important to highlight that there is a considerable rise in May rainfall, with a statistical significance level of 5%.

The results offer precious perspectives into the precipitation trends of Rajnandgaon district and add to an enhanced comprehension of the regional climate dynamics.

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