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RESEARCH ARTICLE

Trend Analysis of Long Term and Seasonal Rainfall in Guntur District of Andhra Pradesh for Implementing Appropriate Measures to Manage Water Resources

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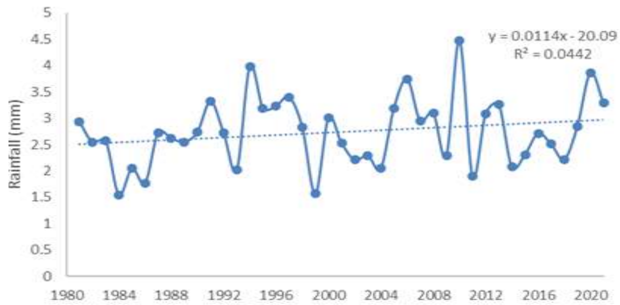
HIGHLIGHTS

- This study emphasizes the need for understanding long-term and seasonal trends to address the impact on agriculture and water resources.
- Understanding these seasonal variations can aid in devising strategies to mitigate risks of crop failure and water scarcity.
- The study highlights the practical significance for farmers by providing insights into the variations in monthly and seasonal rainfall patterns.

GRAPHICAL ABSTRACT

Trend of yearly rainfall of Guntur district from 1981 to 2021



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ABSTRACT

Context: Water, a vital source for agriculture, relies significantly on rainfall. The change in the distribution of rainfall response is an alarming situation to managers of water resources, because they are changing the quantity and frequency of rainfall, which is affecting soil moisture, groundwater reserves, and stream flows and demands. Guntur district in Andhra Pradesh, heavily depends on rainfall for agricultural production. The variability in rainfall has significant implications for major crop productivity, emphasizing the need for a detailed rainfall analysis to devise strategies addressing changing weather patterns and mitigating risks of crop failure and water scarcity.

Objective: The study was taken up with an aim to understand the long term and seasonal trends in the rainfall pattern.

Method: To understand the pattern existing in the rainfall data of Guntur, parametric like linear regression and non-parametric tests such as the Mann-Kendall test, Modified-Mann Kendall tests were applied. Wallis and Moore test was employed to look into the randomness of the rainfall data under consideration. The seasonal rainfall data of Guntur district acquired from the NASA power website which ranged from January 1981 to December 2021 for this study.

Results & Discussion: An increasing and declining trend was seen in linear regression trend method. The significant result was found in the months of April and June which showed an increasing trend, whereas remaining months showed non-significant trend in modified Mann Kendall test. The Monsoon season showed a significant trend whereas pre-monsoon and post-monsoon periods presented a non-significant trend in the rainfall pattern of Guntur district. The yearly rainfall of Guntur district showed a non-significant trend pattern by Modified Mann-Kendall test.

Significance: This study helps the farmers aware of variations in monthly and seasonal rainfall, they can better allocate resources and prepare for predicted water shortages during non-monsoon months.

In the face of escalating climate change, it is crucial to recognize the profound implications on water resources. Water supply is considered as the key source for agriculture which is largely influenced by rainfall and its supply. The shifts in the distribution of rainfall response are an alarming situation to water resource manager, as these changes in rainfall frequency and quantity are altering the pattern of stream flows and demands, soil moisture and ground water reserves (Srivastava *et al.,* 2014). Recognizing these changes is vital for effective water resource management, especially given the potential risks like water scarcity and disruptions in sustainable practices.

In India, farming is the backbone of the economy more than 70 per cent of population dependent on it. Farming is not so linear as we think. Farming is not just influenced by seed, fertilizer, irrigation, plant protection chemicals. It depends on several other factors namely weather conditions *(*Jyothi *et al.,* 2020*).* Weather is the dominant factor determining the success or failure of agricultural enterprises. Any abnormalities in weather during the season, such as delay in onset of rains, untimely or excessive rains, droughts or spells of too high or too low temperatures, would seriously affect the growth and yield of the crops (Ravi Sankar *et al,* 2009). The major problem in crop cultivation is terminal moisture stress (Jyothi and Venkata Subbaiah, 2019). Weather conditions are required to be predicted for future planning in agriculture. It is often used to warn about natural disasters are caused by abrupt change in climatic conditions (Paras and Sanjay Mathur, 2012).

The South-West Monsoon is the primary source of rainfall in the country, accounting for over 70 per cent of the net rainfall received annually. Monsoon rains provide relief from the sweltering summer heat conditions, also replenishes the water bodies and reservoirs, and recharges groundwater aquifers (Abrol and Gupta, 2019). However, the quantity of rainfall received from the Northeast Monsoon is relatively less in comparison to the Southwest Monsoon. Good monsoon is a key indicator for the Indian agriculture as cultivable rainfed area supplies 40 per cent of the foodgrain demand along with supply of fodder, coarse cereals, pulses and oilseeds (Tyagi *et al.,* 2015).

In India, many places have abundant rainfall during the monsoon season, while others experience water scarcity (Goswami, 2016). with this connection Guntur, district of Andhra Pradesh in India, is an agriculturally rich area, in this district crop cultivation mainly reliant on rainfall. Guntur experiences roughly 1000 mm of rainfall on average each year, with the rainy months being July, August, and September. Variability in rainfall pattern creating adverse effect on productivity of major agricultural commodities. Leaning analysis of rainfall is crucial in developing strategies to cope with the changing weather patterns and minimize the risks of crop failure and water scarcity. Rainfall trends analysis in Guntur is crucial because it helps in understanding the long-term behaviour of precipitation in the region. This analysis can be applied to identify any changes or fluctuations in rainfall patterns, which can help farmers and policymakers in making informed decisions related to agriculture and water management.

The majority of studies of trend analysis in numerous regions that have been published were conducted in small groups using standard linear regression trend analysis and a few nonparametric techniques. In this work, we performed modern statistical methods for trend analysis, including non-parametric methods like the Mann-Kendall test, Sen's slope estimate, Modified Mann-Kendall test along with linear regression trend (parametric). The analysis in this paper is further parted into various sections as follows: the basic descriptive statistics are followed by the linear regression trend, the Mann-Kendall test, Sen's slope estimation and the Modified-Mann Kendall test. In the results and discussion part, the findings from each area are explored and discussed. Finally in conclusion section the output of this work is highlighted. The research was done by taking an objective as to analyse the trend analysis of long- term annual and seasonal rainfall pattern in Guntur district of Andhra Pradesh.

METHODOLOGY

Guntur district is located in the southern Indian state of Andhra Pradesh (Fig1.), between 15.45°N latitude and 80.12°E longitude with an average elevation of 108ft to the Bay of Bengal. The district has a diverse topography with a coastal plain to the east and a hilly terrain to the west. For this study the monthly rainfall data of Guntur district of Andhra Pradesh state was collected from January 1981 to December 2021 was collected from the NASA power website. (https://power.Iarc.nasa.gov). To study the variability in rainfall pattern different trend tests have been employed on rainfall (mm/day) data of Guntur. The information gathered was tabulated, evaluated, and statistically analysed in order to forecast the rainfall trend in Guntur district. The data was analysed to explain the trend pattern of Monsoon (June to September), pre-monsoon (January to May), post-monsoon (October to December), and annual rainfall.

Fig 1. Study area map

Trend analysis: Trend refers to a pattern found in the time series dataset. The trend may be positive or negative and upward or downward. It can be estimated by using statistical parametric or non-parametric tests. In this research work to assess rainfall parametric and non-parametric test were used. By applying the standard mathematical procedures descriptive statistics were computed (Surendran *et al.,* 2019). Linear regression analysis, Mann-Kendall's test, Sen's slope estimator, Modified Mann-Kendall test and to test the randomness Wallis and Moore phase-frequency test was used and those details were given as follows;

Linear regression analysis : One of the most standard parametric models for identifying trends in data series is linear regression analysis. This model establishes a relationship between two variables (the dependent and independent variables) by using a linear equation to the collected data. The equation below generally describes the linear regression model:

$$Y = mX + C \ldots (1)$$

Where Y and X are the dependent and independent variables, m is the line's slope, C is the intercept. The t-test was done to assess whether the linear trends deviate substantially from zero at the 5 per cent significance level.

The Mann–Kendall's Trend Test: The significant nature of trends was examined by a nonparametric test known as the Mann–Kendall (MK) test (Mann, 2014 and Kendall,1976). It identifies trends in the data of time series but trend may or may not be linear. Let x_1, x_2, x_3, x_n represents n data points, where x_j represents the data points at time *j*. The Mann-Kendal statistic (S) is given by

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign}(x_j - x_i) \ldots (2)$$

Where x_i and x_j are the annual values in years' *j* and *i, j>i* respectively and N is the number of data points. The values of sign($\chi_j - \chi_i$)=0. This statistic represents the number of positive differences minus number of negative differences for all the differences considered. For large samples (N>10), the test is conducted using z statistics with mean and the variance as follows

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

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

Where q is number of tied groups and t_p represents the total observations in the p^{th} group. Compute MK test statistic, Z_{MK}, as follows:

$$Z_{MK} = \frac{S-1}{\sqrt{VAR(S)}} \text{ if } S>0 \ldots (5)$$

$$= 0 \quad \text{if } S=0 \ldots (6)$$

$$= \frac{S-1}{\sqrt{VAR(S)}} \text{ if } S<0 \ldots (7)$$

A positive (negative) value of Z_{MK} implies that the data tend to increase (decrease) with time. To test either an upward or downward monotone trend (a two tailed test at α level of significance H_0 is rejected if $|Z_{MK}| \geq Z_{1-}\alpha/2$.

Sens's slope estimator: Sen's slope is to conclude the magnitude of trend in the data series which not serially auto-correlated. The Sen's method (Sen, 1968) was used in cases where the trend can be assumed to be linear.

$$f(t) = Qt + B \ldots (8)$$

Where *Q* is slope, *B* is a constant and *t* is time. To get the slope estimate Q, the slopes of the data value pairs is calculated using the equation:

$$Q_i = \frac{x_j - x_k}{j-k} \ldots (9)$$

Where x_j and x_k are the data values at time j and k (*j>k*) respectively. If there are n values x_j in the time series, there will be as many as N=n(n-1)/2 slope estimates Q_t. The N values of Q_t are ranked from the smallest to the largest and the Sen's estimator is

$$Q = Q_{\left[\frac{n(n+1)}{2}\right]} \text{, if N is odd or}$$

$$Q = \frac{1}{2\left(Q_{\left[\frac{N}{2}\right]} + Q_{\left[\frac{(N+2)}{2}\right]}\right)}, if\ N\ is\ even \ldots (10)$$

To obtain the estimate of B in equation *f(t)* the n values of differences $\chi_t - Q_{\tau t}$ values are calculated. The median of values gives an estimate of B.

Modified Mann-Kendall Test : The non-parametric statistical method called as the modified Mann-Kendall test is employed to examine monotonic upward or downward trend of the series when there is a positive autocorrelation (Yue and wang, 2014). It addresses the subject of serial correlation using the variance correction approach. The variance of s statistic is as follows:

$$V^*(S) = V(S)\frac{n}{n^*} \ldots (11)$$

Where n/n^* is a correction factor. V(S) is calculated as in the original MK test. The null hypothesis H_0 indicated the absence of trend in the given series, the null hypothesis is rejected when the Z-transformed statistic value is more than the Z critical value at 5 per cent level of significance ($|Z_{mmk}| \geq |Z_{1-}|\ \alpha/2$).

RESULTS

For this study, seasonal rainfall data was collected for Guntur district of Andhra Pradesh state from the year 1981 to 2021. The rainfall data was processed in the excel sheets to estimate the trend and further analysis. The data was tabularized and the descriptive statistics specifically, the mean, (SD), (CV), skewness and kurtosis were depicted in Table 1 given below.

Table 1. Summary statistics of seasonal rainfall of Guntur district, A.P.

Month	Mean (mm/day)	SD	CV	Skewness	Kurtosis
January	0.34	0.57	165.11	2.37	6.09
February	0.35	0.68	191.64	2.28	4.57
March	0.24	0.59	242.50	4.51	23.46
April	0.43	0.75	174.53	4.35	23.10
May	1.38	1.87	135.65	2.15	3.82
June	3.36	2.20	65.39	1.30	1.20
July	5.36	2.39	44.63	0.64	-0.11
August	5.27	1.79	33.92	0.46	1.65
September	5.45	2.82	51.75	0.71	0.41
October	6.32	4.18	66.16	1.26	2.61
November	3.43	3.20	93.32	1.47	2.43
December	0.76	1.02	135.67	2.10	4.67

Table 2. Summary statistics of yearly and periodic rainfall Pattern of Guntur district, A.P.

	Mean (mm/day)	SD	CV	Skewness	Kurtosis
Pre-monsoon	0.34	0.31	91.09	1.32	1.54
Monsoon	3.84	1.10	28.73	0.19	-1.01
Post-Monsoon	3.99	1.63	40.87	0.73	-0.12
Annual	2.74	0.65	23.74	0.40	0.19

The rainfall variability was more as the average monthly rainfall of CV ranging from 33.92 to 242.50 per cent which means spread of data points in data series around the mean. The rainfall variability was understood by CV, rainfall variability is less if CV is lesser than 20, the variability is moderate if CV is 20-30 and variability is high if it is more than 30 (*Naveena et al., 2020*). The value of skewness ranging from 0.46 to 4.51 and kurtosis ranging from -0.11 to 23.46. The highest values of skewness and kurtosis was found in March i.e., 4.51 rightly skewed and 23.46 indicating leptokurtic respectively.

The Table 2 depicts summary statistics for pre-monsoon, monsoon, post-monsoon and annual rainfall. The CV of annual rainfall was 23.74 per cent. The standard deviation was 0.65 and skewness was 0.40, rightly skewed and kurtosis was 0.19 indicating leptokurtic shape respectively. The CV among seasons was less in monsoon season i.e., 28.73 per cent. Similar findings were observed in (Jyostna *et al.,* 2022).

Trend of annual rainfall : Fig 2 represents the yearly rainfall of Guntur district. The linear regression analysis was done for annual rainfall. The graph depicts the increasing and decreasing rainfall trend pattern of

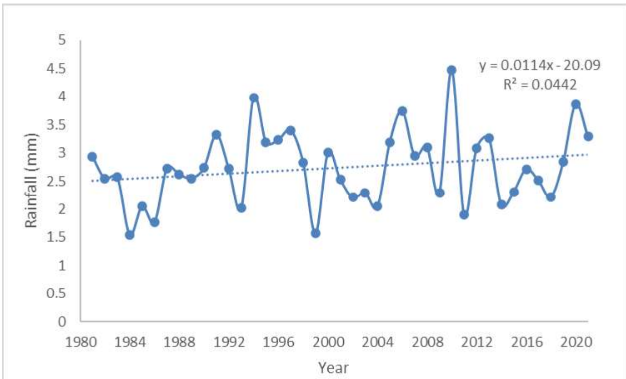

Fig 2. Trend of yearly rainfall of Guntur district from 1981 to 2021.

Wallis and Moore Phase – Frequency test was applied for seasonal and yearly rainfall data (Wallis et al., 2014).

Table 3. Wallis and Moore phase frequency test for monthly, seasonal and yearly rainfall data

Month	Z test	P value
January	2.27	0.02
February	1.14	0.25
March	0.00	1.00
April	0.76	0.45
May	1.14	0.25
June	0.76	0.45
July	0.39	0.70
August	0.00	1.00
September	0.00	1.00
October	0.76	0.45
November	0.38	0.70
December	0.00	1.00
Pre-monsoon	0.75	0.45

Guntur district for the time period 1981 to 2021on the annual basis. However, it does not specify the particular months in which these variations occur significantly. The value of Coefficient of determination (R^2) for linear equation is at lower magnitude which indicate that data under consideration has definite pattern. The application of linear regression analysis for rainfall variability during the years 1980–2019 in Telangana's Jagtial district was observed in (*Navatha et al., 2021*).

Table 3 depicts that seasonal and the yearly rainfall data was random in nature. As the p value was greater than 5 per cent level significance, the rainfall data was random in nature. Shapiro wilk test was used to know the normality of the dataset. The results indicates that p value is less than 0.05 per cent level of significance which means we are rejecting the null hypothesis that is the data follows normal distribution. So, non-parametric test that is Modified Mann-Kendall test was used for study as it is more efficient if the data was not ensuing normal distribution as well as autocorrelated.

Results of rainfall trend analysis using modified Mann-Kendall test and Sens slope estimator: The results of Modified Mann-Kendall trend analysis for rainfall of Guntur district were depicted in Table 4. It revealed the significant growing trend of rainfall in the months of April and June as the Z transformed test statistic is significant at 5 per cent level of significance. There was no noteworthy trend in the remaining months as the test results were non-significant.

Modified Mann-Kendall trend analysis of rainfall of Guntur district was depicted in the Table 5. It revealed the significant growing trend of rainfall in the monsoon season. The period 1981 to 2021 didn't showed any significant trend in Pre and Post-monsoon (Ratnam and Vindhya, 2020) as well as annual rainfall as the Z transformed test statistic Z_{cal} was lesser than Z_{tab} at 5 per cent level of significance so the null hypothesis was accepted.

Table 4. Modified Mann-Kendall test of trend analysis of periodic rainfall data

Parameter	Z- test	Trend	Sens slope
January	-1.98	NS	-0.00
February	0.89	NS	0.00
March	-0.12	NS	0.00
April	2.12	*	0.00
May	1.52	NS	0.01
June	2.56	*	0.06
July	1.25	NS	0.04
August	1.83	NS	0.03
September	0.79	NS	0.03
October	-0.35	NS	-0.02
November	-0.14	NS	-0.00
December	-0.39	NS	-0.00

NS - non-significant trend * - significant trend

Table 5. Modified Mann-Kendall Test used for trend analysis of seasonal rainfall in Guntur district

Parameter	Z- test	Trend	Sens slope
Pre-monsoon	0.00	NS	-0.00
Monsoon	2.44	*	0.04
Post-Monsoon	-0.12	NS	-1.15
Annual	1.21	NS	-0.00

NS – non-significant trend * - significant trend

DISCUSSION

This study carefully investigated the complex annual and seasonal rainfall patterns in the Andhra Pradesh district of Guntur throughout the long period of 1981–2021. Descriptive statistics provided clear idea about the monthly rainfall variability, March month standing out in particular because of its high coefficient of variation (CV), skewness, and kurtosis. The irregularity and special features of the district's rainfall distribution were highlighted by these measurements taken together.

Seasonal and annual rainfall variability summary statistics highlighted non-uniformity in the data. The leptokurtic shape and right skewness of the yearly rainfall, in particular, indicated the complex nature of these changes and explained the distinct features of Guntur's rainfall.

The examination of trend analysis, backed by linear regression and depicted in Fig. 2, revealed dynamic patterns in annual rainfall throughout the length of the study period. Although the coefficient of determination (R^2) indicated a discernible pattern, it also pointed out that further in-depth analysis would be required to identify certain months that were significantly contributing to the observed fluctuations.

The findings from the Wallis and Moore Phase–Frequency test, underscored the random nature inherent in monthly, seasonal, and yearly rainfall data. This test results emphasised the significance of using non-parametric techniques and indicated the complexity of the precipitation dynamics in Guntur district.

To capture the erratic pattern in the data non parametric test that is modified Mann- Kendall's test was used for the study. The results of the Modified Mann-Kendall trend analysis, which revealed significant increasing patterns in specific months as well as during the monsoon season. These revelations provided a clearer picture of Guntur's changing rainfall dynamics, which was important for those involved in the region's planning of agriculture, management of water resources, and climate adaptation. The study's detailed findings have practical significance for well-informed decision-making and sustainable resource management strategies, in addition to furthering scientific understanding of Guntur's historical rainfall patterns.

CONCLUSION

In order to analyse annual and periodic rainfall in the Guntur district of Andhra Pradesh State, this study used parametric tests, like the linear regression trend, and non-parametric tests, like the modified-Mann Kendall test, to discover long-term patterns in the study period (1981 to 2021). There was an increasing and a declining trend evident in the linear regression results. The outcomes of the Modified Mann-Kendall test revealed that there was a substantial increase in rainfall in the months of April and June, but not in the other months. While the monsoon season exhibited a clear increasing trend during the research period. However, there was no significant trend in the pre-monsoon, post-monsoon seasons, and annual rainfall. Rainfall variability was a big issue, and the conclusions of this study can be helpful to policy makers in the Guntur district of Andhra Pradesh State for implementing appropriate measures to manage water resources during the monsoon season. Additionally, identifying increasing trends in certain months, such as April and June, can assist farmers in adapting their farming strategies to optimize crop yields in these periods. Ultimately, this study adds valuable understanding that can enhance agricultural sustainability and resilience in the Guntur district.

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Data availability: Data would be made available on request.

Appendix: The supplementary data, table, graph in jpeg format for online visibility to the readers are submitted as an appendix.

Authors contribution: First author conceptualized, collected data, analysed and interpreted the results and prepared the manuscript. The collaborative effort of the second and third authors was evident in their valuable contributions to text compilation, enriching the manuscript with their insights and perspectives. Furthermore, the guidance and evaluation provided by the fourth and fifth authors played a crucial role in shaping the overall quality of the manuscript.

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