LONG TERM AND SEASONAL RAINFALL TREND IN BAPATLA DISTRICT OF ANDHRA PRADESH USING ADVANCED STATISTICAL METHODS

ABSTRACT:

The primary objective of this study is to analyse the annual and seasonal rainfall trends in the Bapatla district of Andhra Pradesh over the long term. The seasonal rainfall data for Bapatla district was collected from the NASA Power website and covering the period from January 1982 to December 2021. To gain insights into the patterns present in the rainfall data for Bapatla district, a combination of parametric methods, including linear regression, and non-parametric tests such as the Mann-Kendall test,Sen’s slope test, Modified-Mann Kendall test, Innovative trend analysis were employed in this approach. The randomness of the rainfall data under investigation was assessed using the Wallis and Moore test. To detect the single change point of the rainfall pattern Pettitt test was employed. The results of linear regression trend method exhibited both increasing and declining trends in rainfall pattern. Notably, the months of April, May and June exhibited a statistically significant increasing trend, while the other months exhibited no significant trend according to the Mann-Kendall test, modified Mann-Kendall test.In the analysis of the rainfall pattern in the Bapatla district, it was observed that the monsoon season displayed a statistically significant trend in all the tests, whereas both the pre-monsoon and post-monsoon periods exhibited non-significant trends. Additionally, when considering the yearly rainfall for Bapatla district, the Modified Mann-Kendall test indicated a significant increase trend was observed for pre- monsoon and monsoon seasons. To shed the light on the variations in monthly and seasonal and annual rainfall, this study serves as a valuable resource to farmers, enabling them to make informed decisions about resource allocation and preparedness for anticipated water shortages in the non-monsoon months.

***Keywords**:Innovative trend analysis,Mann-Kendall test, Modified Mann-Kendall Test, Pettit test,* *Rainfall, Sen’s slope, Trend,Wallis-Moore test.*

1. INTRODUCTION

Statistical analysis of the temporal trends in rainfall within the state of Telangana was conducted with the application of statistical methods such as linear regression, t-tests, ANOVA, and Tukey's post-hoc test. The results of this comprehensive analysis unveiled a non-significant trend in the rainfall data byDas *et al.,* (2007). Water plays a pivotal role in agriculture and is profoundly affected by both rainfall and its availability. The shift in the distribution of rainfall patterns is a matter of concern for water resource managers. This alteration in the frequency and volume of rainfall is causing shifts in the patterns of stream flows, water demands, soil moisture levels, and groundwater reserves, as highlighted by Srivastva*et al*., (2014). In India, where agriculture forms the backbone of the economy, the South-West Monsoon takes on a pivotal role as the primary source of rainfall, contributing to more than 70% of the annual net precipitation. This monsoon serves as a lifeline for agriculture, replenishes essential water bodies and reservoirs, and recharges groundwater aquifers. However, in contrast to the bountiful South-West Monsoon, the Northeast Monsoon delivers relatively lower levels of rainfall. Consequently, while some regions in India receive abundant rainfall during the monsoon season, others grapple with water scarcity, as noted by Goswami, (2016). The term "rainfall" encompasses the quantity of precipitation that descends as rain, whether over land or water. Owing to the ongoing effects of global climate change, there is potential for significant shifts in long-term rainfall patterns. These alterations could elevate the likelihood of both droughts and floods, increasing their frequency in the future were found byPaul *et al.,*(2017). In this connection the study was planned to identify the trend of rainfall in Bapatladistrict of Andhra Pradesh, India. Bapatla district consists of major portion of area under agriculture and the farmers depend on rainfall for cultivation of the crops.Bapatla typically receives an annual average of 900-1100 mm of rainfall (Fig.1), with the rainy months concentrated in July, August, and September. The fluctuation in the pattern of rainfall has had an adverse impact on the productivity of key agricultural commodities in the region.The analysis of rainfall patterns is of paramount importance for devising strategies to adapt to evolving weather patterns and mitigate the risks associated with crop failure and water scarcity. The examination of rainfall trends in Bapatla holds significance as it provides valuable insights into the enduring patterns of precipitation in the area.This analysis can be applied to identify any changes or fluctuations in rainfall patterns, to help farmers and policymakers in making informed decisions related to agriculture and water management.Most of the previously published studies on trend analysis in various regions were limited in scope, typically involving small sample sizes and employing traditional linear regression trend analysis with only a handful of nonparametric techniques. In contrast, our study stands out by employing contemporary statistical methods for trend analysis. These methods include non-parametric approaches such as the Mann-Kendall test, Sen's slope estimate, the Modified Mann-Kendall test, and Innovative trend analysis, alongside the use of linear regression trends (parametric methods).The analysis in this paper is organized into several distinct sections. It commences with basic descriptive statistics, followed by the application of linear regression trends, the Mann-Kendall test, Sen's slope estimation, Wallis- Moore test, Modified-Mann Kendall test and the Innovative trend analysis and pettit test. The results and discussion section delves into the exploration and discussion of findingsfrom each of these analyses. Finally, the conclusion section encapsulates the key outcomes of this research endeavour and it was undertaken with the objective of analysing the long-term annual and seasonal rainfall patterns in Bapatla district of Andhra Pradesh.

2. METHODOLOGY

2.1 DATA COLLECTION

Bapatla district is situated in the southern Indian state of Andhra Pradesh, positioned between 15.8966°N latitude and 80.4604°E longitude.(https://www.latlong.net/place/bapatla-andhra-pradesh-india) Geographically, it shares its borders with Guntur District to the north Narasaraopet and Prakasam Districts to the west, the Bay of Bengal to the south, and the Krishna Western Delta to the east. For this study, monthly rainfall data for Bapatla district in Andhra Pradesh was acquired from the NASA Power website, covering the period from January 1982 to December 2021.(https://power.larc.nasa.gov). To investigate the variability in the rainfall pattern in Bapatla, various trend tests were applied to the rainfall data. The collected information was organized into tables, thoroughly assessed, and subjected to statistical analysis to make predictions regarding the rainfall trends in Bapatla district. The data analysis was aimed to elucidate the trend patterns in the Monsoon season (June to September), the pre-monsoon period (January to May), the post-monsoon period (October to December), as well as the annual rainfall.

2.2 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 proceduresdescriptive statistics were computedSurendran *et al.*, (2019). Linear regression analysis, Mann-Kendall's test, Sen's slope estimator, Modified Mann-Kendall test, to test the randomness Wallis and Moore phase-frequency test and to detect the single change point of rainfall pattern pettitt test was used to annual rainfall and those details were given as follows;

2.3Linear 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 wasdone to assess whether the linear trends deviate substantially from zero at the 5% significance level.

2.4 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, 1945, 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

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

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 $sign(x_j - x_i)$ = 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

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

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

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:

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

= 0 if S=0...(6)

= $\frac{S-1}{\sqrt{VAR(S)}}$if S<0 ….(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 $|Z_{MK}| \geq Z_{1-}\alpha/2$.

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 ($|Z_{MMK}| \geq Z_{1-}\alpha/2$).

2.5 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 $N = \frac{n(n-1)}{2}$ slope estimates Q_t. The N values of Q_t are ranked from the smallest to the largest and the Sen's estimator is

$Q = Q_{\left[\frac{n(n+1)}{2}\right]}$, if N is odd or $Q = 1/2\left(Q_{\left[\frac{N}{2}\right]} + \right.$ $Q(N+2)2$, if N is even. ...(10)

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

2.6Modified 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 $\frac{n}{n^*}$ is a correction factor. V(S) is calculated as in the original MK test.

Pettitt test:

The Pettitt test was a rank-based nonparametric statistical test used to detect change points present in the data series.

Consider a sequence of random variables X_1, X_2, …, X_T with change point at time τ, which is divided in two sets with distinct distributions functions: $F_1(X_t)$, t = 1, 2, …, T, and $F_2(X_t)$, t = T + 1, …, T.

Thus, the hypotheses to be tested are:

H0:F1(X) = F2(X) (no change point) …(12)

H1:F1(X) ≠ F2(X) (change point) …(13)

To detect the change point, the test uses the statistic $U_{t,T}$, similar to the Mann-Whitney test statistic Mann and Whitney (1947) for two samples, given by Pettitt (1979):

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} sgn(Xi - Xj),\ 1 \le t \le T \quad ..(14)$$

U is the Pettitt's test statistic.
T is the total number of observations in the time series data.
x[i] and x[j] represent the data values at positions i and j in the time series, respectively.
sgn() is the sign function, which returns +1 if the argument is positive, -1 if the argument is negative, and 0 if the argument is zero.

Where,

$$sgn(x) = \begin{cases} 1,\ if\ x > 0 \\ 0, if\ x = 0 \\ -1, if\ x < 0 \end{cases} \quad ……(15)$$

The most probable change point T will be the one that satisfies the following equation:

$$K_T = U_{t,T} = max|U_{t,T}|,\ 1 \le t < T \quad …... (16)$$

Based on asymptotic arguments about the test statistic, Pettitt (1979) defines the following approximate p value of the test:

$$p \approx 2exp\left(\frac{-6K_T^2}{T^3+T^2}\right) \quad …….(17)$$

Thus, given a significance level α, if $p < \alpha$, the null hypothesis, H_0 that the two distributions are equal is rejected.

2.8 Innovative trend analysis (ITA)

The ITA method has been used to investigate hydro meteorological observations and its accuracy was compared with the result of the MK method Gedefaw*et al.,* (2018). In the ITA method, data points were divided into equal halves, and then sort both sub-series in ascending order. After that, the two halves placed on the Cartesian coordinate system, namely xi , i = 1, 2, … , $\frac{n}{2}$ on the horizontal axis and x_j ,j = $\frac{n}{2}$ + 1, $\frac{n}{2}$ + 2, … , n on the vertical axis.

3. RESULTS AND DISCUSSION

For this study, seasonal rainfall data spanning from 1982 to 2021 was collected for the Bapatla district in Andhra Pradesh. The collected rainfall data was then meticulously processed using Microsoft excel spread sheets to evaluate trends and conduct subsequent analyses. To provide a comprehensive overview of the data, it was organized into tables, and Table 1 below illustrates the key descriptive statistics that including the mean, standard deviation (SD), coefficient of variation (CV), skewness, and kurtosis.

3.1 Descriptive Statistics

The rainfall variability exhibited a wide range distribution, with the coefficient of variation (CV) indicating an average monthly rainfall fluctuation spanning from 33.55% to 256.71%. This range signifies the extent of dispersion of data points around the mean in the dataset. CV, as elucidated by Naveena *et al.*, (2020), serves as an indicator of rainfall variability. When the CV is below 20, it signifies a low degree of variability. If the range of 20 to 30 the variability is considered moderate, and when the CV exceeds 30, it indicates a high level of variability in rainfall. The statistical analysis unveiled that the rainfall pattern within Bapatla district exhibits a broad distribution of data points around the mean value. The skewness values range from 0.54 to 4.54, while the kurtosis values span from 2.75 to 24.87. In particular, the month of March stands out with the highest values, exhibiting a positive skewness of 4.54 and a leptokurtic kurtosis of 24.87.

Table 1. Descriptive statistics of monthlyrainfall pattern of Bapatla district, A.P.

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Month	Mean	SD	CV	Skewness	Kurtosis
January	10.62	17.86	168.17	2.27	8.01
February	10.83	19.52	180.19	2.08	6.49
March	7.11	18.26	256.71	4.54	24.87
April	12.85	22.85	177.84	4.15	22.74
May	42.60	58.51	137.34	2.03	6.05
June	99.96	66.47	66.50	1.25	3.82
July	165.01	74.84	45.36	0.65	2.75
August	163.93	54.99	33.55	0.54	4.19
September	161.66	85.75	53.04	0.70	3.19
October	193.16	129.18	66.87	1.10	4.58
November	105.92	97.95	92.48	1.36	4.87
December	23.66	32.16	135.89	1.98	6.76

Table 2.Descriptive statistics of yearly and periodic rainfall Pattern of Bapatla district, A.P.

Parameter	Mean	SD	CV	Skewness	Kurtosis
Pre-monsoon	83.97	67.95	80.92	1.45	23.66
Monsoon	590.56	169.69	28.73	0.04	1.88
Post-Monsoon	322.75	175.30	54.31	1.17	4.69
Annual	997.28	242.27	24.29	0.37	2.94

In Table 2 the summary of statistics for pre-monsoon, monsoon, post-monsoon, and annual rainfall. The coefficient of variation (CV) for the annual rainfall stands at 24.29%. Additionally, the standard deviation is 242.27, with skewness at 0.37, indicating a right skew, and kurtosis at 2.94, signifying a leptokurtic shape. Within the various seasons, the monsoon season exhibited a lower CV of 28.73%. These findings align with those reported by Jyostna *et al.*, (2022).

3.2Trend of Annual Rainfall

Fig. 1 illustrates the yearly monthly rainfall for Bapatla district, covering the period from 1982 to 2021. The graph showcases a discernible pattern of both increasing and decreasing rainfall trends over the years on an annual basis.However, it does not provide specific insights into the months when these variations occur prominently. The Coefficient of Determination (R^2) for the linear equation is relatively low, measuring at 0.056. This suggests that the data being analysed exhibits a less pronounced pattern. It's worth noting that a similar application of linear regression analysis to study rainfall variability during the years 1980-2019 in Telangana Jagtial district was observed by Navatha *et al.,* (2021).

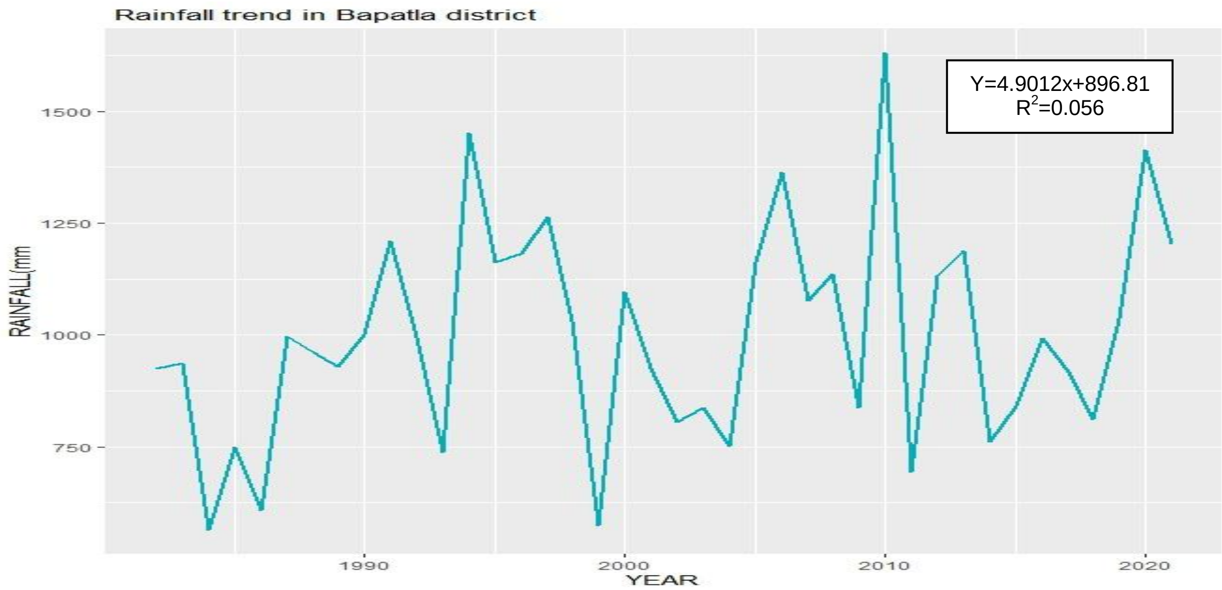

Fig 1. Trend of yearly rainfall of Bapatla district from 1982 to 2021

3.3Mann-Kendall Test:

Mann-Kendall Test for Trend analysis also known as the Mann-Kendall trend test or Kendall's tau test, is a non-parametric statistical test used to detect trends in monthly, seasonal and yearly rainfall data of Bapatla district. The null hypothesis of the test was there is no trend in the data set. Rejection of null hypothesis indicated that there is a statistically significant trend in the data. The direction of the trend (increasing or decreasing) can be determined by the sign of the test statistic. The results of the monthly rainfall data shows significant trend in the months of April to June and the remaining months there is no significant trend was observed. The results of Mann- Kendall test of monthly rainfall pattern in Bapatla district of Andhra Pradesh were depicted in Table 3.

Table 4. depicts the results of Mann-Kendall test were indicated that the seasonal rainfall data also shows significant trend during monsoon period and the pre-monsoon, post- monsoon and annual rainfall there is no significant trend in the dataset.

Table 3.Mann- Kendall Test used for trend analysis of monthly rainfall of Bapatla district, A.P.

Paramater	Z-value	Trend	P-value
January	-1.597	NS	0.110
February	0.594	NS	0.553
March	0.361	NS	0.718
April	2.424	*	0.015
May	2.109	*	0.035
June	2.831	*	0.005
July	1.666	NS	0.096
August	1.387	NS	0.166
September	1.014	NS	0.311
October	-0.105	NS	0.917
November	-0.151	NS	0.880
December	-0.268	NS	0.789

NS - Non-significant trend * - significant trend

Table 4.Mann- Kendall Test used for trend analysis ofseasonal and annual rainfall of Bapatla district, A.P.

Parameter	Z-value	Trend	P-value
Pre-monsoon	1.725	NS	0.085
Monsoon	2.225	*	0.026
Post-monsoon	-0.221	NS	0.825
Annual	1.387	NS	0.166

NS - Non-significant trend * - significant trend

Table 5. Sen's slope Test for Trend analysis of monthly rainfall of Bapatla district, A.P.

Parameter	Z-value	Trend	P-value	Slope coefficient
January	-1.597	NS	0.110	-0.042
February	0.594	NS	0.553	0.000
March	0.361	NS	0.718	0.002
April	2.424	*	0.015	0.290
May	2.109	*	0.035	0.486
June	2.831	*	0.005	1.982
July	1.666	NS	0.096	1.516
August	1.387	NS	0.166	0.921
September	1.014	NS	0.311	1.183
October	-0.105	NS	0.917	-0.264
November	-0.151	NS	0.880	-0.186
December	-0.268	NS	0.789	-0.020

NS - Non-significant trend * - significant trend

Table 6. Sen's slope Test for Trend analysis of seasonal and annual rainfall of Bapatla district, A.P.

Parameter	Z-value	Trend	P-value	Slope coefficient
Pre-monsoon	1.725	NS	0.085	1.1907
Monsoon	2.225	*	0.026	6.1529
Post-monsoon	-0.221	NS	0.825	-0.5154
Annual	1.387	NS	0.166	5.7655

NS - Non-significant trend * - significant trend

3.4 Sen's Slope Test:

Sen's Slope test was applied for trend analysis in time series to determine if there is a significant trend or pattern over time i.e., variables like rainfall. The null hypothesis for the Sen's slope, which represents the magnitude and direction of the trend. A positive Sen's slope indicates an increasing trend, while Sen's slope test was no trend or significant pattern in the data over time. The test calculates a negative Sen's slope suggests a decreasing trend. The results from Table 5, depicts that themonthly rainfall data shows negative slope value for the months January, October, November and December months and rest were exhibiting increasing trend and from z statistic value the months April to June exhibits significant increasing trend in monthly rainfall if Bapatla district, A.P. From Table 6, the results of Sen's slope test indicated that the monsoon rainfall data shows significant trend and the pre-monsoon, post- monsoon and annual rainfall there is no significant trend in the dataset. The slope coefficient of post-monsoon shows negative trend was observed but the post monsoon period exhibits decrease in trend of rainfall in Bapatla district, A.P.

3.5 Wallis and Moore Phase – Frequency test:

Wallis and Moore Phase – Frequency test was applied for seasonal and yearly rainfall data Wallis *et al.*, (2014). The Wallis and Moore Phase-Frequency test was used to evaluate whether a time series data such as seasonal or yearly rainfall data exhibits significant periodic or oscillatory patterns. The primary purpose of the Wallis and Moore Phase-Frequency test is to detect the presence of significant periodic components in time series data. The test was particularly useful for identifying cyclic or oscillatory patterns that may repeat over time. This test is based on the analysis of the phase and frequency components of a time series. It involves decomposing the time series into its constituent frequencies and examining the phases at which these frequencies occur. The null hypothesis of the test typically states that there are no significant periodic components in the data means that the data was random or aperiodic. The Wallis and Moore Phase-Frequency test generates test statistics that are used to assess the significance of any detected periodic components. These statistics are often compared to critical values to determine statistical significance. If the test results are statistically significant, it suggests that the time series data does indeed exhibit periodic behaviour.

Table 7. Wallis and Moore phase frequency test for monthlyrainfall data of Bapatla district, A.P.

Parameter	Z-value	Trend	P-value
January	1.279	NS	0.201
February	0.256	NS	0.798
March	1.024	NS	0.306
April	0.512	*	0.609
May	0.896	*	0.371
June	0.512	*	0.609
July	1.279	NS	0.201
August	0.128	NS	0.898
September	0.128	NS	0.898
October	0.512	NS	0.609
November	0.256	NS	0.798
December	0.128	NS	0.898

NS - Non-significant trend * - significant trend

Table 8. Wallis and Moore phase frequency test for seasonal and annual rainfall data of Bapatla district,A.P.

Parameter	Z-value	Trend	P-value
Pre-monsoon	0.896	NS	0.371
Monsoon	0.128	*	0.898
Post-monsoon	1.279	NS	0.201
Annual	0.640	NS	0.522

NS - Non-significant trend * - significant trend

The results of Wallis and Moore test were depicted in Table 8. It shows that the seasonal and yearly rainfall data was random in nature. As the p value was greater than 5% 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 % 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 Sen's slope estimator.

3.7 Modified Mann-Kendall test:

The results of Modified Mann-Kendall trend analysis for rainfall of Bapatla district were depicted in Table 9. It revealed the significant growing trend of rainfall in the months of April to 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.The Modified Mann-Kendall test efficiently incorporate the seasonal adjustment than Mann-Kendall test which helps in distinguishing between true trends and seasonal effects. This is particularly important in environmental applications like rainfall trend studies. The Modified Mann-Kendall test is considered more efficient, requiring fewer data points to detect trends accurately. In this study, Modified Mann-Kendall trend analysis of seasonal and annual rainfall of Bapatla district was depicted in the Table 10. The results revealed that the rainfall of pre monsoon and monsoon was observed significant trend, annual rainfall didn't shown any significant trend and in post- monsoon season showed negative trend. In case of Mann Kendall test the pre monsoon season also observed that thereis no significant trend. The results indicated that the modified Mann-Kendall test effectively captures the seasonal trend in the dataset. It was also revealed the significant growing trend of rainfall in the monsoon season. Ratnam and Vindhya (2020) studied the analysis of rainfall data at AMF Unit-Lam, Guntur district of Andhra Pradesh from the period 1982 to 2021 and the results showed any significant trend in Pre and Post-monsoon (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 9. Modified Mann-Kendall test of trend analysis of monthly rainfall of Bapatla district, A.P.

Parameter	Z-transformed test statistic	Trend	Sen's slope
January	-1.236	NS	-0.042
February	0.744	NS	0.000
March	0.396	NS	0.002
April	2.690	*	0.290
May	2.318	*	0.486
June	2.950	*	1.982
July	1.377	NS	1.516
August	1.342	NS	0.921
September	1.082	NS	1.183
October	-0.082	NS	-0.264
November	-0.154	NS	-0.186
December	-0.277	NS	-0.020

NS - Non-significant trend * - significant trend

Table 10. Modified Mann-Kendall Test for trend analysis of seasonal and annual rainfall of Bapatla district, A.P.

Parameter	Z transformed test statistic	Trend	Sen's slope
Pre-monsoon	2.001	*	1.191
Monsoon	2.130	*	6.153
Post-monsoon	-0.192	NS	-0.515
Annual	1.369	NS	5.765

NS - Non-significant trend,* - significant trend.

3.7Innovative trend analysis (ITA)

The results from Table 11, revealed that the data on January and February showed the decreasing trends at 10, 5 and 1% level of significance, respectively. The data on November, December months and post-monsoon showed the decreasing trend 10, 5 and 1% level of significance. The months from May to October and season rainfall of Monsoon shows a significant increasing trend at 10, 5 and 1% level of significance.

Table 11. Innovative trend analysis (ITA) of monthly, seasonal and annual rainfall of Bapatla district, A.P.

Parameter	Trend slope	Trend indicator	α= 0.10		α= 0.05		α= 0.01	
			LCL	UCL	LCL	UCL	LCL	UCL
January	-0.355	-5.007	-0.040	0.040	-0.04	0.04	-0.05	0.05
February	-0.071	-1.237	-0.030	0.030	-0.040	0.04	-0.04	0.04
March	0.155	5.584	-0.140	0.140	-0.16	0.16	-0.21	0.21
April	0.089	1.492	-0.255	0.255	-0.304	0.304	-0.400	0.40
May	0.849	4.980	-0.281	0.281	-0.335	0.335	-0.440	0.40
June	1.369	3.173	-0.310	0.310	-0.369	0.369	-0.485	0.48
July	0.647	0.817	-0.355	0.355	-0.423	0.423	-0.556	0.55
August	0.288	0.358	-0.264	0.264	-0.315	0.315	-0.414	0.41
September	0.795	1.035	-0.300	0.300	-0.357	0.357	-0.469	0.46
October	0.653	0.699	-0.489	0.489	-0.582	0.582	-0.765	0.76
November	-1.169	-1.987	-0.438	0.438	-0.522	0.522	-0.686	0.68
December	-0.023	-0.194	-0.126	0.126	-0.150	0.150	-0.197	0.19
Annual	3.224	0.668	-1.096	1.096	-1.306	1.306	-1.717	1.71
Pre-monsoon	0.664	1.716	-0.320	0.320	-0.382	0.382	-0.502	0.50
Monsoon	3.099	1.108	-0.506	0.506	-0.602	0.602	-0.792	0.79
Post-monsoon	-0.539	-0.329	-0.334	0.334	-0.398	0.398	-0.523	0.52

3.8 Pettitt test for single change-point detection:

The Pettitt test, also known as the Pettitt-Mann-Whitney-Wilcoxon test, is a non-parametric statistical test used for detecting abrupt changes or discontinuities in time series data. It is commonly employed in environmental studies like rainfall and temperature etc. To identify significant changes in data patterns over time. The Pettitttest assesses whether there is a significant difference between two halves of a time series, one occurring before the change point and the other after. It helps identify when and where significant changes occur in the data. This test doesn't rely on specific assumptions about the data distribution and is suitable for data with irregular patterns.The results of pettitttest for rainfall pattern in Bapatla district revealed that the test statistic, U*, is a measure of the strength of the change or breakpoint was at 124. The p-value (0.4901) indicates the level of statistical significance. A high p-value suggests that there is no strong evidence to reject the null hypothesis, means that the data does not show a significant change or breakpoint. The present study reveals Pettitt test a change point at time K was obtained as 8, as the number of observations or data points after which the change or breakpoint was detected. It means that the test has detected a change or breakpoint in the data series occurring after the first 8 data points or observations and it was considered that the data exhibits a change in its behaviour or pattern starting from the 9^{th} data point i.e., in the year 1990 (Fig. 1) in the annual rainfall pattern of Bapatla district, A.P.

3. CONCLUSIONS

The study aimed to analyse the annual and periodic rainfall patterns in Andhra Pradesh's Bapatla district during the period from 1982 to 2021. To achieve this, both parametric tests, such as linear regression trends, and non-parametric tests, like the Mann- Kendall test, Wallis and Moore phase frequency test,Sen's slope Test**,** Modified Mann-Kendall test, Pettitt test for change point detectionand Innovative trend analysis were employed. These tests were instrumental in uncovering long-term weather patterns.The findings from the linear regression analysis revealed a mix of increasing and decreasing trends in rainfall. The Modified Mann-Kendall test results, on the other hand, indicated a significant increase in rainfall for the months of April and June. However, this increasing trend was not as evident in the other months, except during the monsoon season, where a clear upward trend was observed over the research period. Contrarily, the pre-monsoon, post-monsoon seasons, and annual rainfall did not exhibit any statistically significant trends.In the Modified Mann-Kendall test, a significant increasing trend was identified in both the pre-monsoon and monsoon seasons. The innovative trend analysis further substantiated these findings, showing a consistent increasing trend from April to October, while months like January, February, November, and December exhibited a decreasing trend. For the farmers, rainfall variability is a significant concern. The conclusions drawn from this study hold valuable insights for policymakers in Bapatla district, Andhra Pradesh, as they can use this information to implement suitable water resource management strategies during the monsoon season. Additionally, recognizing the increasing trends in specific months, such as April and June, can empower farmers to adapt their agricultural practices for optimizing crop yields during these periods. Ultimately, this study contributes valuable knowledge that can enhance agricultural sustainability and resilience in the Bapatla district.

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