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Trend analysis of rainfall and Rainy days of Visakhapatnam district of Andhra Pradesh

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Abstract
Agriculture plays a crucial role in Indian economy; it contributes nearly 17% to Indian GDP. In a country like India where over 70 per cent of rural population depends on agriculture for their livelihood and more than 50 per cent of net sown area comes under rainfed agriculture, it is important to analyse the rainfall trends as it is critical for determining water availability to meet a variety of demands, including agricultural, industrial. We can make better decisions on crop sowing timing and irrigation patterns by doing trend analysis study, resulting on a higher yield. So, the present study has attempted to know the rainfall patterns of Visakhapatnam district of Andhra Pradesh for over 31 years from 1991-2021, 31 years data was collected from Indian Meteorological Department, Pune later using non- parametric methods like Mann- Kendall, spearman rho and Sen slope estimator test.The analysis showed that the average rainfall of Visakhapatnam district in Andhra Pradesh for 31 years from 1991-2021 was 1111.33 mm and 728.62, 223.59, and 159.85 mm of rain on average during the monsoon, pre-monsoon, and winter months. There are 53 annual rainy days during this time, 35, 12, and 6 rainy days over the seasons, respectively. Therefore, the results clearly depict that the intensity of rainfall was higher during monsoon season. The main aim of the study is to provide detailed knowledge of the rainfall pattern and identify if there are any changes in trend change points in the time series. The results will benefit sustainable agriculture activities planning in the region like sowing time of crop, therefore enhancing productivity of crops.

Keywords: Rainfall pattern, non-parametric methods, Sen slope estimator test

1. Introduction

Climate refers to long term changes in a region's weather patterns. Temperature and precipitation are two most essential components in determining a region's climate. Failure to detect and handle increased temperatures can result in variety of disaster's including floods and droughts. The amount of precipitation that falls on the earth's surface is precipitation that falls on the earth surface is often measured in millimeters or inches.

The South-West monsoon dominates the climate of India. In India, the four monsoon months (June-September) account for around 80% of all rainfall, with significant regional and seasonal variations.

Nearly 60% of India's arable land is irrigated; hence the monsoon is crucial for agriculture. South- west monsoon normally happen between June and September. From October to December, north-eastern monsoon occur which is confined to India's southern regions.

The state of Andhra Pradesh typically experiences a hot and humid environment. In this state, the summer months typically run from March to June. The amount of moisture is relatively considerable throughout these months. The monsoon period follows summer; the South-West monsoons have a significant impact on state's climate. The North- East monsoon around the month of October to December bring around one- third of total rainfall in Andhra Pradesh.

The study area is the Visakhapatnam district of Andhra Pradesh, which is located in the states North Eastern Costal region. The latitude for Visakhapatnam district is 17.72°N and the longitude 82.73°E., the district covers an area of 11,161 square kilometers; annual rainfall of Visakhapatnam district is 1202 mm. The average annual rainfall in Visakhapatnam is 955 mm.

2. Materials and methods

To assess the patterns in the meteorological data (such rainfall and rainy days) of the research region, both parametric (Regression analysis) and non-parametric statistical approaches have been applied. Comparatively speaking, non-parametric statistical tests are more suited for non-normally distributed data than parametric statistical tests

The Mann: Kendall (MK) test is the most used non-parametric statistical method for spotting patterns in hydro-meteorological time series variables including water quality, stream-flow, temperature, and precipitation.

The Mann: Kendall test, the Sen's slope test, and the Wilcoxon Mann- Whitney step trend analysis are tests that may be used to determine if a consistent trend is present.

A trend is a noticeable shift over time that a random variable exhibit. Regression analysis (Parametric test) or Mann-test Kendall's are typically used to gauge the strength of a time series' trend (non-parametric method). Both of these strategies presuppose that the time series has a linear trend. Both the Mann-test Kendall's and linear regression were used in this particular investigation. We must conduct yearly and seasonal trend analyses for the objective of the study. The four seasons of the meteorological year are the southwest monsoon season (June through September), the post monsoon season (Oct. through Dec.), the winter season (Jan. through Feb.), and the summer season (Mar-May).

Mean Rainfall

Daily rainfall is the quantity of rain that a specific rain gauge records over the course of a day (In millimetres or centimetres), while yearly rainfall is the amount recorded over the course of a year. In India, the term "mean annual rainfall" refers to the average of the yearly rainfall over a period of 31 years (average annual rainfall or normal annual rainfall)

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

Non- Parametric Trend Test-

1. Mann- Kendall test
2. Sen's Slope
3. Spearman's rho test

Mann-test Kendall's Analysis

Mann-test Kendall's is a non-parametric approach that tests for a trend in time series without stating whether the trend is linear or non-linear.

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

The Mann-Kendall‟s test statistic is given as

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

The variance of S, for the situation where there may be lies (that is equal values) in the x values, is given by:

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

Where

g = Number of tied groups,

t_p= Number of data values in the p^{th} group.

n = Number of years data.

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

The Z_{mk} value is used to determine the presence of a statistically significant trend. A positive or negative Z value implies an upward or downward trend. The null hypothesis $_{Ho}$ should be accepted in a two-sided trend test if Z_{mk}Z(1-)/2 at a certain level of significance. The critical value of Z_{mk} from the standard normal table is Z(1-)/2

Sen's slope

The technique is used to estimate the size of the trend's slope. The Sen's slope estimator is a non-parametric, linear slope estimator that performs best with monotonic data.

First, a set of linear slopes is calculated as follows:

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

Where

d = is the slope,

X =denotes the variable,

n = is the number of data

i, j = are indices

Sen‟s slope is then calculated as the median from all slopes:

b =median (d_k).

Where,

b= is estimate of the slope of trend and

X_i= is the j^{th} observation.

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

The intercepts are computed for each timestep "t" as given by

$a_t = X_t - b \times t$

Spearman's rho (SR) test

The SR test is rarely employed in hydro-meteorological trend analysis since the MK test was widely utilised to determine the importance of trends in hydro-meteorological time series.

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

Where

$R(x_i)$ is the rank of i^{th} observation x_i in the sample of size n.

Under the null hypothesis, the distribution of D is asymptotically normal with the mean and variance as follows

E(D)=0

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

Pettitt's test

The Pettitt's test is a non-parametric test, which means that its application does not need any assumptions regarding data distribution. This test evaluates the null hypothesis (H_0), which states that the data are homogenous throughout the observation time, meaning that the data were acquired from a single or several distributions with the same local parameters (Average values). The alternative hypothesis (H_1) assumes the presence of a non-accidental component within the data, producing a shift in the location parameter at a certain point in time.

When the precise timing of the change is uncertain, this approach detects a large shift in the mean of a time series.

The non-parametric statistics is defined as:

K_t=max $|U_t, T|$

$$U_t, T = \sum_{i=1}^{t} \sum_{j=t+1}^{T} \text{sgn}\,(x_j - x_i)$$

$$\text{Sgn}(X_j - X_i) = \begin{cases} +1 \text{ if } (X_j - X_i) > 0 \\ 0 \text{ if } (X_j - X_i) = 0 \\ -1 \text{ if } (X_j - X_i) < 0 \end{cases}$$

The test statistics count how many times a member of the first sample outnumbers a member of the second sample. The absence of a change point is the null hypothesis of the Pettitt's test.

The test statistics count how many times a member of the first sample outnumbers a member of the second sample. The absence of a change point is the null hypothesis of the Pettitt's test. The test statistics KT and related probability (P) are as follows:

$$P \cong 2exp\left\{\frac{-6K^2}{T^3 + T^2}\right\}$$

4. Results and Discussion

This chapter discusses the findings from the examination of data on precipitation and wet days over 31 years. The following table displays the Visakhapatnam district's mean, coefficient of variation (per cent), and percentage contribution of rainfall and rainy days for the years 1991-2021 months respectively. During this time, there are 53 annual rainy days, 35, 12, and 6 rainy days over the seasons respectively. Monsoon contribution to annual rainfall is 64.94 per cent, whereas pre -monsoon and winter contributes 20.82 and 14.25 per cent. Similarly, the contribution of monsoon is more to the annual rainy days that is (66.04%) followed by pre-monsoon (22.4%) and winter (11.32%). Highest rainfall is observed in the month of October, September and August with rainfall of 241.35, 192.96, 161.82 mm respectively and January received the lowest rainfall among all the months. Comparatively highest rainy days were observed in September that is 10 rainy days followed by August with 9 rainy days and July and October with 8 rainy days. The coefficients of variation of rainfall and rainy days in the table indicate greater variability in most months. In terms of rainfall it is highest in month of December and, it is lower in July, August, September, October (CV>75%). Rainy day months, from August to October, have a lower coefficient of variation. The coefficients of variation for rainfall and rainy days during the winter season are approximately 92.67 per cent and 57.74 per cent, respectively. As a result, rainfall from August to November is more reliable. August and September are most active monsoon months in the Southwest monsoon. The northeast monsoon's active monsoon months are October and November.

From the above table 4.2 it is observed that in August month there is upward trend in rainfall for period 1991-2021 where as in the month of October downward rainfall trend for the period 1991-2021 is observed but in the period 1991-2006 and 2007-2021 shows upward trend at 5% level of significance.

It is interesting to observe that when the analysis is made separately for the data. Trend shift was there, Month of October initially was having downward trend for the period 1991-2021 but when analysis is done separately for the time period 1991-2006 and 2007-2021 we can see upward trend. In the month of August and September upward trend can be observed for the period 1991-2021, and the month of April shows all positives values indicating significant upward trend.

4.3 Change point analysis

The Pettitt's test is used to detect the changes in annual rainfall and annual rainy days for the period 1991-2021 The calculated value of K is 58 with p=0.477 for annual rainfall. For the annual rainy days, the calculated value of K is 64 with p=0.671. For both annual rainfall and rainy days, there is no change point observed for the entire 31 years.

Table 1: Monthly rainfall and rainy days statistics for the period (1991-2021) of Visakhapatnam district in Andhra Pradesh

Month/Period	Mean monthly rainfall (mm) (1991-2021)			Mean monthly rainy days (1991-2021)		
	Mean (mm)	CV (%)	Contribution (%)	Mean (mm)	CV (%)	Contribution (%)
Jan	8.78	220.55	0.79	1	184.33	1.89
Feb	30.60	240.56	2.78	1	184.72	1.89
Mar	11.27	170.96	1.01	1	149.13	1.89
Apr	24.09	147.80	2.17	1	106.27	1.89
May	65.74	118.03	5.92	3	68.22	5.66
Jun	132.49	83.41	11.92	7	60.37	13.21
July	121.75	52.76	10.96	8	42.12	15.09
Aug	161.82	49.46	14.56	9	31.45	16.98
Sept	192.96	60.53	17.36	10	41.22	18.87
Oct	241.35	69.36	21.72	8	47.56	15.09
Nov	102.69	119.30	9.24	3	100.99	5.66
Dec	17.78	243.95	1.60	1	187.45	1.89
Annual	1111.33	30.72	100	53	20.63	100
Monsoon	728.62	24.37	64.94	35	7.09	66.04
Pre-monsoon	233.59	80.95	20.82	12	74.96	22.64
Winter	159.85	92.67	14.25	6	57.74	11.32

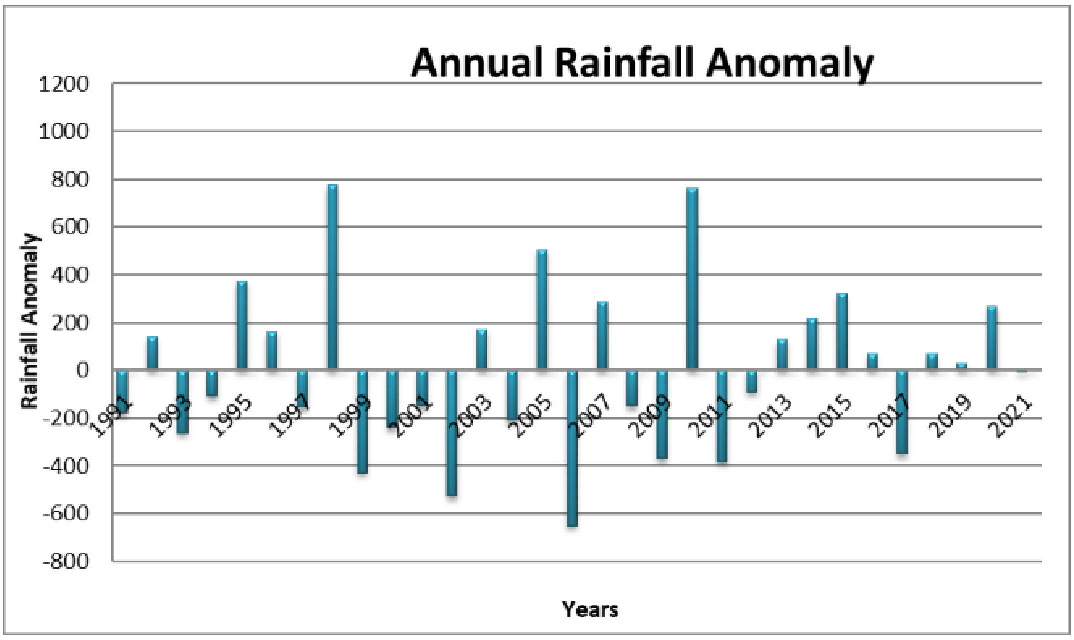

Fig 1: Anomaly plot for rainfall (mm) showing annual anomaly

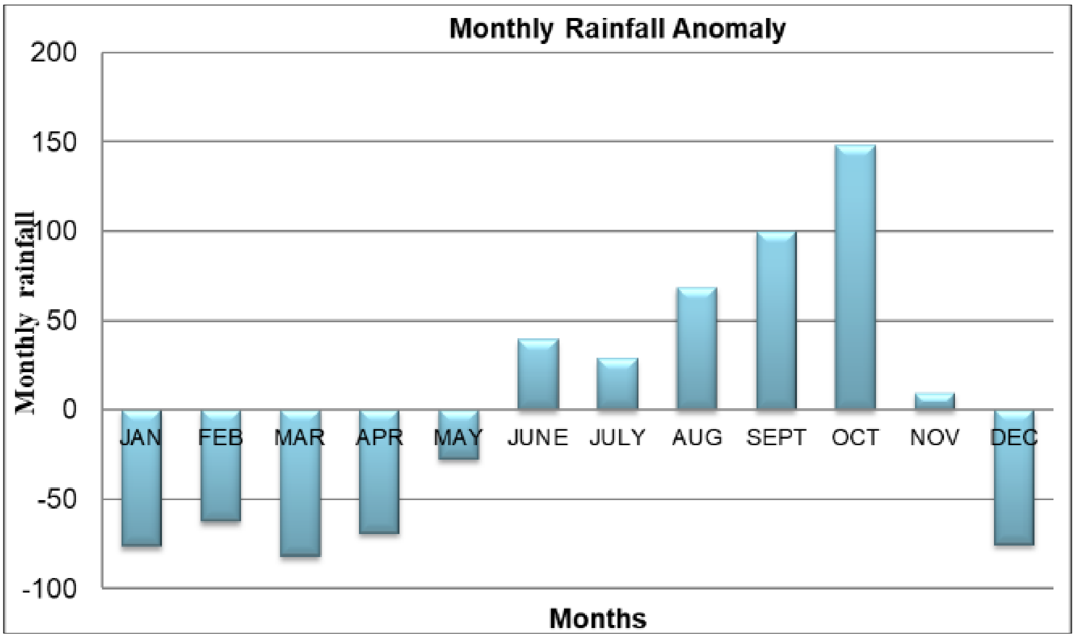

Fig 2: Anomaly plot for rainfall (mm) showing monthly anomaly

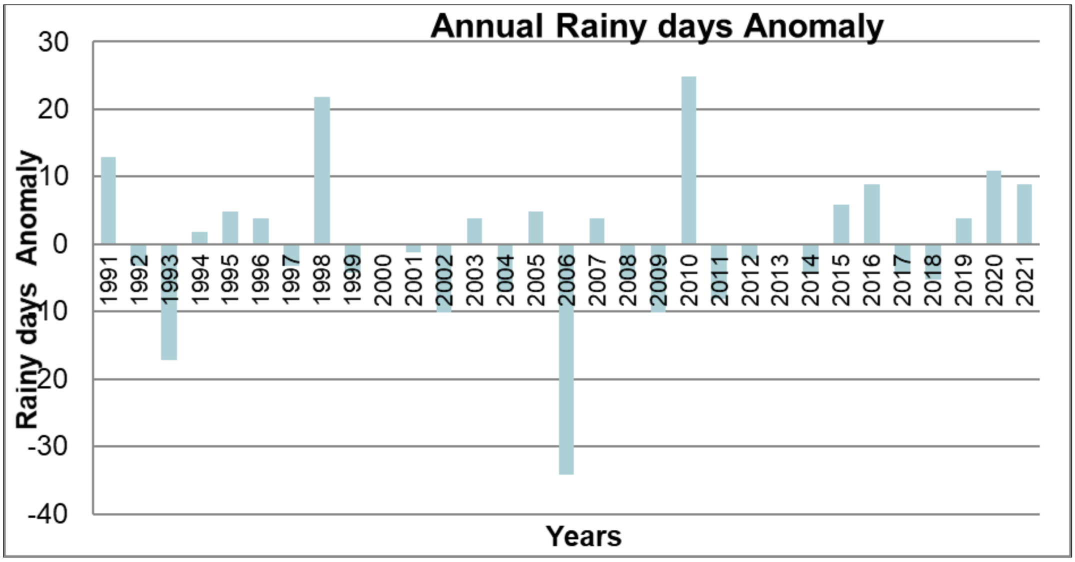

Fig 3: Anomaly plot for rainy days showing annual anomaly

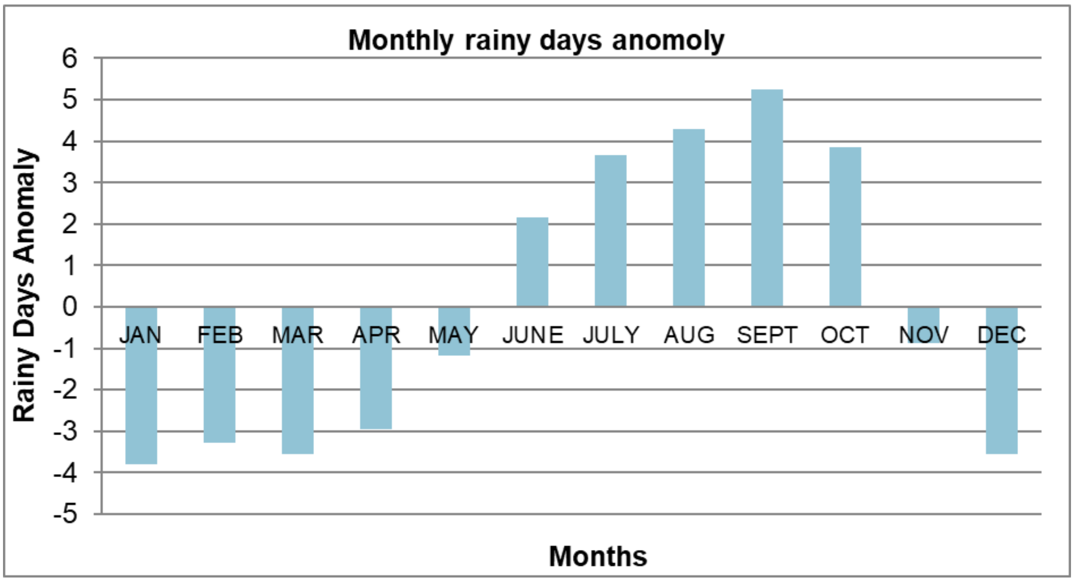

Fig 4: Anomaly plot for rainy days showing monthly anomaly

Table 2: Trend analysis of monthly rainfall

Month/ period	1991-2021				1991-2006				2007-2021			
	MK	SR	Reg.	SS	MK	SR	Reg.	SS	MK	SR	Reg.	SS
Jan	-9.46	0.00	-0.29	0.00	0.06	0.10	-0.62	0.00	-0.15	-0.19	0.43	0.00
Feb	-0.15	-0.22	-0.47	0.00	-0.06	-0.05	0	0.00	-0.28	-0.36	-8.52	0.00
Mar	0.17	0.26	0.29	0.02	0.09	0.17	0.79	0.00	0.00	-0.06	-1.76	0.00
Apr	0.13	0.18	1.04	0.12	0.12	0.11	-0.28	0.15	0.28	0.40	4.78	1.98
May	-0.03	0.00	0.41	-0.18	-0.28	-0.36	-5.39	-3.42	0.09	0.16	2.68	1.8
Jun	7.52	-0.10	0.83	1.03	-0.25	-0.33	-7.28	-6.15	0.14	0.18	1.09	2.36
Jul	8.81	-0.10	0.58	1.21	-0.26	-0.38	-6.37	-6.17	-0.00	0.01	0.79	-1.53
Aug	-0.10	-0.18	2.32	1.73	-0.3	-0.38	-6.58	-7.58	0.42	0.58	-0.73	13.57
Sep	0.05	0.13	0.68	0.76	0.13	0.26	11.21	5.50	-0.17	-0.20	0.63	-6.04
Oct	-0.10	-0.16	-1.74	-1.73	0.28	0.39	12.61	6.95	0.02	0.07	*2.25*	1.40
Nov	-0.08	-0.11	-1.2	-0.2	-0.16	-0.23	-6.81	-2.59	-0.11	-0.17	1.15	-1.46
Dec	0.11	0.15	0.68	0.00	0.16	0.18	0.82	0.00	-0.01	0.04	-1.48	0.00

Here:
MK =Mann –Kendall test
SR=Spearman’s rho test
SS=Sen’s slope
Reg.= Regression analysis

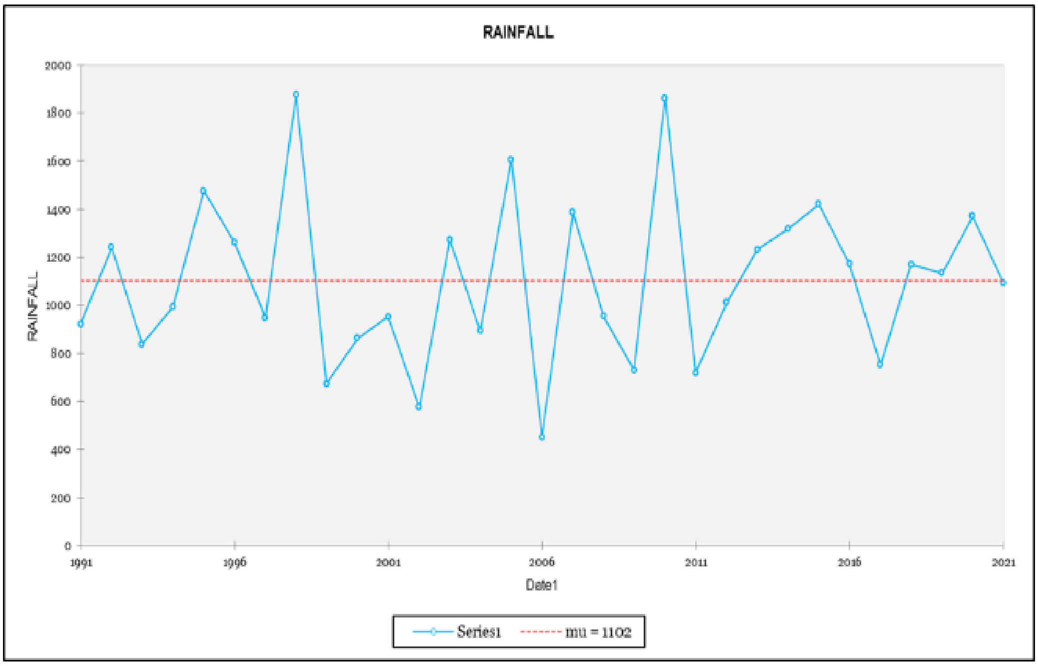

Fig 5: Pettitt’s test for detecting a change in the annual rainfall during the period 1991-2021.

Table 3: Trend analysis of monthly rainy days

Month/ Period	1991-2021				1991-2006				2007-2021			
	MK	**SR**	**Reg.**	**SS**	**MK**	**SR**	**Reg.**	**SS**	**MK**	**SR**	**Reg.**	**SS**
Jan	-3.03	0.00	-0.01	0.00	0.04	0.07	-0.02	0.00	-0.05	-0.05	-0.01	0.00
Feb	-0.05	-0.01	0	0.00	0.09	0.10	0.02	0.00	-0.30	-0.37	-0.27	0.00
Mar	0.16	0.23	0.03	0.00	0.15	0.22	0.07	0.00	0.02	0.00	-0.02	0.00
Apr	0.12	0.16	0.02	0.00	0.11	0.16	0.04	0.00	0.42	0.53	0.18	0.14
May	3.68	0.06	0.02	0.00	-0.23	-0.32	-0.11	-0.11	0.14	0.20	0.14	0.14
Jun	0.16	0.22	0.08	0.11	-0.12	-0.17	-0.2	-0.14	0.17	0.26	0.22	0.20
Jul	-0.02	-0.02	-0.03	0.00	-0.35	-0.48	-0.44	-0.43	-0.21	-0.29	-0.16	-0.22
Aug	0.11	0.14	0.03	0.03	-0.03	-0.11	-0.18	0.00	0.21	0.32	0.15	0.15
Sep	0.18	0.26	0.12	0.11	-0.03	-0.01	0.06	0.00	0.02	0.03	0.03	0.00
Oct	-0.15	-0.19	-0.08	-0.11	0.10	0.23	0.24	0.20	0.23	0.32	0.23	0.22
Nov	-0.14	-0.20	-0.01	-0.04	-0.22	-0.36	-0.38	-0.25	-0.05	-0.02	0.00	0.00
Dec	-0.02	-0.01	0.00	0.00	-0.06	-0.09	0.00	0.00	-0.13	-0.12	-0.07	0.00

Conclusions

According to the results of the study,

1. In case of monthly rainfall, the results show upward trend for August month for the period 1991-2021.
2. From the above study we can conclude that in case of monthly rainfall the coefficient of variation is less in the months of July, August, September and October (CV<75%).
3. The trend analysis is done for Visakhapatnam district of Andhra Pradesh for monthly Rainfall data for the period of 1991-2021 using non- parametric tests Mann –Kendall and Sen's slope estimator test.
4. Monsoon monthly rainfall has a lower coefficient of variance 24.37 (per cent) than pre- monsoon (80.95per cent). The biggest coefficient of variation for rainfall is in winter (92.67 per cent). Similarly, monsoon season has a lower coefficient of variance (7.09 per cent) than pre-monsoon season (74.96 per cent) and winter season (57.74) in the monthly rainy days.
5. The Pettitt's test showed that neither the yearly rainfall nor the number of wet days have reached a change point.

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