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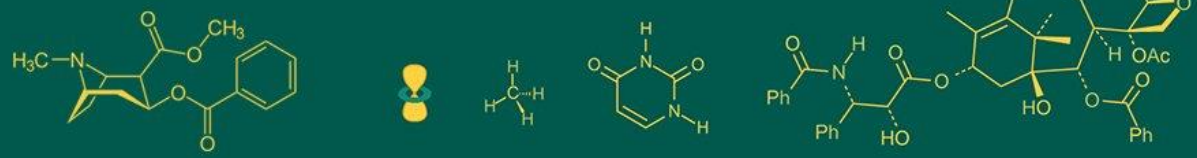

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Spatial and temporal trend analysis of rainfall in eastern India

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Abstract
A study on annual and seasonal (winter, pre-monsoon, monsoon, and post-monsoon) trend analysis of Rainfall at the spatial and temporal scales had been carried out during 1901 to 2017 for Eastern states of India. Non-parametric statistical techniques viz. Mann-Kendall (MK) test with Sen's slope estimator, and Pettitt Mann-Whitney (PMW) test had been carried out to examine the annual and seasonal trends at 5% level of significance. The results of the nonparametric tests showed statistically significant increasing trends in annual and monsoon season for minimum rainfall in West Bengal and statistically decreasing trend was found in annual, winter and monsoon season for Bihar and Jharkhand. Rainfall in Odisha show significant decreasing trend in winter. The rate of change of the rainfall obtained from Sen's slope estimator was found to be higher in annual (1.56 mm/year) and lower average decreasing trend in seasonal rainfall. The most probable year of changes in the rainfall were occurred in between 1918-1977. In conclusion, it was clear that the magnitude of the rainfall trend is highest in monsoon season and variability is greater in winter season.

Keywords: Climate change, non-parametric test, rainfall, trend analysis

Introduction
In recent decades, addressing climate change has emerged as a global priority. Presently, the average global temperature in 2022 is estimated to be approximately 1.15 degrees Celsius higher than the pre-industrial average of 1850-1900, with a range between 1.02 and 1.28 degrees (World Meteorological Organization report 2022).
Eastern states such as Odisha, Bihar, Jharkhand, and West Bengal contribute significantly to India's agriculture and economy. While the extent and significance of their contributions vary, they all contribute to the Nation's agricultural output, labour force, and general economic development and over the year these states also face challenge of climate change. Thus, the trend analysis of climate variables like rainfall (Partal and Kahya, 2006, Addisu *et al*. 2015) [6, 7] on different spatial scales will help in the prediction of future climate scenarios. The planning and management of sustainable water resources in the area will be made easier with the help of this analysis of rainfall trends.
While numerous research on climate change have been conducted in the central, northern, and southern parts of India, the eastern part of the country has seen little action. It is therefore utmost importance to understand its vulnerability in term of population and sectors at risk and its potential for adaptation to climate change. In this research, variability and trend analysis of rainfall in eastern part of India was studied using observational data for the period between 1901-2017.

Materials and Methods
Eastern states of India consisting of the Indian states of Bihar, Jharkhand, West Bengal, and Odisha were taken for the study. The long term (1901-2017) annual and seasonal rainfall data were acquired from Indian Metrological Department. In the present study, the 1901 to 2017 rainfall time series were segregated into 5 data sets viz. annual (1) and seasonal (4) as characterized by the India Meteorological Department (IMD) guidelines: monsoon (June-Sept); post-monsoon (Oct-Nov); winter (Dec-Feb) and pre-monsoon (Mar-May).

Descriptive statistics such as Mean, Standard deviation and coefficient of variation were used to measure variability of rainfall. The non-parametric Mann-Kendall trend and Sen's slope estimator test and Pettitt Mann Whitney test were applied for trend analysis.

Mann-Kendall Test

The MK test is a widely used non-parametric rank-based test for analyzing trend in hydrological and climatological data. It offers advantages over other tests because it does not rely on specific data distributions and is robust against outliers. The test assumes that the time series being studied are stable, independent, and random, with an equal probability distribution. In the MK test, the null hypothesis (HO) tests for the absence of a trend, while the alternative hypothesis (H1) examines whether there is an increasing or decreasing trend.

Sen's Slope Estimator

In the context of time series data or data with intrinsic ordering, the "sen slope estimator" is a technique used to estimate the slope of a linear connection between two variables. It is based on the idea of computing the median of all potential slopes between pairs of data points and was proposed.

A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series data.

$Qxj-xk$, fori=1,2,3….N,j>k
$i=j-k$

The magnitude of a trend in a time series can be determined using a slope estimator known as Sen's estimator. For estimation of the true slope of an existing trend, Sen's non-parametric method is used.

A negative value of Sen's slope indicates a downward or decreasing trend whereas an upward or increasing trend in the time series is denoted by a positive value. It is calculated at 100(1-α) % confidence interval and by a two-sided test. The Theil-Sen's estimator is a hearty gauge of the size of a trend that has been used for recognizing the trend line slope in hydrological time.

Pettitt Mann-Whitney Test

The Pettitt Mann-Whitney (PMW) test distinguishes the most likely change year in the yearly precipitation sequence.

Results and Discussion

Annual and seasonal variation in the eastern India.

Annual and seasonal rainfall variability patterns from 1901 to 2017 for Bihar are shown in Table 1. Among all seasons, the highest rainfall (1014.923 mm) was recorded in monsoon season while the lowest rainfall (31.027 mm) was recorded in the winter season. The SD, CV was found of 193.15 mm, 16.14%, respectively for annual series; within seasonal rainfall, The highest variability of rainfall was occurred in post-monsoon season (82.62%) while the lowest variability occurred in monsoon season (17.25%). In Jharkhand result showed in Table 2 that, states differed in annual and seasonal rainfall distribution. The mean annual rainfall was received of 1307.68 mm with SD, CV of 197.02 mm and 15.06%. Within seasonal rainfall, the highest rainfall was received of 1083.87 mm in monsoon season while lowest winter season (46.16 mm). The analysis of seasonal variability showed that there was high variation in winter season (76.07%) and lowest in monsoon (15.93%). Table 3 in West Bengal. West Bengal experienced an average annual rainfall of 1490.61 mm. The average monsoon rainfall was 1130.96 mm, while the lowest amount was received during winter at 40.58 mm. The coefficient of variation (CV) for annual rainfall in the study area was 15.27%. Concerning seasonal rainfall, the CV ranged from a minimum of 16.31% during the monsoon season to a maximum of 78% during the winter season, highlighting the lower variability of annual rainfall. Table 4 provides information about the rainfall patterns in Odisha from 1901 to 2017. It shows that the average annual rainfall during this period was 1455.44 mm, with a standard deviation of 186.73 mm. The coefficient of variation for annual rainfall is 12.83%, indicating moderate variability. The winter season had the highest variability in rainfall at 77.55%, whereas the monsoon season had the lowest variability at 13.09%.

Table 1: Descriptive statistical trend analysis of rainfall for Bihar state

Parameter	Mean (mm)	Standard Deviation (mm)	CV (%)
Annual	1196.5632	193.1536	16.1423
Winter	31.0273	22.2108	71.5848
Pre-monsoon	80.6162	34.7212	43.0698
Monsoon	1014.923	175.1381	17.2563
Post-monsoon	70.0000	57.8370	82.6242

Table 2: Descriptive statistical trend analysis of rainfall for Jharkhand

Parameter	Mean (mm)	Standard Deviation (mm)	CV (%)
Annual	1307.6897	197.0206	15.0663
Winter	46.1666	35.1211	76.0747
Pre-monsoon	85.9846	39.1304	45.5086
Monsoon	1083.8786	166.8867	15.3971
Post-monsoon	91.6606	67.1920	73.3051

Table 3: Descriptive statistical trend analysis of rainfall for West Bengal state

Parameter	Mean (mm)	Standard Deviation (mm)	CV (%)
Annual	1490.6128	227.6949	15.2752
Winter	40.5820	31.6571	78.0077
Pre-monsoon	181.2179	68.8987	38.0198
Monsoon	1130.9692	184.4684	16.3106
Post-monsoon	137.8504	83.0520	60.2479

Table 4: Descriptive statistical trend analysis of rainfall for Odisha state

Parameter	Mean (mm)	Standard Deviation (mm)	CV (%)
Annual	1455.4487	186.7389	12.8303
Winter	37.1948	28.8478	77.5586
Pre-monsoon	119.7709	51.5481	43.0389
Monsoon	1156.8282	151.4714	13.0936
Post-monsoon	141.6555	84.8004	59.8638

Trend analysis of Annual and Seasonal Rainfall in Eastern States

Non-parametric tests were utilized to examine rainfall patterns in the eastern regions of India. The analysis involved applying the Mann-Kendall (MK) test, Sen's slope estimator, and the Pettitt-Mann-Whitney (PMW) test to assess trends in both annual and seasonal rainfall data. Table 5-8 provide information on the direction (indicated by Z

values), the magnitude of the trends (denoted as Q), and the potential identification of change points for annual and seasonal rainfall, including Winter, Pre-monsoon, Monsoon, and Post-monsoon, covering the period from 1901 to 2017.
Significant negative trends were identified in annual, winter, and monsoon season rainfall, in Bihar and Jharkhand while in West Bengal annual and monsoon seasons showed significant positive trends. And Odisha showed statistically significant negative trends. The magnitude of these rainfall trends was determined using Sen's slope estimator. Highest annual rainfall increases at a rate of-1.56 mm/year, with the lowest decline observed in seasonal rainfall. Change point detection analysis revealed the most probable years for significant changes in rainfall patterns as 1947, 1967, 1965 and 1959 for annual, 1977, 1918, 1970 and 1918 for pre-monsoon, 1954, 1960, 1965 and 1959 for monsoon, 1924, 1921, 1925 and 1961 for post-monsoon, and 1957, 1943, 1946 and 1946 for winter rainfall.

Table 5: Non-Parametric statistical trend analysis of Rainfall for Bihar

Parameter	MK Test (Z value)	Sen's Slope Estimate(Q)	PMW test (Kt)	P-value
Annual	-2.6289	-1.3441	1947	0.0085
Winter	-1.9600	-0.1153	1957	0.0500
Pre-monsoon	1.1425	0.1160	1977	0.2532
Monsoon	-2.4688	-1.2022	1954	0.0135
Post-monsoon	-0.0094	-0.0008	1924	0.9925

Table 6: Non-Parametric statistical trend analysis of Rainfall for Jharkhand

Parameter	MK Test (Z value)	Sen's Slope Estimate(Q)	PMW test (Kt)	p-value
Annual	-2.9470	-1.5859	1967	0.0032
Winter	-3.2745	-0.2750	1943	0.0010
Pre-monsoon	-0.7585	-0.0774	1918	0.4481
Monsoon	-2.5606	-1.2425	1960	0.0104
Post-monsoon	-0.1813	-0.0254	1921	0.8561

Table 7: Non-Parametric statistical trend analysis of Rainfall for West Bengal

Parameter	MK Test (Z value)	Sen's Slope Estimate (Q)	PMW test (Kt)	p-value
Annual	2.2544	1.5668	1965	0.0241
Winter	-0.6407	-0.0414	1946	0.5217
Pre-Monsoon	0.3651	0.0681	1970	0.7150
Monsoon	2.6007	1.3174	1965	0.0093
Post-monsoon	0.6124	0.1261	1925	0.5402

Table 8: Non-Parametric statistical trend analysis of Rainfall for Odisha state

Parameter	MK Test (Z value)	Sen's Slope Estimate (Q)	PMW test (Kt)	p-value
Annual	-1.5689	-0.8242	1959	0.1167
Winter	-2.1461	-0.1452	1946	0.0318
Pre-monsoon	-1.0789	-0.1330	1918	0.2806
Monsoon	-1.6537	-0.6517	1959	0.0981
Post-monsoon	-1.0459	-0.2624	1961	0.2956

Conclusions

Mean annual rainfall varies from minimum of 1196.56 mm to maximum of 1490.61mm across all states under consideration. In eastern states, the highest rainfall was found in monsoon season and the lowest rainfall was found in the winter season. it was discovered that the winter season had the greatest variation in rainfall when compared to the monsoon season except in Bihar, where the highest variation was found in post-monsoon season. The MK test showed decreasing trend of annual and seasonal rainfall in Jharkhand, Odisha, and Bihar (except in pre-monsoon) but in West Bengal, annual and seasonal rainfall showed increasing trend except in winter season where decreasing trend was observed.
The Sen's slope estimator revealed that the magnitude of annual rainfall was decreasing significantly in case of Bihar, Jharkhand, and Odisha whereas in case of West Bengal, annual rainfall was found to be increasing.
The PMW test revealed that the most probable change point varies from 1947 to 1965 across all states under consideration within the annual season and within seasonal rainfall in varies from 1918 to 1977.

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