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RESEARCH ARTICLE

Precipitation Trend Analysis of India - A Climate Change Study

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Abstract

Objectives: To identify the trend and variability of precipitation in the Indian subcontinent. **Methods:** To identify the trend component the non-parametric test statistic Mann - Kendall and Statistical Process Control (SPC) methodologies are used to conduct a statistical study. **Findings:** Precipitation of India has shown decreasing trend throughout the winter, monsoon, and on an annual basis, and an increasing tendency was observed during the rest of the seasons. During the winter season, there was more variation in precipitation with Coefficient of Variance (CV) is 33.7919%. **Novelty:** The long period (120 years) average data from 1901 - 2020 is used to know the long run trend and distribution pattern variation of precipitation in India with the proposed statistical methods. **Applications:** This mechanism is suitable to change the crop pattern and manage the adverse effects in associated sectors.

Keywords: Statistical Process Control; India; Mann Kendall Statistic; Precipitation; Trend

1 Introduction

The weather in India is not uniform thorough out its boundary. It is situated in Southeast Asia and has climatic variations range from arid to semi-arid in the plateau region, sub-humid to humid tropical inside the Western Ghats, and humid tropical monsoon inside the coastal lowlands due to its diverse geographic and physiographic circumstances. Therefore, India has diverse weather conditions at any point of time along within its boundary. To understand the dramatic weather conditions, a detailed study is to be carried out. There is much research has done on Indian weather predictions but so far the long period 120 years precipitation study is not taken place. As a result, in the current investigation, a thorough examination was carried out to comprehend the shifting trends in developing appropriate procedures to deal with changing weather conditions is a priority for the country. The attempts had been made to examine the trend pattern. Some of authors made their contributions towards the precipitation analysis. With trend component methodologies, Akhtar et al emphasized on the historical rainfall features and drought situations in two significant southern Indian states, namely Tamil Nadu and Karnataka, over a 110-year span[(1)]. The climate change trends aids in the development of appropriate coping mechanisms[(2)]. Any rate of climate change during the monsoon season has a significant impact on agriculture, the economy, and water supply during non-monsoon months, necessitating systematic and immediate attention to precipitation patterns[(3)]. Kumar et al. studied a 68-year study of summer seasonal rainfall in the framework of decadal shifts in trends across India's climatic zones, incorporates two time periods: 1951-1984 and 1985-2018 [4]. The country's seasonal rainfall distributions vary per state. Precipitation is one of the most important meteorological variables for climate change detection [5], and across several meteorological sub divisions, long-term trends techniques using traditional Man-Kendall and Modified Man-Kendall statistics were used [6].

This paper focuses mainly on trend and distribution pattern variation of precipitation in India and the study is carried out with the Statistical Process Control and Mann - Kendall statistic methods. The section 1 describes about a brief introduction, section 2 depicts the data source and methodologies have been used, section 3 shows the predicted results and discussion and finally conclusions are presented in section 4.

2 Methodology

2.1 Data Source

Precipitation data (1901-2020) was collected from Indian Meteorological websites regularly. Fundamental monsoonal statistics such as average, variance (SD), Coefficient of Variation (CV), and relative contribution to average rainfall were computed for each month and season, namely winter (January-February), pre-monsoon (March-May), monsoon (June-September), and post-monsoon (October-December) (October December). The rainfall is categorized based on threshold rainfall figures as no rain (0 mm), very light (0.1 to 2.4 mm), light (2.5 to 7.5 mm), moderate (7.6 to 35.5 mm), rather heavy (35.6 to 64.4 mm), heavy (64.5 to 124.4 mm) and very heavy (more than 124.5 mm) in 24 hours.

2.2 Statistical Process Control

This study employed a periodic variation of SPC, I - chart of precipitation data to detect variations in variability. The Center Line (CL) was set at the mean of the performances, while the Upper and Lower Action Lines (UAL and LAL) were set at usually three Standard Deviations (SD) from the centerline to create the I-Chart. For better understanding, the control limits are given as for Individual chart (I - Chart) (1)

$$standard\ deviation\ (\sigma) = \frac{\sqrt{\sum_{i=1}^{N}(x_i-\mu)^2}}{N} \quad (1)$$

Where, x_i = the individual sample value, μ= sample mean, and N = size of the sample.

Upper Control (Action) limit = Average + 3 * standard deviation

Lower Control Limit (Action) limit = Average - 3 * standard deviation

Lower Warning limit = Average - 2 * standard deviation

Upper Warning limit = Average - 3 * standard deviation

Central limit = Average.

While plotting the distinct results on the I-Chart, the "out of control" situations are examined.

2.3 Non-parametric Test

The Mann Kendall test is a frequently used statistical tool for analyzing the trend in climatologic and hydrologic time series. The null hypothesis H_0 assumes that there is no trend (data is independent and randomly arranged) and is compared to the alternative hypothesis H_1, which asserts that there is a trend. The Mann-Kendall S Statistic is computed as follows(2)(3)

$$S = \sum_{i=1}^{n}\sum_{j=i+1}^{n} \operatorname{sign}(T_j - T_i) \quad (2)$$

$$\operatorname{sign}(T_j - T_i) = \begin{cases} 1 \text{ if } T_j - T_i > 0 \\ 0 \text{ if } T_j - T_i = 0 \\ -1 \text{ if } T_j - T_i < 0 \end{cases} \quad (3)$$

where, T_j and T_i are the annual values in years j and i respectively, with j >i.

The statistic S is almost normally distributed for n > 10, with the mean and variance as follows:

$$E(S) = 0 \text{ and Variance } (S) = \sigma^2 = \frac{n(n-1)\,(2n+5-\sum_i t_i(i)(i-1)(2i+5)}{18}$$

The number of ties to an extent i is denoted by t_i. If the data series contains tied values, the numerator summation term is used. The standard test statistic Z_s is used to determine the trend's significance and is calculated as follows:(4)

$$Z_s = \begin{cases} \frac{S-1}{\sigma} \text{ if } S > 0 \\ 0 \text{ if } S = 0 \\ \frac{S+1}{\sigma} \text{ if } S < 0 \end{cases} \quad (4)$$

3 Results and Discussion

The average annual rainfall in India is 1252 mm. The highest rainfall, 1463.9 mm was recorded in 1917, and the lowest, 930.1 mm was recorded in 2002 (Figure 1).

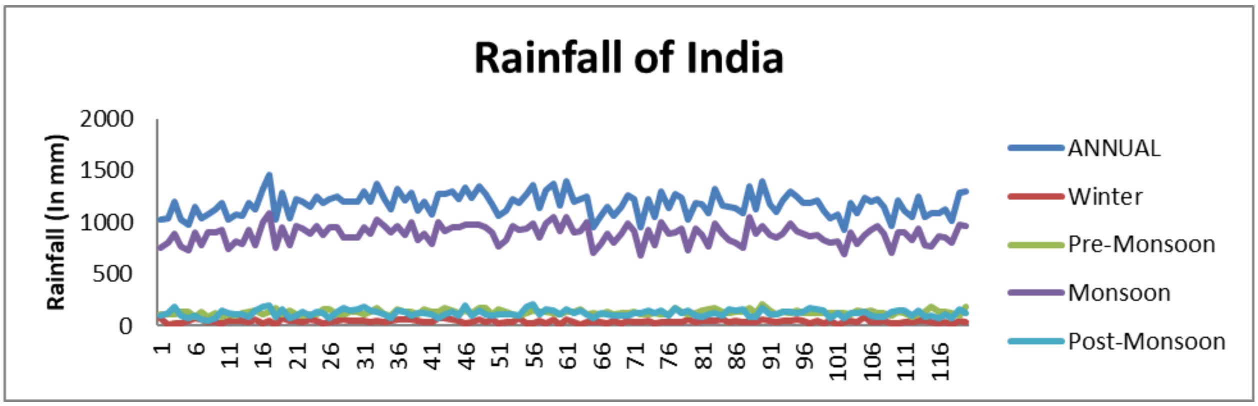

Fig 1. Precipitation distribution pattern of India

The annual and seasonal premise of trend and slope has been calculated and is provided below.

3.1 Seasonal and Annual Trends of Precipitation using Non-parametric test

During the winter season, India exhibited a dropping trend, but during the pre-monsoon season, India showed a significant trend. During the monsoon season, all months showed a negative trend, with the exception of August, which showed a positive trend. After the monsoon season, the post-monsoon season had shown an increasing trend, and India had seen a decreasing trend of annual rainfall over the last 120 years, with a negative trend. These results were confirmed from Table 2.

Table 1. Descriptive Statistics of Precipitation of India from 1901 to 2020

Season	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
Mean	19.09	22.66	27.92	38.02	62.67	167.74	289.10	256.70	171.97
Std. Dev.	9.45	11.28	11.96	10.12	15.48	35.08	39.37	34.73	36.24
CV	49.52	49.77	42.83	26.61	24.70	20.91	13.62	13.53	21.07
Season	**OCT**	**NOV**	**DEC**	**ANNUAL**	**JF**	**MAM**	**JJAS**	**OND**	
Mean	75.87	29.44	15.00	1176.19	41.76	128.61	885.52	120.98	
Std. Dev.	27.95	16.18	8.73	107.60	14.11	22.59	86.43	32.22	
CV	36.83	54.97	58.25	9.15	33.79	17.56	9.76	26.63	

3.2 Seasonal and Annual Trends of Rainfall using a Control chart

The amount of rain received in India throughout the winter season had shown substantial effects, i.e., the amount of rain received by India had demonstrated varying out of control concerning the January month. Over the last 120 years, India has shown out

Table 2. Mann Kendall test (Z) and Sen's slope (Q) for Precipitation month-wise

Season	Z	Q
JAN	-1.184 ↓	-0.029
FEB	0.181 ↑	0.004
MAR	1.602 ↑	0.048
APR	0.411 ↑	0.011
MAY	0.808 ↑	0.031
JUN	-0.345 ↓	-0.042
JUL	-1.54 ↓	-0.155
AUG	0.145 ↑	0.017
SEP	-0.209 ↓	-0.022
OCT	0.161 ↑	0.016
NOV	-0.758 ↓	-0.027
DEC	0.225 ↑	0.004

Table 3. Mann - Kendall test (Z) and Sen's Slope (Q) for Precipitation season-wise

Season	Z	Q
ANNUAL	↓	-0.089
Winter	↓	-0.050
Pre-Monsoon	↑	0.061
Monsoon	↓	-0.154
Post-Monsoon	↑	0.013

of control during the pre-monsoon season, i.e., all months are out of control. During the monsoon season, India has shown within control and the same in the post-monsoon season. India's annual rainfall was found to be within acceptable norms.

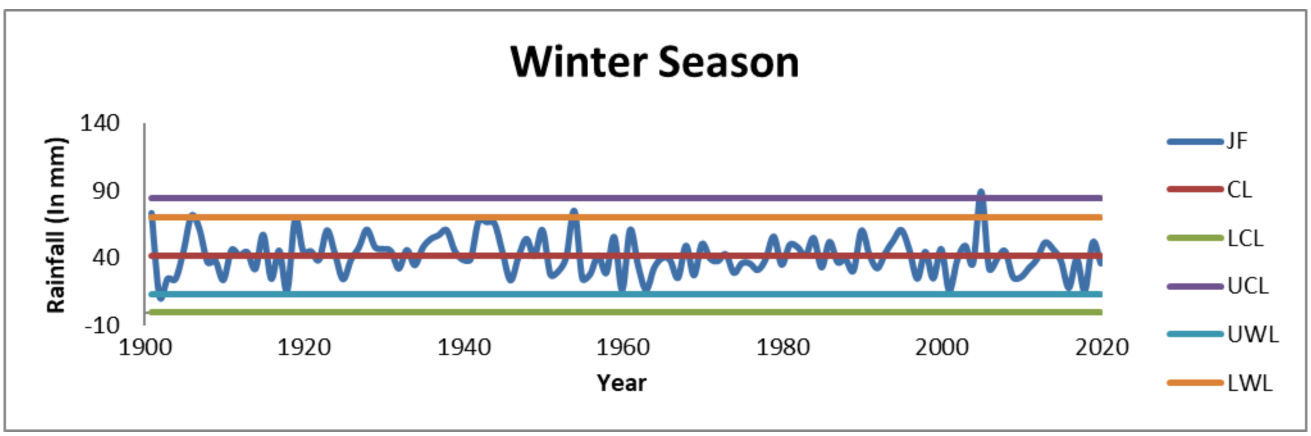

Fig 2. Control chart for rainfallof India during the winter season

Discussion

The long period (120 years) average data from 1901 - 2020 is used to know the long run trend and distribution pattern variation of precipitation in India with the Mann - Kendall and Statistical Process Control statistical methods. The study reveals that India has shown the negative trend in receiving of precipitation in Annual, Winter and Monsoon seasons and the pre and post monsoon seasons have shown the increasing tendency. The control charts are specified the variations of precipitation in the study period. These charts are identified the mean process trend pattern behavior of precipitation whether the received amount of precipitation is within the tolerable limits or not. The seasons winter and pre - monsoon are showing variable in receiving of

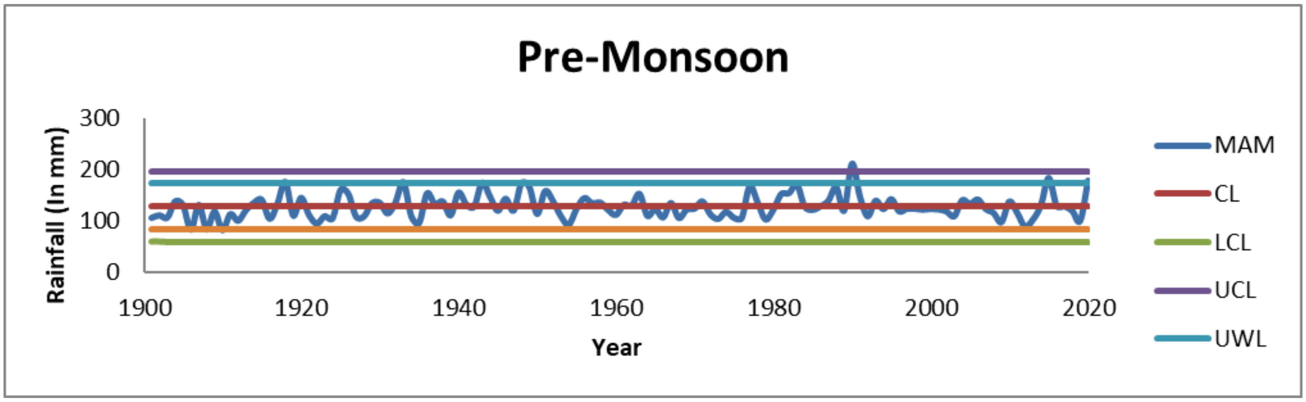

Fig 3. Control chart for precipitation of Indiaduring Pre-Monsoon season

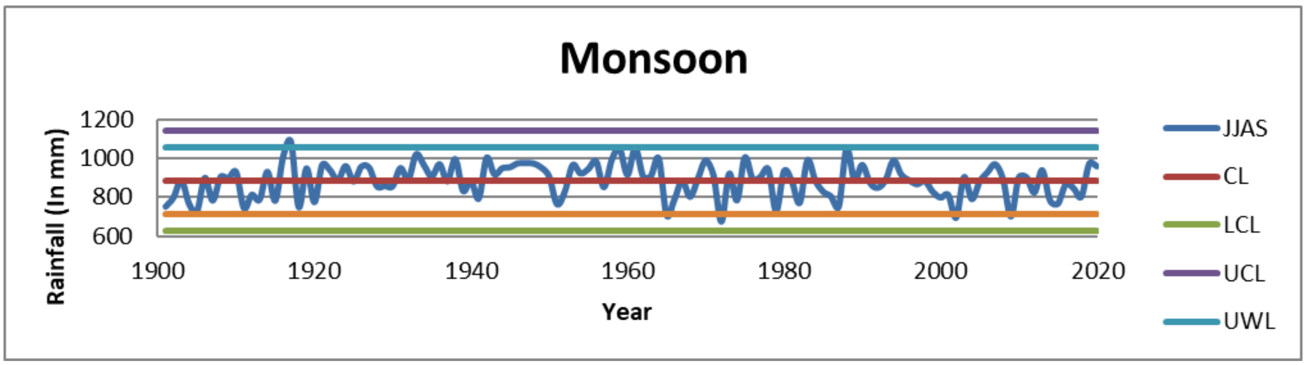

Fig 4. Control chart for precipitation of Indiaduring the Monsoon

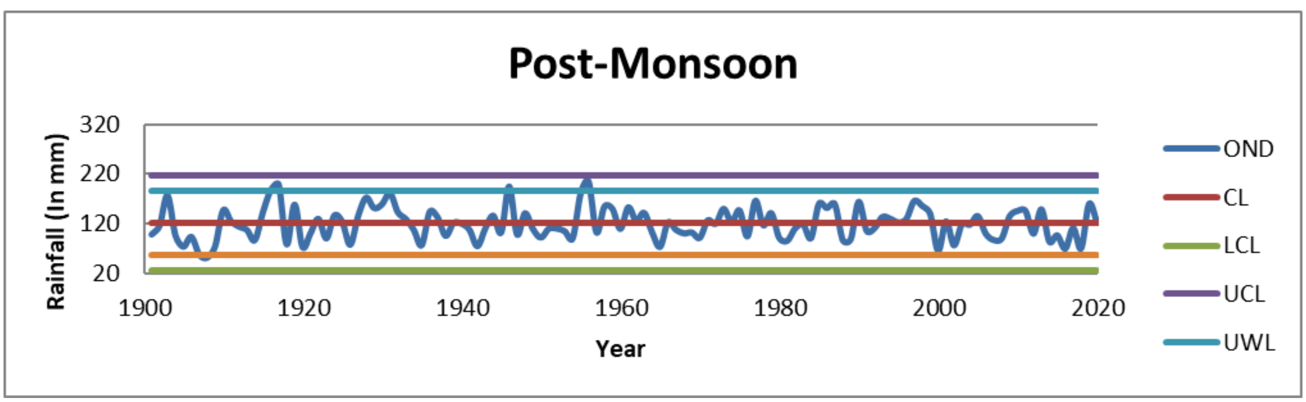

Fig 5. Control chart forprecipitation of India during Post-Monsoon season

precipitation while the other seasons are within the three sigma limits.

4 Conclusion

The long period average precipitation data is used for the statistical study on identifying the trend and variation pattern in distribution of precipitation in India. As a whole the major precipitation receiving monsoon season is shown declined trend and which results the annual rainfall in decreasing pattern and also pre and post monsoon seasons are shown increasing trend. The control charts are giving bird's eye view in helpful making necessary adjustments to suppress the diverse affects whenever the action limits are reached. The present study is limited to the identification of trend pattern. Further to gain more insights, future predictions are to be made and the study extended with the precipitation and temperature variables are examined to bind their behavior in the long run through various statistical measures.

Future Scope: The extensive comparative study is aimed at the trend pattern of precipitation in India according to geographical climatic zones, compute future projections, and cto ompare the effectiveness of prediction models employing multiple techniques.

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