International Journal of Biology, Pharmacy
and Allied Sciences (IJBPAS)
'A Bridge Between Laboratory and Reader'

www.ijbpas.com

CHANGE POINT DETECTION AND TREND ANALYSIS OF MONTHLY, SEASONAL AND ANNUAL RAINFALL SERIES OVER THE MYSORE DISTRICT, KARNATAKA

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ABSTRACT

Climate change has become a worldwide issue in recent decades. Climate change refers to changes in the earth's environmental factors. This is due to a multitude of internal as well as external variables. Rainfall is an important weather factor in climate change. Analyzing rainfall changes is an important step in determining the impact of climate change on water availability and food security. The purpose of the present study is to evaluate rainfall data to identify patterns and moments of trend change. Monthly, seasonal, and annual rainfall information was collected for the Mysore district of Karnataka, India, from a period of 2006 to 2019. Mann-Kendall and Sen's Slope tests were used for analyzing annual rainfall data. Changes were observed for annual rainfall statistics which were obtained using a change point detection test. The mean monthly rainfall change point occurred in December 2012, August and November 2017 at the confidence level of 94%, 95% and 94% at levels 3, 1 and 2 respectively.

Keywords: Temperature, Rainfall, Trend analysis, Change point detection, Mann-Kendall, Sen's slope

INTRODUCTION

Nearly every component of our life is impacted by the climate, including our food supplies, transportation systems, clothing choices and vacation destinations. Climate change significantly affects our future, health and means of subsistence. Climate change, which is primarily caused by an increase in greenhouse gas emissions and human activity, has a considerable impact on hydrological variables such as precipitation, stream flow, runoff, soil moisture, temperature and relative humidity. These consequences manifest as rapid changes or trends [1, 2]. According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change stated that there is increase in global temperature which as affected land and ocean for the last three decades [3]. Thus Climate change has serious affect locally and globally throughout the worldwide.

Climate change is currently regarded as a threat due to its primary influence on temperature and rainfall in various places of the planet [4]. Rainfall, along with temperature, is possibly the most essential aspect in defining climate. Excessive rainfall can cause flooding as well as significant property and crop damage. In other way lack of rainfall might result in drought and agricultural failure. Rainfall is also an important source of energy that propels atmospheric circulation. According to a

study [5] looked for annual and seasonal rainfall patterns in India's north and northwest places by applying non-parametric methods on data collected over 115 years. According to Getahun who examines the changes in rainfall and temperature data using change-point detection tests and Mann-Kendall (MK) trend analysis [6-8].

Our present study attempts to understand the variability of rainfall and temperature of Mysore district through non parametric test such as Mann-Kendall and Sen's slope estimator through Change Point analyzer using Cumulative Sum chart (CUSUM).

MATERIAL AND METHOD

We considered Mysore district as the study area which is located on the Southern Deccan plateau between latitude $11^{\circ}45'$ to $12^{\circ}40'$ N and longitude $75^{\circ}57'$ to $77^{\circ}15'$ E. It is bounded by Mandya district to the northeast, Kerala state to the south, Kodagu district to the west and Hassan district to the north. It has an area of 6,853 Km^2. It experiences tropical savanna type of climate; the temperature in the district varies from $15^{\circ}C$ in winters to $35^{\circ}C$ in summer. Mysore district receives an average rainfall of 785mm. It is divided into 7 taluks such as Mysore, Hunsur, and H. D kote, Nanjangud, T. Narasipura, Periyapatna and K.R Nagara **(Figure 1)**. **Figure 1** gives the study area of Mysore district along with its taluk.
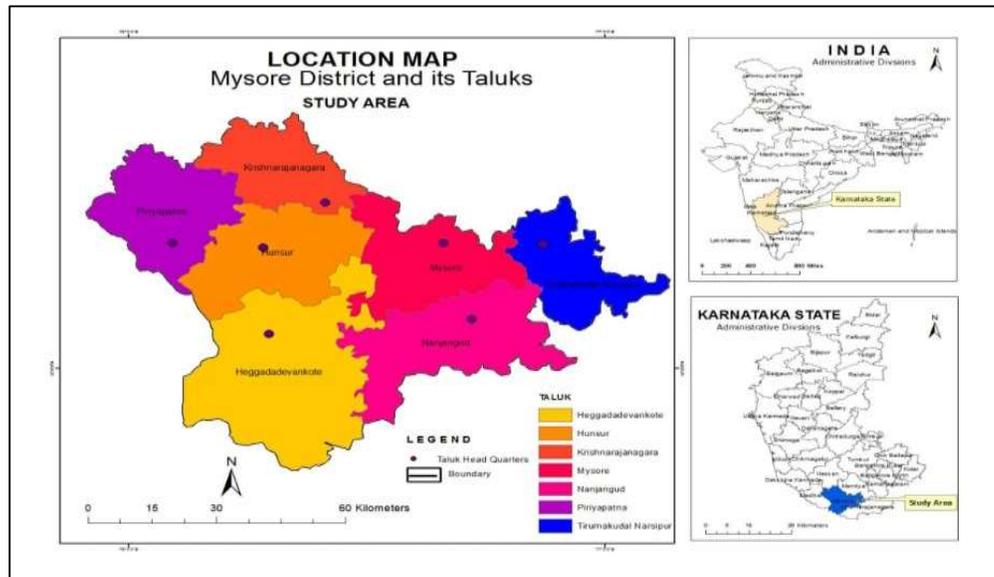
Figure 1: Study area of Mysore district, Karnataka, India and its taluks

In the Present study, Average rainfall from 2006-2019 were considered which does not follow normality condition. Thus we adopted the non-parametric test Mann-Kendall and Sen's slope estimator for the study.

Mann-Kendall Test for Trend Detection

Mann-Kendall (M-K) test is one of the essential measures for determining whether monotonic trends are significant. According to the World Meteorological Organization (WMO), the M-K test is useful and adaptive for places with a variety of climatic and hydrological circumstances as well as water resource conditions **[5]**. It is given by standardized test statistics Z and the Mann-Kendall statistic S,

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

$$sgn\,(x_j - x_i) = \begin{cases} +1, if\ X_j - X_i > 0 \\ 0, if\ X_j - X_i > 0 \\ -1, if\ X_j - X_i < 0 \end{cases}$$

$$Var(S) = \frac{1}{18}\big[n(n-1)(2n-5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\big]$$

$$Z = \begin{cases} \frac{s-1}{\sqrt{Var(S)}}, if\ S > 0 \\ 0 \dots\dots\dots, if\ S = 0 \\ \frac{s+1}{\sqrt{Var(S)}}, if\ S < 0 \end{cases}$$

The variables used in the statistical analysis are: X_i and X_j successive data values in the years i and j; n, the number of recorded data; t_p, the number of ties for the pth values; and q, the number of tied values.

A positive Z value signifies growing trend values, whereas negative Z values point to a declining trend in the associated time series. If a trend is present in the Series, the Z value is calculated using the predetermined significance level and the standard normal distribution.

Sen's Slope Estimator

It is an sufficient tool to determine the magnitude of trend in meteorological time

series (5). In this method, the slopes (T_i) of each pair of data are calculated using

$$T_i = \frac{x_j - x_k}{j - k} \text{ for } i = 1, 2,.., N$$

…where x_j and x_k are, respectively, the successive data values at times j and k (j > k). The amplitude of the trend slope of the data values is represented by the median of these N values of T_i.

Change Point Detection Method

A useful tool to identify climatic unpredictable behavior in climate data series is the change point detection approach. A technique for identifying changes brought about by multiple iterations combines cumulative sum charts (CUSUM) and boot strapping (3,7,8). The cumulative sum S_i is estimated as follows:

$$S_i = S_{i-1} + X_i - \bar{X}$$

…where $S_o = 0$; initial cumulative sum S_o; i = 1, 2, 3… 25; and $\bar{X}$ is the average of the sample series.

Here to calculate CUSUM values, the difference between the current value and the average of the previous sum is added. The numbers that are above or below the overall average are shown by an upward or downward slope. The series with two means are divided into segments at the change point, and the mean square of the estimates is computed iteratively until the least mean square of error (MSE) is attained. This demonstrates the passage of time and ultimately supports the idea that the climate

system is changing. The importance of the change point as presented is determined using the boot strapping-based confidence level is given by

$$\textbf{\textit{Confidence level}} = 100 \times \frac{X}{N} \%$$

...where X is the number of bootstrapped S values that are higher than the original S values, N is the number of bootstraps, and S is the difference between the maximum and minimum CUSUM values.

The change point analyzer version 2.3 software was utilized for change point detection for the given data set. It was used as an effective tool for the detection of the exact year for the change or shift that has been taken place by using minimum mean square of error (MSE) and CUSUM charts. The major change point in the given data set was indicated by the level of change and confidence interval. The study rise or decline lines in the CUSUM plots are the indicator of the likelihood of the climate shift for the given year which is computed by the confidence level equation. The values normally oscillate between the horizontal axes if there is no change point present in the data series.

RESULT AND DISCUSSION

We have utilized 14 years rainfall data (2006-19) for our study. We used the traditional meteorological definitions of the seasons: For winter we consider (December, January, and February), spring (March,

April, and May), summer (defined as June, July, and August), and autumn (September, October, and November). **Table 1** shows the rainfall descriptive statistics for Mysore city.

From **Table 1**, we noticed that winter has mean of 5.74mm with maximum value 19.55mm and minimum of zero. And the autumn season have highest rainfall with mean 65.03 and standard deviation of 25.69 mm. When compared to other seasons autumn has highest value of 117.4mm. **Figure 2** shows the seasonal and annual patterns of rainfall data for the year 2006 to 2019.

From **Table 2**, we have calculated month wise distribution of rainfall and its descriptive statistics. The maximum mean rainfall is observed in the month of October is 26.69mm (σ=11.69) and minimum mean rainfall observed in the month of January is 0.3mm. The maximum rainfall was observed in the month of August and September which falls under autumn season. The more variations can be observed for the august month where the standard deviation is 22.62. **Figure 3** shows the month wise and year wise time series plot. Here we observe that for 2017, there is a peak value for the August month.

Further the trends and change points for the rainfall data were determined by using the Mann-Kendall test and Change point analyzer. The estimated Mann-Kendall Z

and P values of each month for annual mean, seasonal and annual time scales are shown in table 3. The trend results where abbreviated as IT (increasing trend), DT (decreasing trend), NT (no trend). A statistically significant decreasing trend is seen in the AMR statistics of the month of March and statistically insignificant trend is perceived in remaining months. A statistically insignificant trend is perceived in all the seasons and annual statistics.

The Sen's slope is utilized to compute trend magnitude. In AMR statistics, the greatest decrease in trend magnitude is seen in March month by 2.25mm. The magnitude of remaining months, seasons and annual rainfall showing insignificant decreasing and increasing trend. The 2012 year is the surplus year in the period of study, with rainfall of 188.65mm, which is above the average rainfall.

Analysis of Change Point

An essential statistical strategy for identifying climatic leaps over the entire climatological data period is the identification of change points. The change points for the average Rainfall was observed in the **Figure 4**. It is observed that for the year 2017, where there is a change point for the month August 2017.

The cusum chart for mean rainfall obtained by the boot-strapping technique has a noticeable change that α=0.05 which is

depicted by modified background in **Figure 5**.

The Level represented in **Figure 6** implies change which is linked with climate change. The mean monthly rainfall change point occurred in December 2012, august 2017 and November 2017 at the confidence level of 94%, 95% and 94% at levels 3, 1 and 2 respectively. For December 2012, the change of mean monthly rainfall was 14.562mm and after the change the value was 8.8955mm. For August 2017, the change on mean monthly rainfall was 8.8955 and after the change the value was

67.667. For November 2017, the change was 67.667 and after the change the value was 11.998mm. The change point monthly is clearly shown in **Figure 6**.

The present study shows a statistical importance of change point at a confidence interval setting of 95% with 1000 boot-straps and a method of mean squares of estimates. The process shifts estimation and generations of trends are well indicated by using CUSUM charts. **Figure 6** estimates the change point months for mean rainfall at different levels.

Table 1: Rainfall descriptive statistics for Mysore city

Parameter	WINTER	SPRING	SUMMER	AUTUMN	ANNUAL
Mean (mm)	5.74	42.31	45.63	65.03	158.69
Median (mm)	3.83	41.08	40.18	63	163.53
Standard Deviation (mm)	6.18	17.31	23.26	25.69	40.62
Kurtosis	0.39	1.78	0.63	1.75	1.17
Skewness	1.10	1.10	0.99	-0.15	0.11
Range (mm)	19.55	67.1	81.85	110.2	169.8
Minimum (mm)	0	17.9	18.15	7.2	77.2
Maximum (mm)	19.55	85	100	117.4	247
Sum (mm)	80.35	592.22	638.85	910.36	2221.78

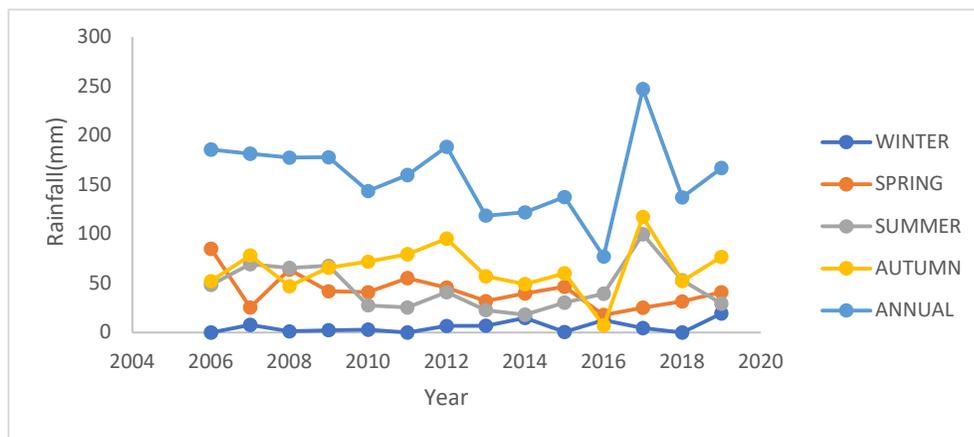**Figure 2: Graph showing the seasonal and annual patterns of rainfall data**

Table 2: Statistical summary of monthly rainfall data (2006-2019)

| Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean(mm)	0.3	1.72	8.30	13.95	20.05	11.90	11.86	21.88	25.10	26.69	13.24	3.72
Median(mm)	0	0.00	5.13	15.73	21.65	6.90	7.43	16.00	19.95	21.78	15.43	2.48
Standard Deviation(mm)	0.74	4.49	10.38	9.04	6.50	12.20	10.67	22.62	18.88	11.69	8.26	4.55
Sample Variance(mm)	0.55	20.15	107.66	81.76	42.19	148.74	113.90	511.83	356.59	136.58	68.27	20.74
Kurtosis	5.35	9.90	1.41	-0.64	0.23	0.57	0.61	6.77	5.39	-0.01	-1.26	1.50
Skewness	2.48	3.00	1.43	0.03	0.14	1.19	1.22	2.46	1.92	0.08	-0.45	1.43
Range	2.40	16.30	32.50	30.52	25.40	39.50	32.60	86.40	77.80	41.05	23.69	14.90
Minimum(mm)	0.00	0.00	0.00	0.00	8.10	0.00	2.10	4.10	2.20	3.20	0.01	0.00
Maximum(mm)	2.40	16.30	32.50	30.52	33.50	39.50	34.70	90.50	80.00	44.25	23.70	14.90
Sum(mm)	4.20	24.10	116.25	195.27	280.70	166.55	166.05	306.25	351.40	373.65	185.31	52.05
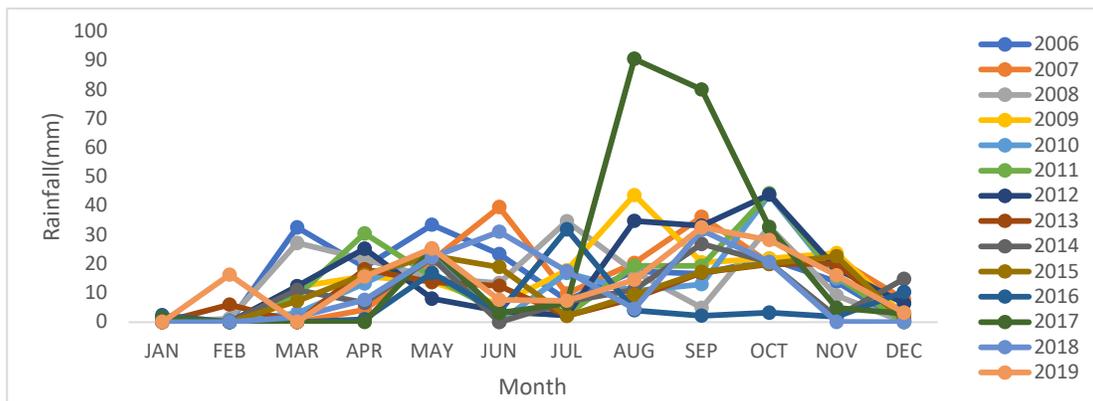
Figure 3: Rainfall Time series seasonal plot with respect to month and year from 2006-2019

Table 3: Mann-Kendall statistics and trend analysis of average monthly, Seasonal, and annual rainfall

| Time Scale	AMR Statistics			
Monthly statistics	S	Z	P	Trend
January	0.00	1.155	0.248	NT
February	0.00	0.207	0.836	NT
March	-1.57	-2.247	0.025	DT
April	-0.90	-1.423	0.157	NT
May	0.22	0.876	0.381	NT
June	-0.39	-0.822	0.411	NT
July	-0.11	-0.766	0.443	NT
August	-1.05	-1.314	0.189	NT
September	1.23	0.985	0.324	NT
October	-0.13	-0.438	0.661	NT
November	-0.77	-0.932	0.351	NT
December	0.08	0.774	0.437	NT
Seasonal Statistics				
Winter	0.75	1.266	0.205	NT
Spring	-2.17	-1.861	0.063	NT
Summer	-1.45	-0.766	0.443	NT
Autumn	0.37	0.109	0.913	NT
Annual	-4.03	-1.423	0.155	NT
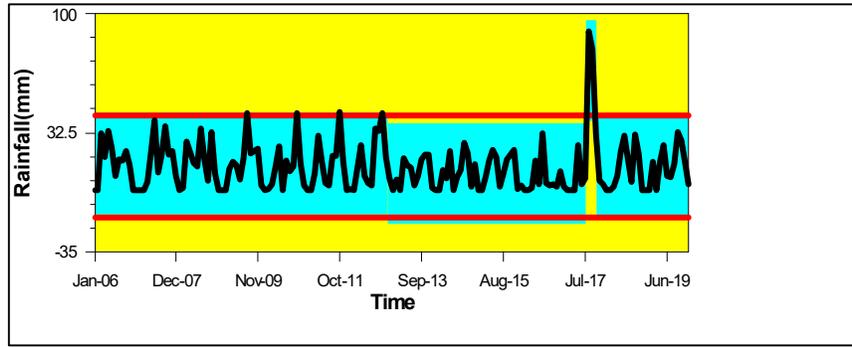
Figure 4: Identifying change point for mean monthly rainfall for the year 2006-2019
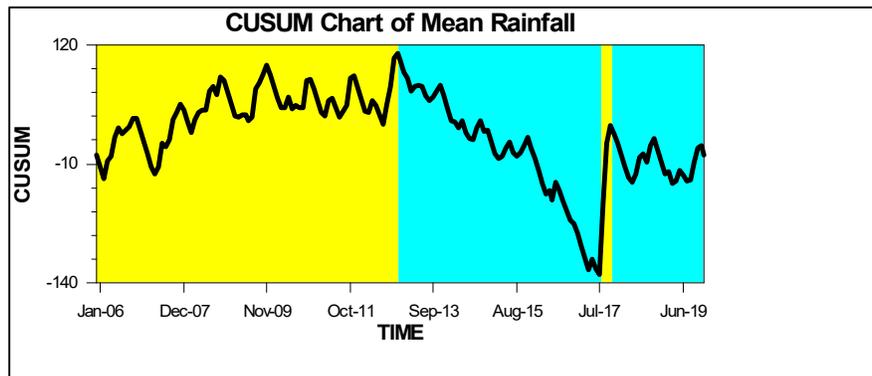

Figure 5: CUSUM chart for mean monthly rainfall

Table of Significant Changes for Avg Rain

Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, CUSUM Estimates

TIME	Confidence Interval	Conf. Level	From	To	Level	
Dec-12	(Aug-09, Oct-13)	94%	14.562	8.8955	3	▬
Aug-17	(May-16, Aug-17)	95%	8.8955	67.667	1	▬▬▬
Nov-17	(Nov-17, Jun-18)	94%	67.667	11.998	2	▬▬

Figure 6: Estimated change point months for mean rainfall

CONCLUSIONS

Rainfall is the most substantial climate element to describe India's climatic conditions. It plays a vital role in the global climate weather system. Climatic events are rarer and more severe than normal or common weather conditions, which include heat waves (high temperature events), cold spells (low temperature events), showers (high temperature events), precipitation) and drought (low precipitation events). Both the identification of change points and the analysis of trends use several non-parametric tests. The present study, based on the characteristics of meteorological variables revealed in the Mysore region of Karnataka, is useful in determining the climate change scenario. We observed that the average rainfall tend to decrease gradually. The mean monthly rainfall

change point occurred in December 2012, august 2017 and November 2017 at the confidence level of 94%, 95% and 94% at levels 3, 1 and 2 respectively. Rainfall trends indicate climate change has occurred in Mysore taluk, Karnataka.

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