# Rainfall Trend analysis using Mann-Kendall and Sen's slope test estimation- A case study

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**Abstract.** In order to analyze the changing pattern of rainfall in one of the important district in Kerala, this study concentrated on a crucial meteorological variable: precipitation. Agriculture in this region depends on rain, but because it occurs erratically and without warning, it has an adverse impact on the cropping system and the availability of natural water resources. Non-parametric analysis was used to determine the monthly, seasonal, and annual rainfall variability (trend and slope magnitude) from rainfall data spanning 30 years (1989-2018) on a monthly basis. To determine the strength of a trend for time series data, the Mann-Kendall (MK) Test for monotonic analysis of trend and non-parametric Sen's Slope Estimator were utilized. The past 30 years have been used to create monthly, seasonal, and yearly precipitation trends. The 30-year monthly data was used to generate monthly, seasonal, and yearly precipitation trends. The results of the statistical analysis of the entire reference time series data shows that the trend appears to be primarily positive (growing), both on an annual and seasonal scale. There was a decreasing tendency in the spring, pre-monsoon, and post-monsoon seasons. Individually, the seven months of January through February show a growing tendency, whereas the remaining five months of March through December show a declining trend with 99% and 95% confidence levels, respectively, the annual total rainfall and monsoon seasons demonstrated a positive significant increasing trend.

**Keywords.** Rainfall trend; Mann-Kendall test; Sen's Slope Estimates; Trend Analysis, Forecasting

## 1 Introduction

Kerala is a state on India's South Western coast that has a tropical monsoon climate which is distinguished by heavy rainfall during the monsoon season and relatively dry weather during the rest of the year. It is the thirteenth largest Indian state by population with 33,387,677 residents. One of India's high-rainfall states receives 2855 mm of rain annually. Kerala receives a significant amount of rainfall during the monsoon season which is essential for agriculture, hydroelectric power generation, and the overall economy. The state has a unique geographical location that allows it to receives geographical location that

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allows it to receive both the Southwest (June-September) and Northeast monsoons(October-December). Alappuzha's recent variations in rainfall patterns have been researched.

Alappuzha is a district located in the Southern Indian state of Kerala. The region has a tropical monsoon climate, which means it gets a lot of rain during the monsoon season, which lasts from June to September. Alappuzha has one of the highest annual rainfall amounts in the country, with an average annual rainfall of around 2,763 millimeters. The months of June, July, and August typically receive the most rainfall, with September also receiving significant rainfall. Alappuzha's heavy rainfall is caused by its location along the Arabian Sea coast and proximity to the Western Ghats, causing them to rise and release their moisture as rainfall. While heavy rainfall in the region can cause flooding and landslides, it is also necessary for the area's agriculture and economy, as it provides water for rice cultivation and promotes the growth of coconut, banana, and other crops. However, the district has recently experienced some extreme weather events such as heavy rain, floods, and landslides, which have caused significant damage to infrastructure and agriculture. The primary causes of these extreme weather events are thought to be changing climate and human activities. In order to effectively address the effects of climate variability and extreme events on human variability and food security, particularly in agriculturally based developing countries facing the challenge of feeding rapidly expanding populations within the coming decades, it may be essential to improve understanding of the full range of impacts of global climate change on biological and food systems. In the face of rising global surface temperatures, the consistency of Indian monsoon rainfall over the last century has been puzzling. We show significant rising trends in the frequency and magnitude of extreme rain events and a significant decreasing trend in the frequency of moderate events over central India during the monsoon seasons from 1989 to 2018. Because the contribution from increasing heavy events is offset by decreasing moderate events, the seasonal mean rainfall does not show a significant trend. A significant increase in hazards associated with heavy rain is predicted for Kerala in the near future.

## 2 Study Area

The topography in Alappuzha is varied. Lagoons, rivers, and canals pierce the sandy expanse of land. Apart from a few isolated hillocks between the Bharanikkavu and Chengannur blocks in the district's eastern half, there are no hills or mountains in the area. The entire territory of the taluks of Cherthala, Ambalappuzha, Kuttanad, and Karthikappally is lowland. The district's coastal section makes up 80% of its area, while the remaining 20% is in the midland. A continuous 82 km long shoreline runs through the area. There are no highlands or forested areas in Kerala's Alappuzha district. The district is 13% covered by water, and Kuttanad is located below sea level. Alappuzha's humid and temperate climates can be described. The district experiences 2763mm of rainfall annually. The area has monthly average temperatures of 250° C. During the winter, Alappuzha's climate is more agreeable. 20°C to 32°C is the temperature range throughout the winter.

## 3 Research methodology and analysis

**Table 1** shown that in **Alappuzha district** during the last 30 years highest average rain fall in the month of **June (594.54mm) and July (492.78mm)** and lowest in **January (19.16mm) and December(40.74mm)** but highest variability shows there is **no consistency** in year wise rainfall.

**Table 1.** Rainfalldata for Alappuzha District.

| Months | Mean | STD Deviation | Variance | Skewness | Kurtosis |
|---|---|---|---|---|---|
| JAN | 19.15 | 21.95 | 481.94 | 1.12 | 0.48 |
| FEB | 41.72 | 53.38 | 2793.80 | 1.75 | 4.04 |
| MAR | 64.05 | 67.32 | 4401.00 | 2.07 | 5.45 |
| APR | 140.14 | 90.79 | 8124.22 | 1.30 | 3.33 |
| MAY | 288.65 | 154.82 | 23144.38 | 1.33 | 2.19 |
| JUN | 594.54 | 204.13 | 40449.89 | 1.02 | 1.97 |
| JUL | 492.78 | 173.69 | 29360.45 | 0.20 | -0.88 |
| AUG | 339.54 | 135.19 | 17895.30 | 0.23 | -0.48 |
| SEP | 275.84 | 144.91 | 20608.75 | 0.18 | -0.56 |
| OCT | 349.45 | 179.26 | 31146.18 | 0.83 | 1.13 |
| NOV | 181.05 | 90.86 | 8311.01 | 0.84 | 0.96 |
| DEC | 40.74 | 45.20 | 2025.03 | 1.09 | 0.70 |

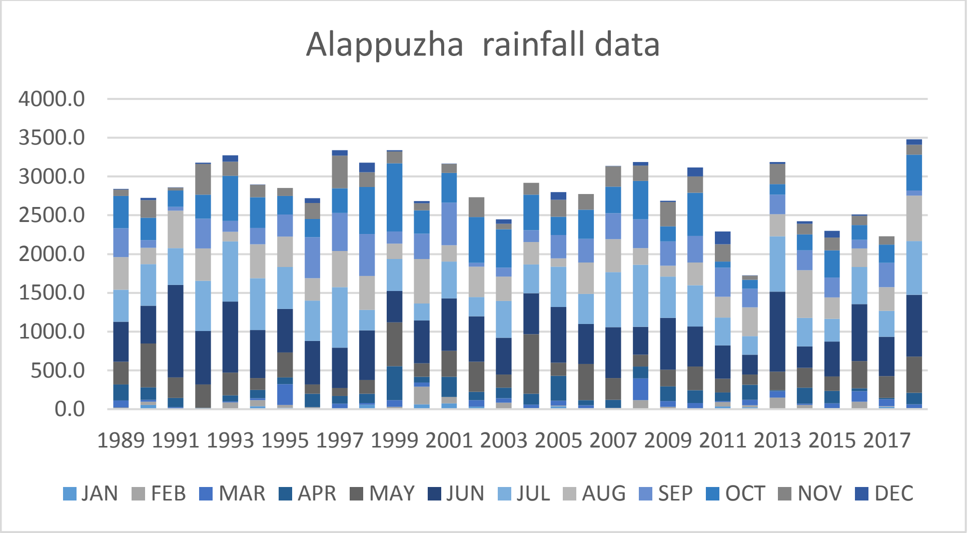


**Fig. 1.** shows the graph of Alappuzha rainfall data.

## 4 Methodology

The non-parametric Mann-Kendall test is frequently used to detect monotonic trends in a series of environmental data, climate data, or hydrological data. $H_0$ is the null hypothesis, which states that the data come from a population with independent realizations and are uniformly distributed. The alternative hypothesis $H_a$ , which states that the data show a monotonic trend. The Mann- Kendall test statistic is determined as follows:

### 4.1 Mann-Kendall Test

$S = s - n\sum_{i=1}^{n}\sum_{j=1}^{i=1} sign(x_i - x_j)$ where n is the total length of the data $x_i$ and $x_j$ are two generic sequential data values and function $sign(x_i - x_j)$ assumes the following values

$$\mathrm{sign}(x_i - x_j) = \begin{cases} 1, \mathrm{if}(x_i - x_j) > 0 \\ 0, \mathrm{if}\ (x_i - x_j) = 0 \\ -1, \mathrm{if}(x_i - x_j) < 0 \end{cases}$$

### 4.2 Pettitt's Test

This Pettitts test method is commonly used to test a single shift in climate variations in the continuous set of data. It explains the null hypothesis $H_0$. There is no change in variation against the alternative hypothesis that $H_1$ there is a change in variations. The non-parametric statistic is defined as:

$$K_T = \max |U_t|$$

Where

$$U_t = \sum_{i=1}^{t} \sum_{j=t+1}^{n} sign(x_t - x_j)$$

$$\mathrm{sign}(x_t - x_j) = \begin{cases} 1, \mathrm{if}(x_i - x_j) > 0 \\ 0, \mathrm{if}\ (x_i - x_j) = 0 \\ -1, \mathrm{if}(x_i - x_j) < 0 \end{cases}$$

The test statistic tracks how frequently a first sample participant outperforms a second sample participant. The absence of a change point is the null hypothesis for Pettitt's test.

### 4.3 Sen's Slope Test

According to Sen's technique, this test determines the slope (i.e., linear rate of change) and intercept. The following formula is used to calculate a set of linear slopes:

$T_j = \dfrac{x_j - x_k}{j - k}$, where i=1,2,3,….N and j>k, where $x_1, x_2, x_3 \ldots\ldots x_j, x_k, \ldots x_n$ are the data values and the median of N values of Ti series can be obtained as Sen's estimator of slope.

### 4.4 Coefficient of Variation

Coefficient of Variation = (Standard Deviation / Mean) * 100. In terms of symbols:

$$CV = \left( \frac{SD}{\overline{X}} \right) * 100$$

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**Table 2** shows the Mann-Kendall Sens slope table of Alappuzha.

| Months | Min | Max | Z-VALUE | Shift | N-value | P-value | Sens-slope | Result |
|---|---|---|---|---|---|---|---|---|
| JAN | 0.00 | 77.40 | -0.5019 | Downward | 30 | 0.615 | -0.085 | Negative |
| FEB | 0.00 | 227.10 | 0.80297 | UPWARD | 30 | 0.042 | 0.26 | Positive |
| MAR | 0.00 | 266.70 | 1.4817 | UPWARD | 30 | 0.138 | 1.5 | Positive |
| APR | 15.8 | 440.20 | 0 | No shift | 30 | 1 | 0.048 | Positive |
| MAY | 32.1 | 766.20 | 0.071364 | UPWARD | 30 | 0.943 | 0.230 | Positive |
| JUN | 28.60 | 1190.20 | -1.0705 | Downward | 30 | 0.284 | -3.775 | Negative |
| JUL | 28.50 | 779.70 | -0.89205 | Downward | 30 | 0.372 | -3.065 | Negative |
| AUG | 28.30 | 582.70 | -0.57091 | Downward | 30 | 0.568 | -2.19 | Negative |
| SEP | 29.30 | 549.40 | -0.24977 | Downward | 30 | 0.802 | -1.06 | Negative |
| OCT | 30.40 | 879.80 | -1.2846 | Downward | 30 | 0.198 | -4 | Negative |
| NOV | 30.40 | 418.70 | -0.08921 | Downward | 30 | 0.928 | -0.453 | Negative |
| DEC | 0.00 | 124.20 | 0.71554 | UPWARD | 30 | 0.474 | 0.32 | Positive |

### 4.5 Mann-Kendall trend graph of Alappuzha

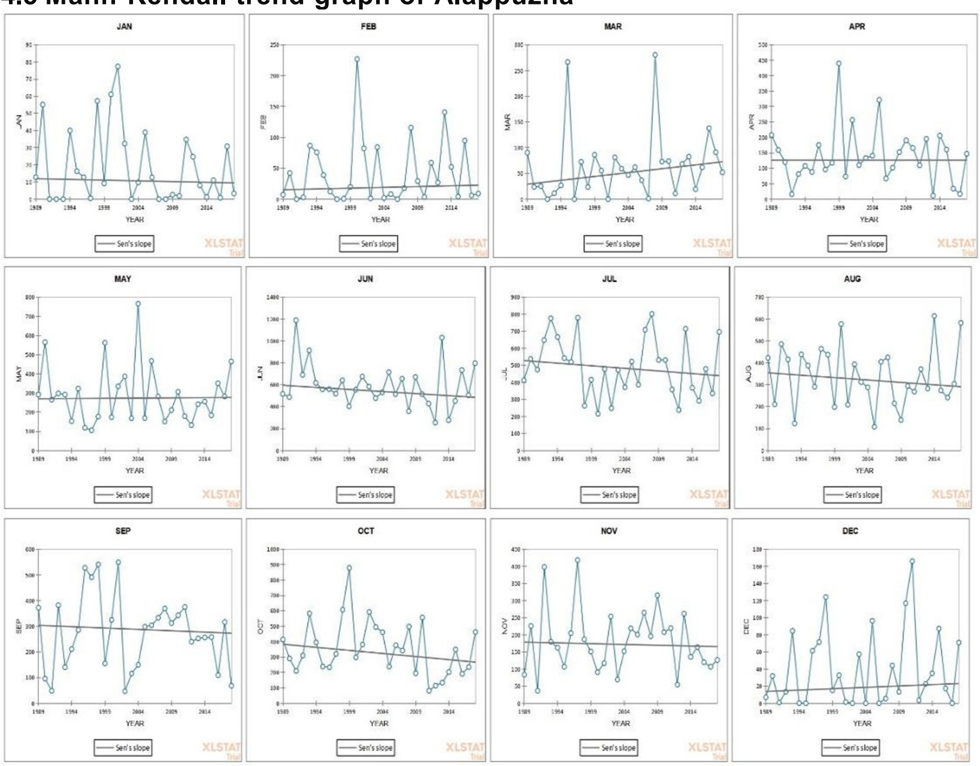


**Fig 2.** shows Mann-Kendall trend graph of Alappuzha

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## 4.6 For Rainfall Data of Alappuzha

**Table 3.** shows the forecasting table of Alappuzha

| Timeline | values | Forecast | Lower confidence bound | Upper confidence bound |
|---|---|---|---|---|
| 2012 | 1725.7 | | | |
| 2013 | 3185.0 | | | |
| 2014 | 2423.2 | | | |
| 2015 | 2298.7 | | | |
| 2016 | 2510.5 | | | |
| 2017 | 2230.4 | | | |
| 2018 | 3480.2 | 3480.2 | 3480.2 | 3480.2 |
| 2019 | | 2787.5 | 2004.7 | 3570.4 |
| 2020 | | 2426.5 | 1643.7 | 3209.4 |
| 2021 | | 2555.9 | 1773.0 | 3338.7 |
| 2022 | | 2747.1 | 1939.2 | 3555.0 |
| 2023 | | 2386.2 | 1578.3 | 3194.1 |
| 2024 | | 2515.5 | 1707.5 | 3323.4 |
| 2025 | | 2706.7 | 1837.9 | 3539.5 |
| 2026 | | 2345.8 | 1513.0 | 3178.6 |
| 2027 | | 2475.1 | 1642.2 | 3308.0 |
| 2028 | | 2666.4 | 1808.8 | 3523.9 |
| 2029 | | 2305.4 | 1447.8 | 3163.0 |
| 2030 | | 2434.7 | 1577.0 | 3292.4 |

## 4.7 Rainfall data series of Alappuzha (1989-2018)

**Table 4.** shows the rainfall data series of Alappuzha (1989-2018)

| Months | N | Mean | STD.Deviation | Coef.vari | Variance | Z-value | Shift | S-Value | P-value | Sig.level | Sen's slope | Trend |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JAN | 30 | 26.431 | 20.349 | 0.0043 | 414.107 | -0.50 | Downward | -29 | 0.615 | P>0.05 | -0.08 | Increasing |
| FEB | 30 | 34.900 | 44.464 | 0.7699 | 1977.098 | 0.802 | UPWARD | 46 | 0.042 | P<0.05 | 0.26 | Increasing |
| MAR | 30 | 45.216 | 48.366 | 1.2740 | 2339.318 | 1.481 | UPWARD | 84 | 0.138 | P>0.05 | 1.5 | Increasing |
| APR | 30 | 109.96 | 95.865 | 1.0696 | 9190.172 | 0 | No shift | 1 | 1 | P>0.05 | 0.048 | Increasing |
| MAY | 30 | 223.10 | 196.262 | 0.8718 | 38518.922 | 0.071 | UPWARD | 5 | 0.943 | P>0.05 | 0.230 | Increasing |
| JUN | 30 | 430.43 | 321.434 | 0.8797 | 103319.86 | -1.07 | Downward | -61 | 0.248 | P>0.05 | -3.77 | Decreasing |
| JUL | 30 | 347.76 | 266.004 | 0.7467 | 70758.312 | -0.89 | Downward | -51 | 0.372 | P>0.05 | -3.06 | Decreasing |
| AUG | 30 | 249.31 | 192.548 | 0.7649 | 37075.112 | -0.57 | Downward | -33 | 0.568 | P>0.05 | -2.19 | Decreasing |
| SEP | 30 | 191.61 | 179.040 | 0.7723 | 32055.654 | -0.24 | Downward | -15 | 0.802 | P>0.05 | -1.06 | Decreasing |
| OCT | 30 | 281.63 | 224.036 | 0.9344 | 50192.322 | -1.28 | Downward | -73 | 0.198 | P>0.05 | -4 | Decreasing |
| NOV | 30 | 135.68 | 108.131 | 0.7954 | 11692.372 | -0.08 | Downward | -6 | 0.928 | P>0.05 | 0.45 | Decreasing |
| DEC | 30 | 33.293 | 32.154 | 0.7969 | 1033.897 | 0.715 | UPWARD | 41 | 0.474 | P>0.05 | 0.32 | Increasing |

The application of this trend analysis indicates an overall increasing and decreasing trend even though not statistically significant. Furthermore in this study, the Mann-Kendall Test represents both positive and negative trends in the area although not much significant. For January, February, March, April, May, November, and December, there is evidence of a rising trend while test value is showing a negative trend in June, July, August, September, and October. According to Sen's slope summer and autumn indicated decreasing trend and of all, summer indicates a maximum decreasing trend with a significant value. The spring and winter seasons indicate positive values insignificantly and the overall annual slope is the second maximum negative value. Sen's Slope indicates increasing and decreasing magnitude of slope in correspondence with the Mann-Kendall Test values. There are four months with decreasing trend value along with the decreasing slope magnitude, and three months indicate positive with no Sen's slope. However, the rest four months indicates positive value and Sen's Slope. However, study of the area may reveal other aspects which will be helpful in controlling flood causing havoc in this particular area.

An upward or downward trend in a sequence of hydrological data and environmental data is typically detected using the Mann-Kendall (non-parametric) test. The alternative hypothesis in this test implies a trend, either an upward or downward trend, whereas the null hypothesis indicates no trend. For the trend analysis of the hydro-climate data set, another non-parametric method is used: Sen's estimator. Also, it's utilized to determine the size of the trend. In light of this, this test calculates the intercept and linear rate of change in the manner described by Sen. The Mann-Kendall test is preferred over other tests due to its applicability in time-series data, which does not follow the statistical distribution. It is well-documented in various literature as a powerful trend test for effective analysis of seasonal and annual trends in environmental and hydrological data. However, the Mann-Kendall test, a non-parametric (distribution-free) test, is employed to examine time-series data for persistent monotonic patterns. These non-parametric techniques have a number of advantages, including how they handle missing data, how few assumptions they require, and how they don't depend on the distribution of the data.

Rainfall trend analysis was investigated using the Mann-Kendall Trend Test and Sen's Slope estimator. The results of the Mann-Kendall trend test, including the test statistics (Z), P-value, and Sen's slope Q, were calculated using XLSTAT 2020, while Microsoft Excel was used to calculate the descriptive statistical techniques, including the minimum, maximum, mean, standard deviation, variance, and average annual rainfall .The data analysis was done in order to identify the trend of climate change. Thirty years' worth of rainfall data from Alappuzha were used to conduct a trend analysis of temperature (1989–2018). The rainfall trend was determined using the Mann-Kendall test and Sen's Slope estimator displays a graph of the average, lowest, and maximum temperature. Figure displays a graph of the average, lowest, and maximum. The zero slope indicates that there is no trend in the data for the study period and that things remain the same. The positive sign denotes a growing slope, the negative sign denotes a declining slope. The Sen's slope estimations for the minimum, maximum, and average rainfall from 1989 to 2018 for Alappuzha, as given in Table 1, each showed an increasing trend, which is consistent with the positive values of the Mann-Kendall statistic (Z) result.

## 5 Conclusion

It is clear from the study that there is a positive trend and statistical significance in the trend analysis of yearly temperature for Alappuzha. The null hypothesis should be rejected and the alternate hypothesis should be accepted because the computed P-value is less than the alpha (significance level). Nonetheless, although not statistically significant, the annual rainfall trend analysis for Alappuzha shows an upward tendency. Since the computed p-value is bigger than the significant level of alpha, one cannot rule out the null hypothesis, $H_0$ (0.05) the additional the Mann-Kendall trend test and Sen's Slope estimator both revealed that there is a tendency for rainfall to rise in the studied area, according to the study. Hence, the capital city may experience extreme weather as a result of the rising trend in rainfall brought on by climate change and other reasons.

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