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Article

Analysis of Rainfall Trend Using Mann– Kendall Test and Sen's Slope Estimator in Ikole Ekiti, Ekiti State, Nigeria

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Abstract

Precipitation plays a crucial role in shaping the climate system, affecting temperature patterns, atmospheric circulation, and regional climate variations. Monitoring precipitation is essential for assessing the intensity and duration of rainfall events, enabling the prediction and mitigation of risks associated with excessive rainfall. This research aims to investigate long-term rainfall trends in Ikole Ekiti, positioned at latitude 7.805° and longitude 5.495°, southwestern Nigeria. The study utilizes extensive time series data to analyze precipitation patterns in the area. The study relies on daily precipitation data spanning from January 2013 to December 2022, obtained from the PDIR-Now system, a satellite-based product that employs Artificial Neural Networks and Dynamic Infrared Rain Rate Technology to provide high-resolution precipitation estimate in near real-time. The evaluation of rainfall trends was carried out by employing the Mann-Kendall Test in conjunction with Sen's Slope Estimator. The results reveal a distinctive two-peak pattern in the distribution of rainfall throughout the years. The first peak, occurring in September, exhibits an average value of 185.4 mm, while the second peak emerges in July, with an average value of 147.9 mm. Although, it was observed that there was a decrease in annual rainfall, it was not statistically significant. The findings of this research can provide valuable insights for developing future strategies aimed at adapting to and mitigating climate change, with the goal of ensuring the sustainable management of rainfall resources in the study region.

Keywords: Rainfall, Mann-Kendall Test, Sen's Slope Estimates, Trend Analysis.

1. Introduction

Precipitation serves as a fundamental driver of the climate system, influencing various aspects like temperature patterns, atmospheric circulation, and regional climate fluctuations. It plays a crucial role in the global water cycle, which encompasses the continuous movement and transformation of water between the atmosphere, land, and oceans. Precipitation acts as a vital link connecting different components of the earth system, including the atmosphere, hydrosphere, biosphere, and lithosphere [1, 2].

In terms of water resources, precipitation acts as a primary source of freshwater on earth, replenishing surface water bodies, groundwater aquifers, and soil moisture. It supports diverse ecosystems such as forests, wetlands, and rivers, which rely on adequate water availability for their functioning. Precipitation also plays a significant role in the formation and sustainability of freshwater resources, providing essential water supplies for human consumption, agriculture, and industrial activities [3, 4].

Monitoring precipitation is crucial for assessing the intensity and duration of rainfall events, which is essential for predicting and mitigating the risks associated with excessive rainfall. Heavy rainfall can result in flash floods, landslides, and infrastructure damage, posing threats to human lives and property. Accurate measurements and monitoring of precipitation enable timely warnings, effective disaster management strategies, and the implementation of measures to minimise the impacts of extreme rainfall events [5, 6]. Similarly, monitoring precipitation is equally important for assessing and responding to insufficient rainfall and drought conditions. Inadequate rainfall can lead to droughts that severely affect agriculture, potentially resulting in crop failures, food shortages, and famines. Precise measurement of rainfall allows for monitoring and mitigating the impacts of drought, facilitating proactive water resource management, and enabling effective irrigation planning while minimising the consequences of water scarcity [7, 8].

In Nigeria, studies on rainfall patterns have utilised rain gauge data [9-11]. Additionally, historical rainfall data can be obtained from meteorological stations and satellite observations. The Nigerian Meteorological Agency (NiMet) maintains a network of weather stations across the country by providing data on rainfall patterns. In recent years, satellite-based rainfall estimation products, such as those provided by Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks PERSIANN [12], Tropical Rainfall Measuring Mission TRMM [13], and Global Precipitation Measurement GPM [14], had contributed to the analysis of rainfall trends.

Decades ago, Nigeria experienced variations in rainfall patterns, with different regions displaying changes in the timing, duration, and intensity of rainfall. Studies have examined these trends, revealing spatial and temporal variations. Northern regions, including the Sahel, have shown a decreasing trend in rainfall, affecting total annual rainfall and the length of rainy seasons. This trend has implications for agricultural productivity and food security in these areas [15]. Conversely, southern parts of Nigeria, particularly the Niger Delta region, have experienced an increased trend in rainfall [16]. Transitioning from dry to wet seasons, indicating an upward shift in rainfall distribution, had also been observed in certain climate zones of Nigeria [17].

The rise in occurrence and severity of these events presents a significant obstacle to socioeconomic progress, particularly in less developed nations. Consequently, the regular and systematic examination of weather and climate data is essential for effective planning in sectors of the economy that are vulnerable to weather conditions.

This study aims to examine long-term rainfall trends in Ikole Ekiti, located in Southwestern Nigeria, utilising extensive time series data. The analysis employed is the Mann-Kendall (MK) Test in conjunction with Sen's Slope Estimator to assess the significance of these rainfall trends. The outcomes of this research will contribute to enhanced accuracy in seasonal rainfall predictions and flood forecasting. Moreover, policymakers, researchers, and stakeholders can utilise these findings to inform the development of climate change adaptation and mitigation strategies in Nigeria.

1.1 Study area

Ikole Ekiti is a town situated in the southwestern part of Nigeria within Ekiti State. It serves as the administrative centre of the Ikole Local Government Area. Geographically, it is located between latitudes 7°40'N and 8°00'N and longitudes 5°30'E and 5°55'E as presented in Figure 1. The terrain in Ikole Ekiti can be defined as undulating, featuring gently rolling topography. It is positioned on slightly elevated land compared to the surrounding areas. The landscape features are hills, valleys, and gentle slopes, accompanied by a combination of vegetation. The climate experienced in this area is tropical, exhibiting distinct wet and dry seasons. The wet season typically commences in April and continues until October, with the highest amount of rainfall occurring between June and September. On the other hand, the dry season spans from November to March, characterized by lower rainfall levels and higher temperatures.

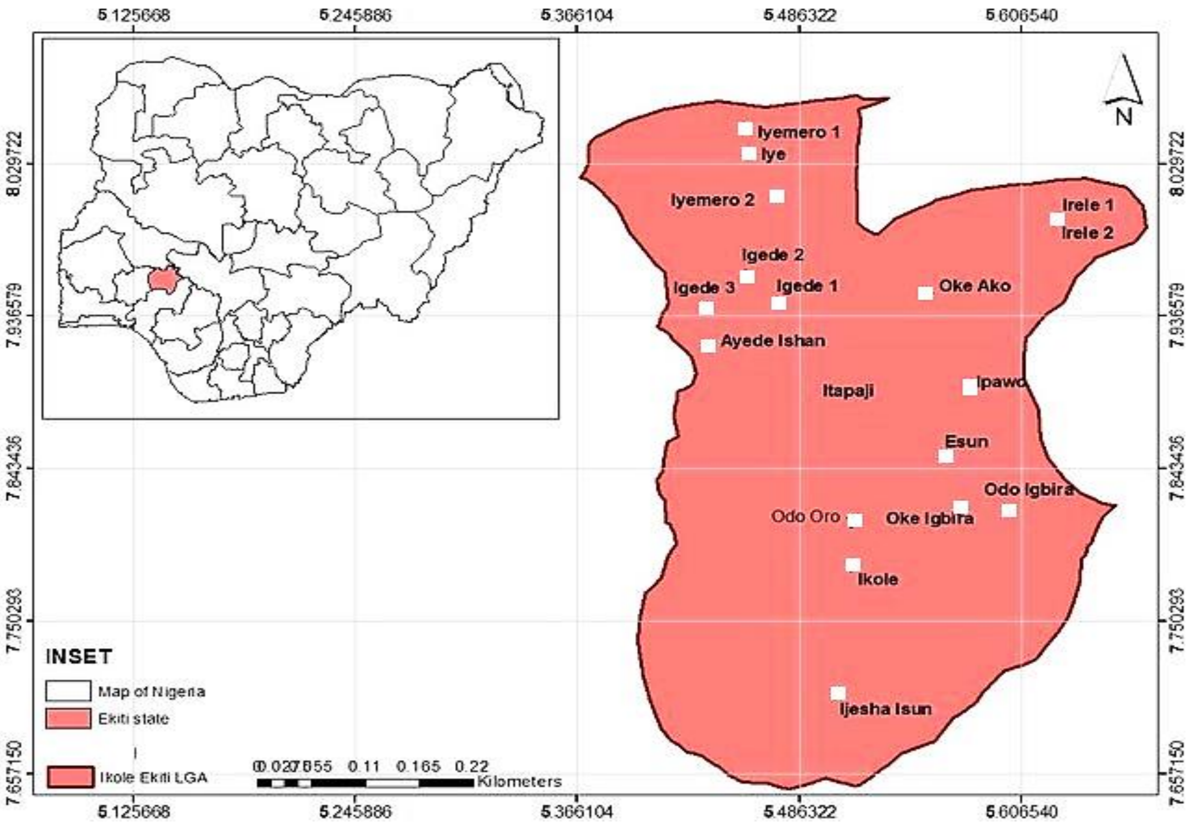

Figure 1: Map of Nigeria showing Ikole Ekiti, Source: Adeyolanu [18].

2. Methods

The daily rainfall data for Ikole Ekiti, positioned at latitude 7.805° and longitude 5.495°, was collected for the duration of ten years, ranging from January 2013 to December 2022. This data was sourced from the real-time global satellite precipitation product known as Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks - Dynamic Infrared Rain Rate (PDIR-Now) system. PDIR-Now is a high-resolution satellite precipitation product developed by the Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California, Irvine (UCI). The product provides near real-time information with a spatial resolution of 0.04° x 0.04° or approximately 4 km x 4 km. The data obtained from PDIR-Now was specifically focused on daily rainfall. Each day's precipitation measurements were aggregated to calculate the total rainfall for each month. This dataset covered all the months of the year, allowing for a comprehensive analysis of the monthly rainfall patterns in Ikole Ekiti over the past ten years. The analysis of the rainfall data was conducted at different time scales, including monthly, seasonal, and annual levels.

2.1 Trend Analysis

A statistically significant trend refers to a notable change over time that can be detected through various statistical procedures, both parametric and non-parametric. Trend analysis of a time series involves evaluating both the magnitude of the trend and its statistical significance. In this study, the assessment of statistical significance for trend analysis was performed using the Man-Kendall test, which is a non-parametric method. Furthermore, the magnitude of the trend was determined using the non-parametric Sen's estimator method.

2.2 Mann–Kendall Test

The Mann-Kendall test is a statistical technique commonly employed to examine the null hypothesis of no trend in comparison to the alternative hypothesis that a hydro-climatic time series exhibits a monotonic increasing or decreasing trend. This non-parametric test is suitable for data series where the trend is expected to be consistently either increasing or decreasing without any presence of seasonal or other cyclic patterns [19, 20]. There are two categories of statistical analyses depending on the quantity of available data values. When the number of data values is below 10, S-statistics is employed. However, if the data values are 10 or more, Z-statistics, which approximates a normal distribution, is used as suggested by Salmi [21]. Mann–Kendall statistics (S) is calculated as shown in equation (i).

$$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\operatorname{sgn}\left(x_j-x_i\right) \quad \ldots(i)$$

Where, x_j and x_i are annual values in years j and i, $j > i$ respectively, n is the length of data series, $i = 1, 2, 3,\ldots n-1$, $j = i + 1, i+ 2, i + 3,\ldots n$, and

$$\operatorname{sgn}\left(x_j-x_i\right)=\begin{bmatrix}1 \text{ if } \left(x_j-x_i\right)>0\\ 0 \text{ if } \left(x_j-x_i\right)=0\\ -1 \text{ if } \left(x_j-x_i\right)<0\end{bmatrix} \quad \ldots(ii)$$

A positive or negative value of S denotes an upward (increasing) or downward (decreasing) trend, respectively. When the number of data values is 10 or greater, the S-statistics approximately follow a normal distribution. In such cases, the test is conducted using the normal distribution with mean and variance determined by equations (iii) and (iv), respectively.

$$E(S)=0 \quad \ldots(iii)$$

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

Where q is the number of tied groups (tied groups are a set of data samples with the same value) and t_p is the number of data values in the p^{th} tied group. The standard normal distribution (Z – statistics) is computed using equation (v).

$$Z=\begin{bmatrix}\dfrac{S-1}{\sqrt{Var(S)}} & \text{if } S>0\\ 0 & \text{if } S=0\\ \dfrac{S+1}{\sqrt{Var(S)}} & \text{if } S<0\end{bmatrix} \quad \ldots(v)$$

The statistical significance of the trend is evaluated using the Z-value. A positive Z-value indicates an upward (increasing) trend, whereas a negative Z-value indicates a downward (decreasing) trend. The Two-tailed test is employed for four distinct significance levels: α of 0.1, 0.05, 0.01, and 0.001. A significance level of 0.001 indicates a 0.1% probability that the values x_i are derived from a random distribution, and thus, there exists a possibility of making an error in rejecting the null hypothesis (H_0) that states there is no trend [21]. Therefore, a significance level of 0.001 indicates a high likelihood of the existence of a monotonic trend. Similarly, a significance level of 0.1 signifies a 10% probability of making an error when rejecting H_0.

2.3 Sen's Estimator method

Sen's non-parametric estimator method has been employed to estimate the true slope of hydro-meteorological time series data. The method utilizes a linear model to analyze the trend [22]. The slope (T_i) of all data pairs is determined using equation (vi).

$$Q_i = \frac{x_j - x_k}{j-k} \quad \text{for i = 1, 2, 3, ……., n} \qquad \text{…(vi)}$$

Where x_j and x_k are data values at time *j* and *k*, *j* is subsequent time after time *k*(*j* > *k*).

If there are values of x_j in the data time series, we get as many as $N = n(n-1)/2$ slope estimates *Qi*. Sen's estimator of the slope is the median of these *N* values of *Qi*. The *N* values of *Qi* are ranked from the smallest to the largest, and Sen's estimator is the median of all slopes. If the time series data contains values of x_j, the number of slope estimates Qi obtained would be $N = n(n - 1)/2$, where n represents the number of data points. Sen's estimator of the slope is determined as the median among these *N* values of Q_i. The *N* values of Q_i are ranked in ascending order, and Sen's estimator is calculated as the median of all the slopes as;

$$Q = \begin{bmatrix} Q_{[(N+1)/2]}, & \text{if N is odd} \\ \frac{1}{2}\left(Q_{[N/2]} + Q_{[(N+2)/2]}\right), & \text{if N is even} \end{bmatrix} \qquad \text{…(vii)}$$

A two-sided confidence interval at a level of *100(1-α)%* regarding the slope estimate is derived using the nonparametric method, which relies on the normal distribution. In this technique, a positive Q_i value indicates an increasing or upward trend within the time series, while a negative Q_i value indicates a decreasing or downward trend.

3. Results and Discussion

3.1 Monthly, Seasonal, and Annual Rainfall

Figure 2 illustrates the monthly mean rainfall amounts in Ikole Ekiti from 2013 to 2022. The analysis of the data reveals a bimodal pattern in the distribution of rainfall throughout the years. The first peak in rainfall occurs in September, with a mean value of 185.4 mm. This indicates that September experiences the highest average rainfall among all the months. The second peak is observed in July, with a mean value of 147.9 mm. These two months can be identified as the primary rainy seasons in Ikole Ekiti. On the other hand, the month of December exhibits the lowest mean monthly rainfall, with an average value of 3.4 mm. This suggests that December receives the least amount of rainfall on average compared to other months. The data indicates a significant contrast between the rainfall amounts in September and December.

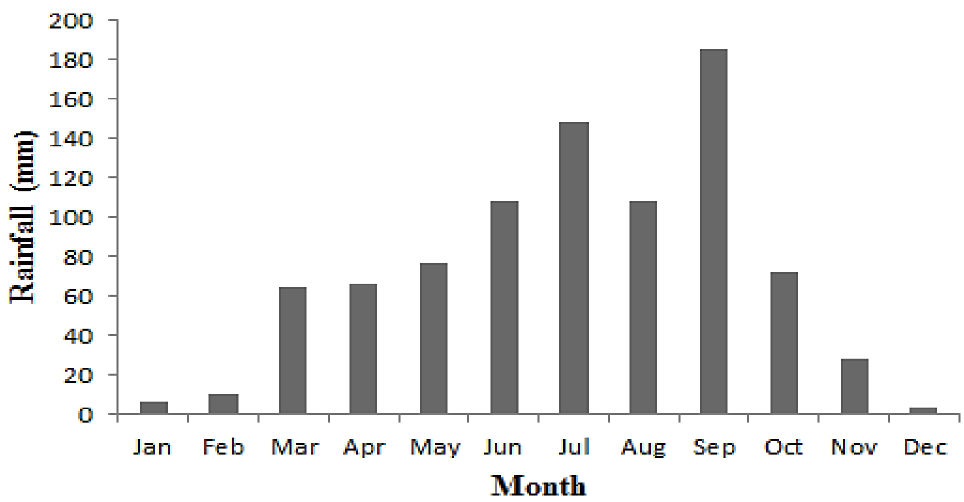

Figure 2: The average monthly rainfall amount between 2013 and 2022

The seasonal accumulated rainfall depicted in Figures 3 and 4 provides insights into the rainfall patterns in Ikole Ekiti, showing the range of values observed during the wet and dry seasons. In the wet season, the accumulated rainfall varies from 300 mm in the year 2018 to 1036 mm in the year 2014. This indicates the fluctuation in rainfall amounts experienced during different wet seasons. On the other hand, the dry season rainfall in the study area ranges from 25 mm in the year 2017 to 241 mm in the year 2013. These figures represent the amount of rainfall received during the dry season, highlighting the variability in precipitation levels from year to year.

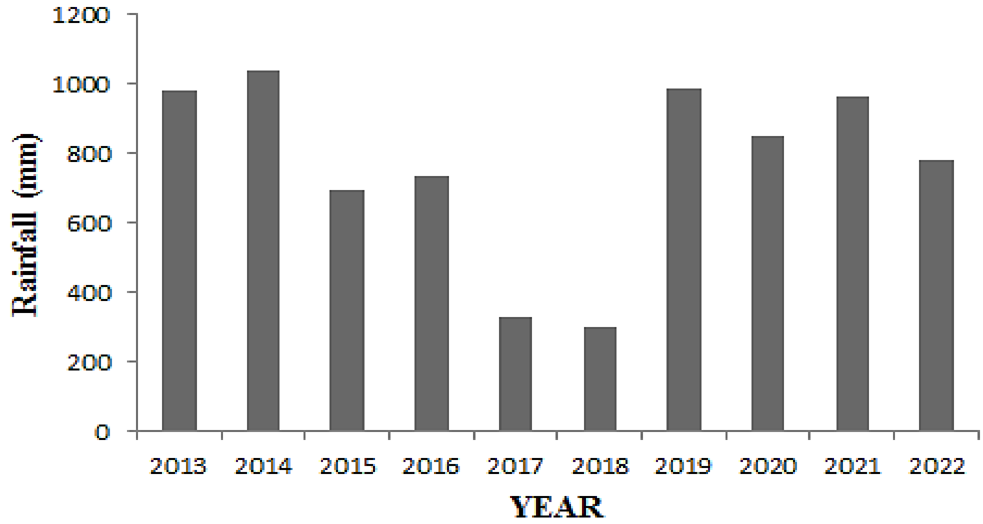

Figure 3: The rainfall amount during the wet season from 2013 to 2022.

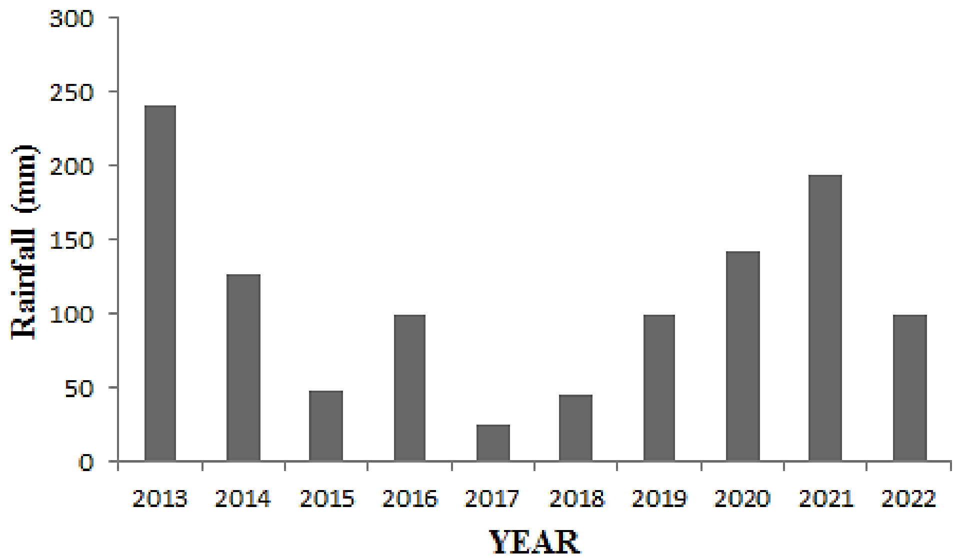

Figure 4: The rainfall amount during the dry season from 2013 to 2022.

Figure 5 illustrates the annual rainfall amounts in Ikole Ekiti, providing an overview of the total rainfall received throughout the years. The recorded values range from 740 mm to 1220 mm, demonstrating the inter-annual variability in annual rainfall. To further examine the descriptive statistics of annual rainfall in the area, Table 1 presents relevant statistical measures. These measures include metrics such as mean, median, minimum, and maximum values, providing a summary of the annual rainfall distribution in Ikole Ekiti.

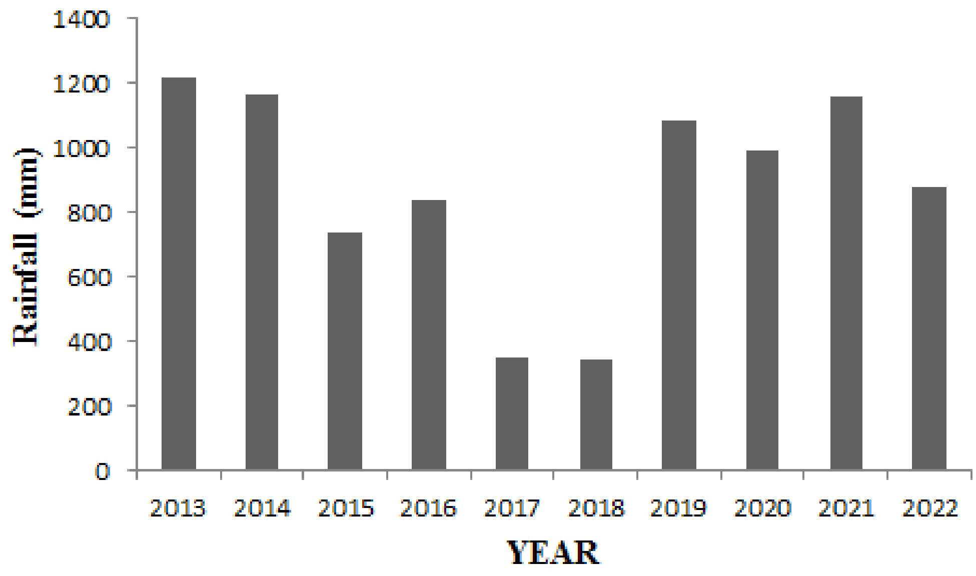

Figure 5: The annual cumulative rainfall during the period from 2013 to 2022.

Table 1: The descriptive statistics of annual rainfall in Ikole Ekiti for the period from 2013 to 2022

Statistics	Magnitude (mm)
Minimum	345
Maximum	1220
Mean	876.80
Median	934.50
Standard deviation	318.92

Table 2: Monthly, seasonal and annual rainfall trend for the period (2013 - 2022)

Month	Mann-Kendall Test (Z)	Signific. (α)	Sen's slope (Q)	Trend
Jan	-1.53	-	-0.75	↓
Feb	-1.43	-	-2.20	↓
Mar	-0.18	-	-1.29	↓
Apr	0.89	-	2.67	↑
May	-0.63	-	-2.78	↓
Jun	1.71	*	14.00	↑
Jul	-1.25	-	-10.00	↓
Aug	-0.72	-	-2.00	↓
Sep	-0.36	-	-5.13	↓
Oct	0.36	-	1.56	↑
Nov	0.18	-	0.33	↑
Dec	1.44	-	0.57	↑
wet season	-0.36	-	-10.00	↓
Dry season	0.00	-	0.00	
Annual	-0.54	-	-15.40	↓

*↑ = upward trend, ↓ = downward trend, signific. = Significance, * = significant at 90%, - = not significant*

3.2 Rainfall Trends

The variation in rainfall data (trend) on a monthly basis is calculated individually for each month using Mann-Kendall statistical method and the magnitude of slope is calculated with Sen's slope estimator. The rainfall trends are presented in Table 2.

3.2.1 Monthly Rainfall Trend

The monthly analysis of rainfall indicates that from January to March, May, and July to September, there is a decreasing trend in rainfall. This decline is attributed to the presence of negative values in both Z and Q statistics during these months. These months experience a consistent decline in rainfall over the analysed period, suggesting a potential shift in precipitation patterns. Conversely, the months of April, June, and October to December exhibit an increasing trend in rainfall. This observation is supported by the positive values of both Z-Statistics and Q-Statistics. These months demonstrate a consistent rise in rainfall, indicating a potential shift towards higher precipitation levels during these periods. Figures 6 and 7 present visual representations of the trends in rainfall. The analysis reveals a 90% confidence level of a positive trend in June, indicating a high degree of certainty in the observed increase in rainfall during this month. The magnitude of the positive trend varies between 0.33 mm/year and 14.00 mm/year. This indicates the rate at which the rainfall is increasing over time. On the other hand, the magnitude of the negative trend ranges from -0.75 mm/year to -10.00 mm/year, signifying the rate at which rainfall is decreasing.

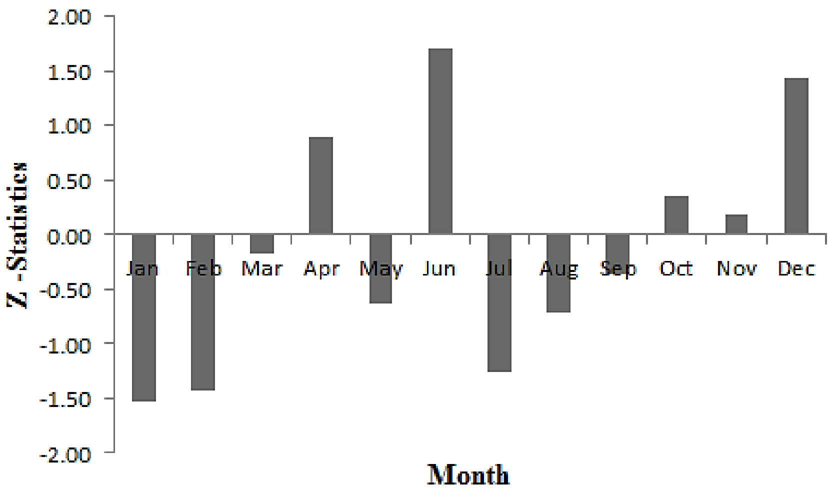

Figure 6: The Mann-Kendall Z -Statistics for Monthly Trend Analysis

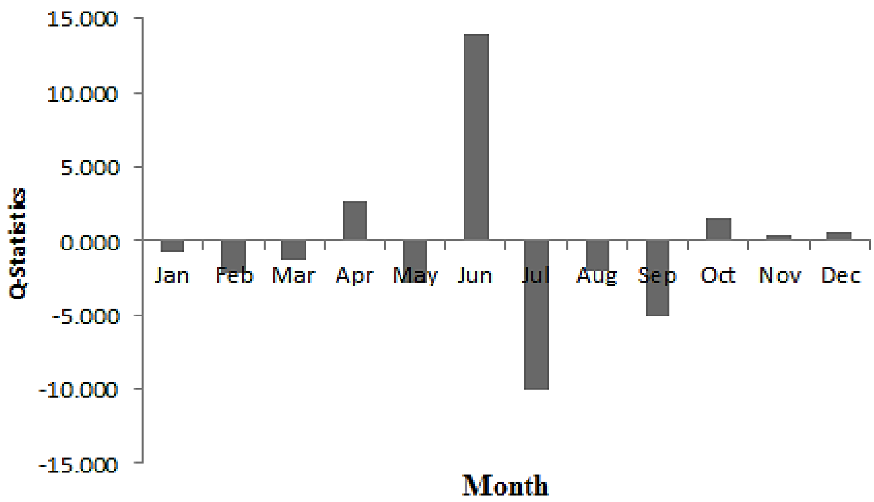

Figure 7: The Monthly Trend Analysis using Q –Statistics

3.2.2 Seasonal Rainfall Trend

The analysis of rainfall patterns in the study area reveals interesting findings regarding the trends observed during the wet and dry seasons. Specifically, a decreasing trend in wet season rainfall was identified, with a magnitude of -10.00 mm/year. However, it is important to note that this trend was found to be statistically insignificant, meaning that the observed decrease in wet-season rainfall may not be a conclusive result. On the other hand, the analysis showed that there was no discernible trend in rainfall during the dry season, as indicated by a trend magnitude of 0.00 mm/year. Similar to the wet season trend, the lack of a significant trend suggests that there is no conclusive evidence to support any consistent change in rainfall during the dry season. These findings underscore the complexity of rainfall patterns and the importance of considering statistical significance when interpreting trends. While a decreasing trend was observed in wet season rainfall, the lack of statistical significance indicates that caution should be exercised when attributing this trend to long-term changes. The absence of a trend in the dry season further emphasizes the natural variability in precipitation patterns during this period.

3.2.3 Annual Rainfall Trend

Based on the observations conducted in the study area, the yearly outcome of -15.40 mm/year suggests a potential decrease in the rainfall rate over a period of time. However, it is important to highlight that this trend was not found to be statistically significant, meaning that caution should be exercised when interpreting the observed decrease in annual rainfall as a long-term trend. Despite the lack of statistical significance, the analysis of the entire dataset on an annual basis did reveal a negative, decreasing trend in rainfall. This suggests that, overall, there has been a tendency for the annual rainfall to decrease over the analysed period.

4. Conclusions

The analysis of cumulative monthly rainfall indicates that the highest total rainfall occurs in September, with a cumulative value of 1854 mm. This means that September receives the highest cumulative rainfall over the analysed period, reflecting its importance as a peak month in terms of overall precipitation. The information presented in Figures 3 to 5, along with the descriptive statistics in Table 1, offers a comprehensive view of the seasonal and annual rainfall patterns in the study area. The observations in the area indicate a decrease in annual rainfall, although this decrease was not found to be statistically significant. The negative decreasing trend observed in the entire dataset on an annual basis highlights the need for continued monitoring and analysis to fully understand the dynamics of annual rainfall and its potential implications for the local environment and society. Understanding the long-term trends in annual rainfall are crucial for various sectors, including agriculture, water resource management, and climate change adaptation. However, it is important to recognise that localised factors, natural climate variability, and the limited duration of the dataset may influence the observed trend. Additional research in other sub-region and in-depth analysis, coupled with the collection of long-term data, are imperative to develop a more thorough understanding of the fluctuations in rainfall patterns throughout both the wet and dry seasons. These findings contribute to the understanding of the local climate and decision-making processes in various sectors, including agriculture, water resource management, and disaster preparedness. These measures will contribute to more reliable and substantiated conclusions regarding the evolving trends in annual rainfall within the specified region.

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