

Original Research Article

Rainfall Variability and Trend Analysis over Nguru Yobe State Nigeria

Abstract

The degree to which rainfall amount vary across an area or through time is an important characteristic of the climate of an area. This subject area in meteorology/climatology is called “rainfall variability. Therefore, this study aimed to analyze rainfall variation in a semi-arid environment by examining the annual precipitation over Nguru in Yobe, Nigeria. Coefficient of variability (CV) was used to evaluate rainfall variation over time in the area, and trend investigation on the rainfall data and the trend magnitude were carried out using non-parametric (Mann Kendalls and Sen’s slope) tests. The investigation was based on data collected over a 31-year period at a single site. The result indicates that the coefficient of variation CV for the annual rainfall in Nguru revealed a moderate inter annual variability (25%), whereas the CV for seasonal rainfall demonstrates that rainfall in the MJJ monsoon period is highly variable between seasons (more than 40%). The CV for the ASO monsoon period, on the other hand, was 31.6%, indicating a considerable and high variability in total rainfall received.

Keywords: Rainfall trend; variability; Mann Kendall test; sen slope; coefficient of variability

Introduction

Climate is a long-term average of a location's meteorological conditions. It is the statistical description of key parameters' average and variability over timescales ranging from months to thousands or millions of years [1]. It is an important part of the earth's system. rainfall, atmospheric pressure, temperature, and humidity are all factors that influence weather and climate. Extreme weather and climatic events have become more common in recent decades, raising serious worries about climate change. It has a negative impact on human activities, the economy, and the environment [2]. Climate variability is a difficult process that comprises the shift between variability and climate change [3]. Various regions are experiencing climate variability differently across the world, and Nigeria is not exceptional. The intergovernmental

panel on climate change 5th assessment report stated that global temperature will rise continuously due to anthropogenic activities [1]. Therefore, this changing trend may likely increase hydrological extremes such as drought and flood.

Rainfall is a meteorological variable that has an impact on almost all human activities. For example, rainfall is a key determinant in calculating or quantifying the amount of water available to meet diverse demands such as agricultural, industrial, home water supply, and power generation. Rainfall availability or non-availability is typically used to assess the level of wetness or dryness during the growing season, making rainfall the single most important element of the climate system affecting any region's agricultural and water resource management [1,3].

The degree to which rainfall amount vary across an area or through time is an important characteristic of the climate of an area. This subject area in meteorology/climatology is called “rainfall variability”. There are two types of rainfall variability, areal and temporal. The study of the latter is important in understanding climate change. Temporal variability is the variation of rainfall amount at a given location across a time interval (area does not vary). Temporal variability of rainfall may be used both to characterize a climate and to deduce evidence of climate change [4]. Both temporal and areal variability of rainfall may be measured in various ways. The resulting numerical value can be used to characterize the climate of a region in various ways [4]. Therefore, coefficient of variation (CV) can be used to analyse annual rainfall variations of Nguru station. The CV of annual climate is an index of climatic risk, indicating a likelihood of fluctuations in reservoir storage or crop yield from year to year. Agriculturally it is, perhaps a more crucial statistics in marginal areas [5].

On a temporal and spatial basis, rainfall in Nigeria is very dynamic and changeable [6]. However, the recent occurrences of a dry spell in Northern Nigeria have heightened public worry that the region is experiencing a climate transition toward aridity [7]. In Nigeria, rainfall is seasonal, with a double maximum in the south and a single maximum in the north. The northern part has a savannah-like environment with wet and dry seasons. The annual rainfall in this region ranges from 1500 mm in the south to 400 mm in the north [8]. The rainy season in the southern part lasts around 7 months (April to October), but in the northern part it lasts only 3 to 4 months (Jun to September). Between July and August, the rainfall intensity is extremely high. As a result, even though the region is normally dry, crops are regularly lost due to excessive rainfall

[9]. Therefore, studies of rainfall variation at the local and regional level give the antidote in battling the harmful impacts of droughts and crop failure, allowing the huge agricultural potentials and productivity in the Northern region to be completely harnessed and optimized [10].

Long-term trends of environmental climatic parameters must be assessed to understand the impact of climate variability on the environment [11]. Different methodologies were used to examine trends in time series data for a variety of societal issues, including socioeconomic, medical, and environmental issues. Hydro-climatic time series data are frequently characterized by data that is not normally distributed; in such time series, a non-parametric method of determining trend is typically used [11]. The non-parametric Mann-Kendall test, which is based on rank, is often used to evaluate the significance of trends in hydro-climatic time series. In addition to the original Mann-Kendall trend significance test, Sen provided a non-parametric estimator for determining trend magnitude [11].

In addition to the rainfall trend, it is critical to assess the inter-annual variability of rainfall, which has received little attention so far [12]. Inter-annual rainfall variability, in fact, is a measure of year-to-year fluctuation in cumulative rainfall occurrences that allows us to distinguish between years with abundant rainfall and years with little rainfall. The relative variability index was first introduced to quantify inter-annual rainfall variability, although the coefficient of variation (CV) has recently gained popularity [13].

The purpose of this work was to analyze rainfall variation in a semi-arid environment by examining the annual precipitation over Nguru in Yobe, Nigeria. Coefficient of variability (CV) was used to evaluate rainfall variation over time in the area, and trend investigation on the rainfall data was carried out using non-parametric (Mann Kendalls and Sen's slope) tests. The investigation was based on data collected over a 31-year period at a single site.

Materials and Methods

2.1 The Study Area

The study area is a low-agricultural-potential marginal setting where smallholder rain-fed agriculture and livestock husbandry are the two main sources of income. For the years 1940 to 2005, the average annual rainfall and temperature in the area were 552mm and 30.5°C,

respectively. The Intertropical Convergence Zone, which annually reaches its maximum northerly location above Nigeria in July or August and whose influence generates the distinct wet and dry seasons characteristic of Sub-Saharan West Africa, influences the climate of the region [14]. Nguru town is located in the north-eastern section of Nigeria, on latitude 12°52'45"N and longitude 10°27'09"E, on a floodplain of the Hadejia-Nguru marshes [11].

The rainy season begins in late May or early June, peaks in August, and ends in late September or early October. Low and irregular rainfall is common in the area, and drought-related harvest failure is common. Millet (*Pennisetum typhoides*), sorghum (*Sorghum bicolor*), maize (*Zea mays*), cowpea, beniseed, and groundnuts are the main crops farmed (*Arachis hypogaea*) [15]. The value and amount of labour invested in crop cultivation is usually larger than the volume and value of the harvest in most seasons. Furthermore, as a drought-prone region, the past 40 years have seen droughts of varying magnitude and intensity [15]. Smallholder farmers diversify their livelihoods to maintain food security and overall well-being under the tough conditions of farming in these drought-prone areas. Men and women both play important roles in the process of diversifying livelihoods to contribute to household food security [15].

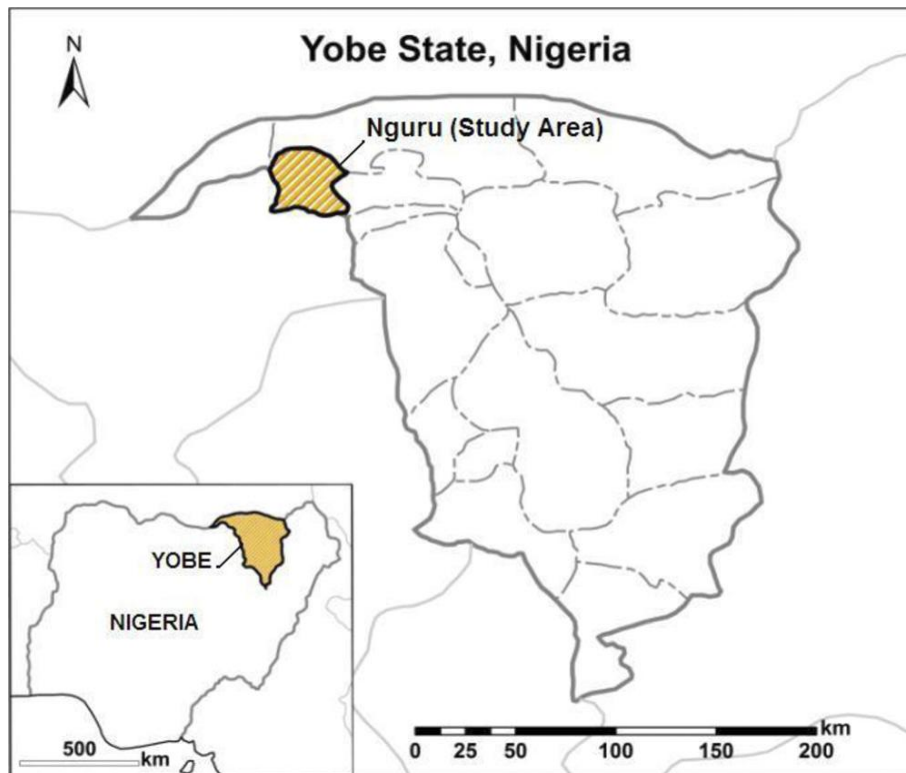


Figure 1 Study area map (source: Jummai et al. 2014)

2.2 Data

The study used monthly rainfall data collected from the Nigerian Meteorological Agency (NIMET) Nguru station for a period of thirty (31) years, from 1975 to 2005. The data were quality controlled and were examined for missing values and typing errors. For the rainfall variability and trend analysis, annual rainfall data were obtained from the monthly rainfall data.

2.3 Analysis of Rainfall Variation

2.3.1 Coefficient of Variation (CV)

The coefficient of variation (CV), defined as the ratio of the standard deviation to the mean rainfall in each period, was used to determine the variability in rainfall for representative meteorological station. It computes or measures the deviation of individual data points from the mean value. A higher CV value indicates increased geographical variability, and vice versa. CV is used to classify the degree of variability as less ($CV < 20\%$), moderate ($20 < CV < 30\%$), high

(CV >30%), very high (CV > 40%) and CV > 70% indicate extremely high inter-annual and seasonal variability of rainfall.

Coefficient of Variation Formula: $CV = \frac{\sigma}{\mu}$

Where: σ = standard deviation μ = mean

2.4 Rainfall Trend analysis (Significance of trend)

2.4.1 Mann Kendall Test

The Mann Kendall trend test was performed using the XLSTAT programme in this investigation. This test was performed to determine whether the data sets had any trends. The non-parametric Mann Kendall Trend Test was used to investigate the temporal variation trend of rainfall in the research area from 1975 to 2005. The M–K test is a nonparametric statistical test commonly used for trend analysis in hydrological and climatological data. This method is used to determine if the variable has a monotonic trend over time (i.e., a trend that is continuously falling and never increasing or consistently growing and never declining) [16].

An upward trend, according to this test, means that the variable consistently climbs over time, whereas a downward trend suggests that the variable consistently decreases over time, however the trend may or may not be linear. S with a positive number suggests an upward trend, whereas S with a very low negative value indicates a downward trend. *"The value of Z is used to assess the presence of a statistically significant trend"* [17].

Mann–Kendall statistic (S) for a time series $x_1, x_2, x_3, \dots$, and x_n is calculated as,

$$S = \sum_{k=1}^{n-1} \sum_{i=k+1}^{n-1} \text{sign}(x_i - x_k)$$

Where S denotes the Mann-Kendal test statistics; x_i and x_k (denote the time series sequential data values in the years i and k ($i > k$); and n denotes the time series' length. A negative S value implies a falling trend in the data series, while a positive value suggests an increasing trend.

2.4.2 Sen's Slope Estimator Test

Sen's estimate is a nonparametric method for determining the magnitude of a trend in a time series. Sen's nonparametric approach is used to establish the true slope of an existing trend, such as the amount of change every year. A positive Sen's slope indicates an upward tendency in the time series, while a negative value indicates a downward trend [18].

The Sen's slope estimator predicts the magnitude of the trend using the slope (T_i) of all data pairs, which is calculated as follows:

$$T_i' = \frac{x_j - x_k}{j - k} \quad \text{For } i = 1, 2, \dots, N$$

Where, x_j and x_k (are data values at time j and k ($j > k$), respectively.

Result and Discussion

Rainfall variation analysis for Nguru met stations in Yobe state was conducted using coefficient of variability and Mann-Kendall trend test along with the Sen's slope estimator of time series data from 1975 to 2005 based on mean annual and seasonal basis. In Nigeria, rainfall is seasonal [8] usually from May to October in the northern region. The six months rainy season was separated into two May-June-July (MJJ) and August-September-October (ASO) figure 4 and 5. The result of the analysis is presented below:

Figures 2 depict the variations in annual rainfall during a 31-year period. Rainfall is the source of all water on the earth's surface, so the more rain that falls in each location, the more water is available for home, agricultural, and industrial use. The coefficient of variation was used to see if the region's mean monthly rainfall levels were the same in 1975, 1976, 1973..., and 2005, or if they differed significantly.

3.1 Coefficient of variation (CV)

The coefficient of variation CV for the annual rainfall in Nguru revealed a moderate inter annual variability (25%), whereas the CV for seasonal rainfall demonstrates that rainfall in the MJJ monsoon period is highly variable between seasons (more than 40%). The CV for the ASO monsoon period, on the other hand, was 31.6%, indicating a considerable and high variability in total rainfall received (Table 2). The result is similar with the findings of [19] which reported low and moderate inter seasonal rainfall variability in north-eastern Nigeria, with over 70% of rainfall occurring between June and September (Figure 3). These findings indicate that inter annual variability in rainfall distribution affects agricultural operations in the study area, which is completely reliant on rainfall. As a result, even minor changes in the quantity and distribution pattern of main season (summer) rainfall may have a severe impact on crop productivity. Table 1 shows the results of the inter-annual rainfall variability analysis performed through the CV.

Table 1 Coefficient of Variation of Annual Rainfall

Coefficient of Variation Annual Rainfall
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Station	Mean Value	CV%	Standard Deviation	Min Value	Max Value
Nguru	409.2761	25.2%	103.088	204.000	605.800

Table 2 Coefficient of Variation of seasonal rainfall (MJJ)

Station	Period	CV%	Standard Dev.	Mean Value	Min Value	Max value
Nguru	MJJ	41.1%	74.08756	180.368	53.200	393.800

Table 3 Coefficient of Variation of seasonal rainfall (ASO)

Station	Period	CV%	Standard Dev.	Mean Value	Min Value	Max value
Nguru	ASO	31.6%	71.49772			

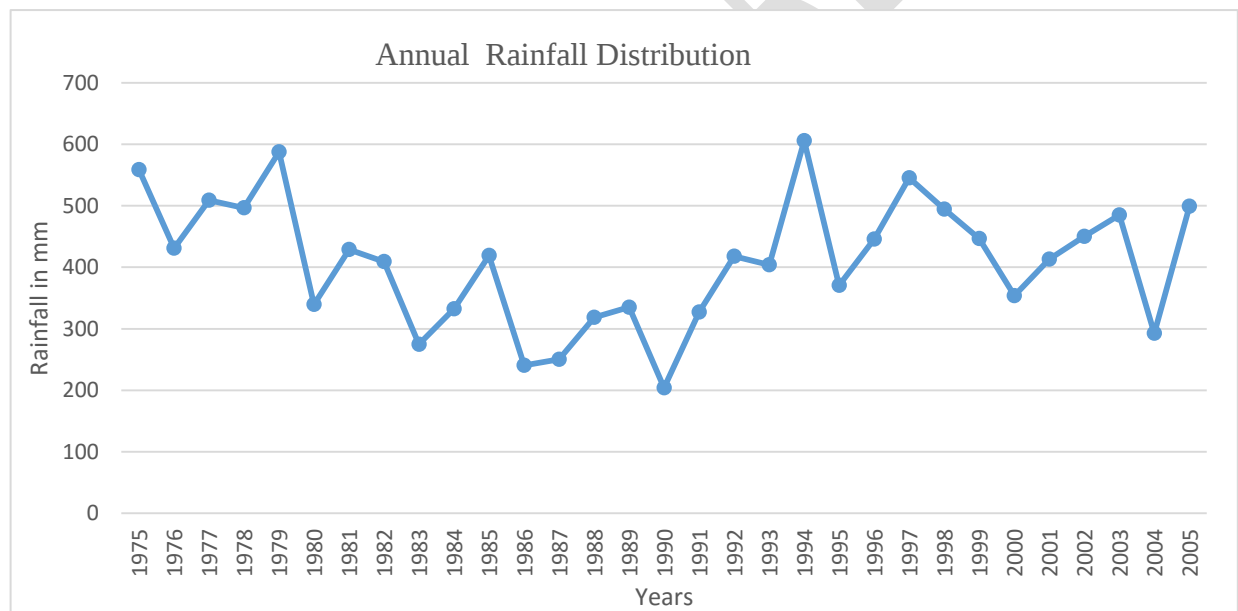


Figure 2: Annual rainfall distribution over Nguru

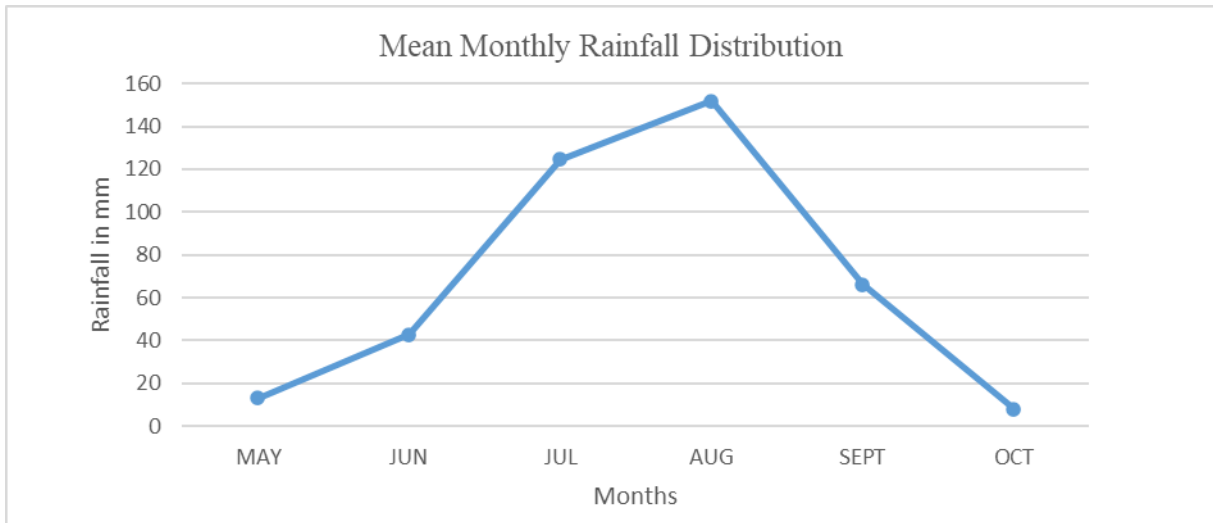


Figure 3: Mean Monthly Rainfall Distribution

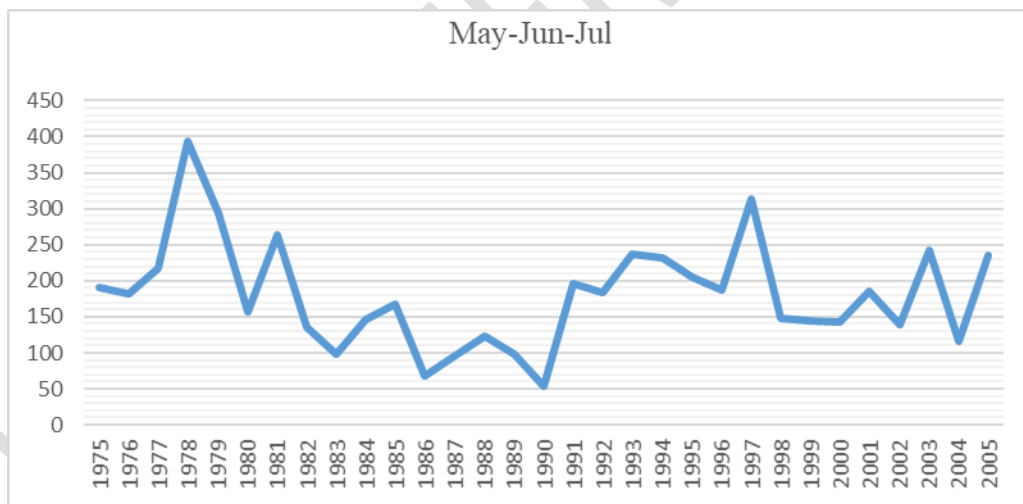


Figure 4: MJJ rainfall distributions over the years

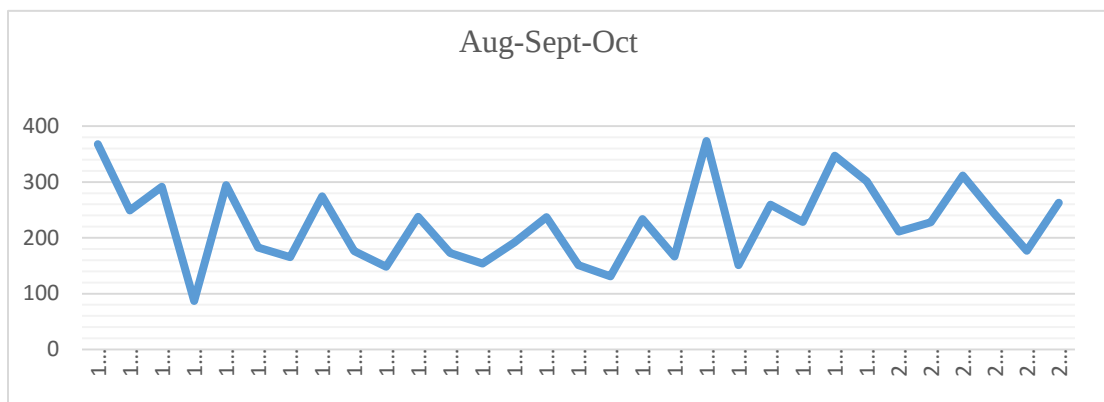


Figure 5: ASO rainfall distributions over the years

3.2 Annual and Seasonal Rainfall Analysis and Trend

Mann-trend Kendall's test was used to conduct a statistical study of annual rainfall trend at 95% confidence level. An increasing trend was suggested by a positive value of Mann-test Kendall's statistics (S) and Sen's slope at ($p = < 0.05$) significance level. The analysis from Mann-Kendall Trend Test have resulted the trend of rainfall from 1975 to 2005 on Nguru station. From Table 4, the Kendall's tau values were 0.011, and the computed p-value was 0.946 which was higher than the significant level alpha equal to 0.05 thus, indicating that there is no significant trend of precipitation in the area. The result corroborates the findings of [11] which revealed that there is no significant trend of rainfall over Nguru over the period of his study from 1976 to 2015.

Table 4 Annual Rainfall Variation Analysis of Nguru

Station	Parameter	P-value	Min	Max	Mean	SD	CV	S	Kendall
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Nguru	Rainfall	0.946	204.00	605.80	409.27	103.08	0.25	5.00	0.011

Table 5 Rainfall seasonal variation analysis of Nguru (MJJ)

Station	Parameter	P-value	Min	Max	Mean	SD	CV	S	Kendall Tau
Nguru	Rainfall	0.708	53.20	393.80	180.36	74.08	0.41	-23.00	-0.049

Table 6 Rainfall seasonal variation analysis of Nguru (ASO)

Station	Parameter	P-value	Min	Max	Mean	SD	CV	S	Kendall Tau
Nguru	Rainfall	0.587	86.90	373.60	225.97	71.49	0.31	33.000	0.071

3.3 Slope and Confidence Interval

The confidence interval value is usually used to determine the slope value. As shown in Table 7, when the minimum interval value is greater than maximum interval value, the slope will be negative value and when the maximum interval value is greater than the minimum value the resulting slope will be positive value [20]. Thus, for the annual rainfall the slope value is positive thereby indicating an increasing trend. The results of positive slope have been found during ASO period at 95% confidence level which also indicate an increasing trend whereas negative slope value was found during MJJ rain period over the station revealing a decreasing trend over the period table 8 and 9.

Table 7. Slope and Confidence Interval of Mann Kendalls Trend Test for Annual Rainfall

Station	Parameter	Slope	Confidence Level (95)	
Nguru	Rainfall	0.300	Minimum	Maximum
			-4.275	5.792

Table 8. Slope and Confidence Interval of Mann Kendalls Trend Test for MJJ Rainfall

Station	Parameter	Slope	Confidence Level (95)	
Nguru	Rainfall	-0.550	Minimum	Maximum
			-4.225	2.594

Table 9. Slope and Confidence Interval of Mann Kendalls Trend Test for MJJ Rainfall

Station	Parameter	Slope	Confidence Level (95)	
Nguru	Rainfall	0.773	Minimum	Maximum
			-2.113	4.350

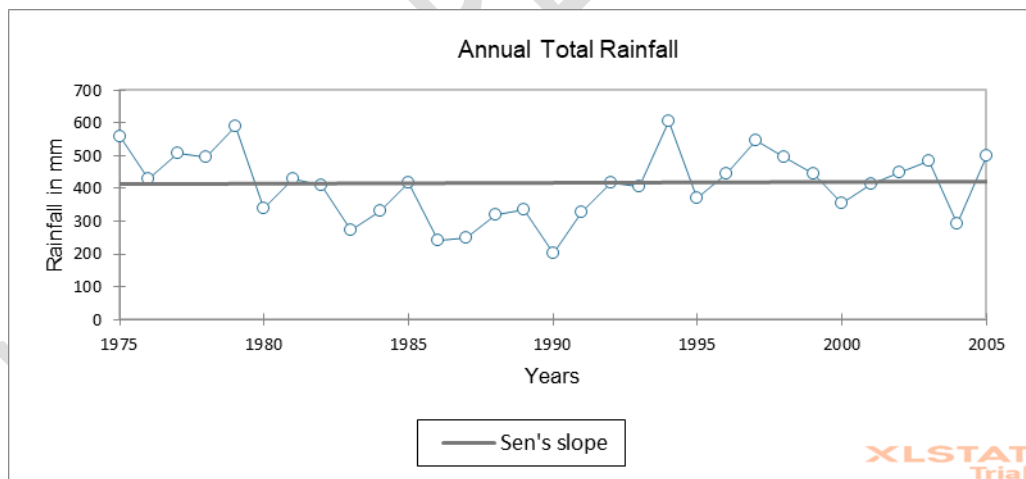


Figure 6: Annual rainfall trend (1975-2005)

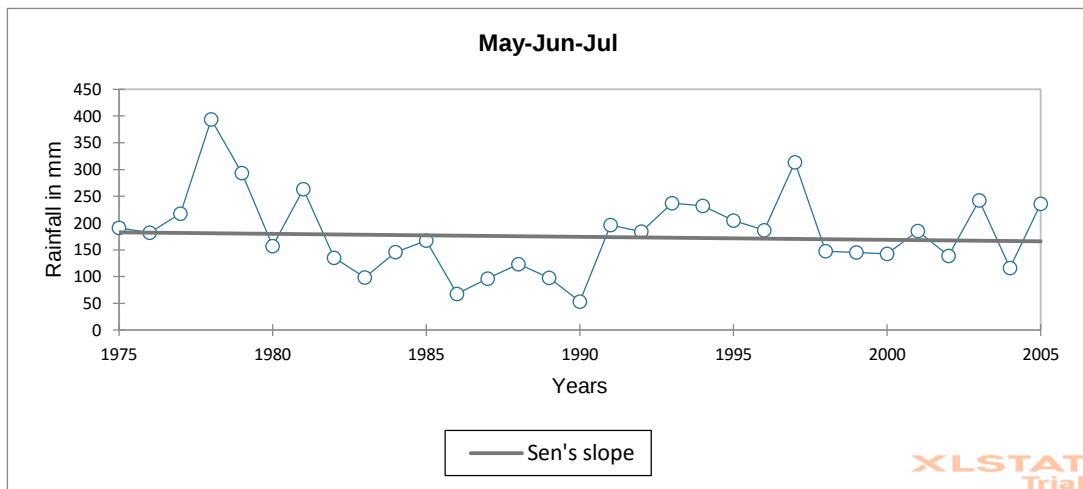


Figure 7: Seasonal (MJJ) rainfall trend over the years

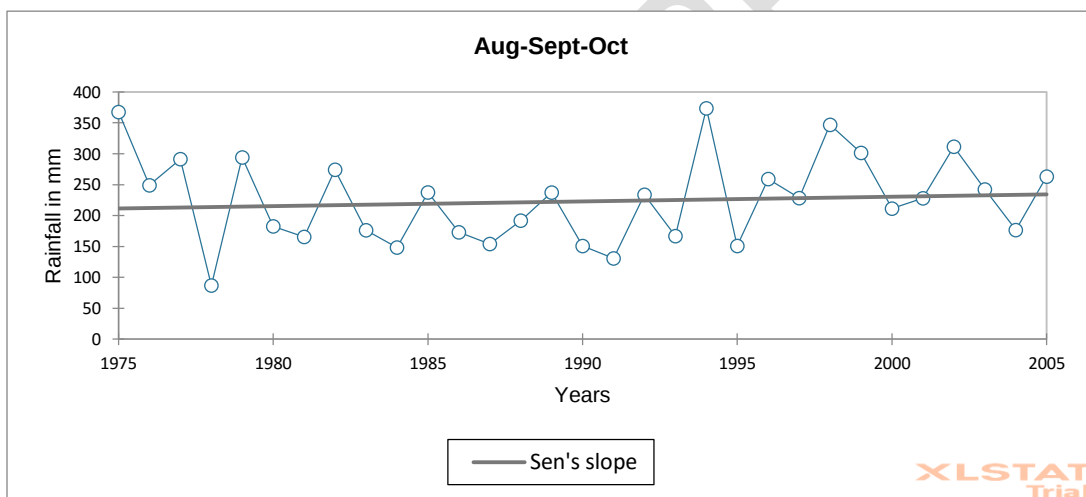


Figure 8: Seasonal (ASO) rainfall trend over the years

Conclusion

The purpose of this study was to determine the annual rainfall variability and trend in Nguru using monthly precipitation data for 31 years (1975 to 2005). The study used the coefficient of variation to analyze rainfall temporal variation, the Mann Kendall's test to determine annual rainfall trends, and Sen's slope estimator to evaluate the magnitude of the trend. The result indicates that the coefficient of variation CV for the annual rainfall in Nguru revealed a moderate inter annual variability (25%), whereas the CV for seasonal rainfall demonstrates that rainfall in

the MJJ monsoon period is highly variable between seasons (more than 40%). The CV for the ASO monsoon period, on the other hand, was 31.6%, indicating a considerable and high variability in total rainfall received.

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