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Rainfall and sea-surface temperature analyses over Maiduguri, Nigeria using Mann-Kendall test

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Monitoring of rainfall has become necessary, because of the adverse effects of rainfall variability (e.g. floods, drought, poor harvests, etc.) on agriculture as well as economy. This study is geared towards a better understanding of rainfall variability in Maiduguri, an agrarian community, and sea-surface temperature using Mann-Kendall statistical analyses of data for a period of thirty-four years from Nigeria Meteorological Agency (NIMET) and National Oceanic and Atmospheric Administration (NOAA) website. Results showed that generally, rainfall in Maiduguri is on the decline and very variable. The sea surface temperature showed an increasing monotonic trend within the period studied.

Key words: Rainfall, sea-surface temperature, trend, variability.

INTRODUCTION

It is well known that global climate is varying, particularly rainfall, and in Africa this variability in rainfall has been attributed to increase in greenhouse gases, higher aerosol concentrations among other factors (Mike et al., 2000; Maynard et al., 2002; Patrick, 2004, Ojo; 2007). This necessitated a change in the global climate models (GCMs), but El Niño/Southern Oscillation (ENSO) and land cover change are not all that represented in the models. ENSO is seen as a major driver of African rainfall followed by sea-surface temperature (SST). (Nicholson, 1993; Sharon and Jeeyoung, 1996), Bose et al. (2015) studied variability and spatial distribution of annual rainfall in Northern Nigeria which revealed that a positive increase of 2.16 mm of significant rainfall was recorded in the entire northern Nigeria within the period of 1970 to 2012. The results further indicate that majority of the stations had an increase or upward trend, with Borno, Bauchi, Sokoto and Kebbi stations showing positive significant rainfall trends of 4.30, 8.13, 4.42 and 4.76 mm, respectively. It was concluded that northern Nigeria had a high variability in rainfall which is an indication of climate change in the region. Diagi (2018) reported a similar wetter condition for Ebonyi State, Southeast Nigeria between 1984 and 2015. However, Animashaun et al. (2020) are of the opinion that most areas within the Niger Central Hydrological Area (NHCA), Nigeria experienced dry weather between 1981 and 1990 with 1983 as the wettest year. Prior to this period, precisely between 1921 and1930, the same area witnessed very wet seasons, 1911 being the driest year. For the entire period of 1911-

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2015, Animashaun et al. (2020) reported 61% moderate rainfall and 39% high concentration rainfall for the thirty (30) basins they studied. Sokoto State had nearly a near normal condition within the period 1980 and 2010 except for few extreme cases of extremely wet and extremely dry conditions in isolated places (Adegboyega et al., 2016; Opeyemi et al, 2016). Itiowe et al. (2019) observed a decline in rainfall in Abuja between 1986 and 2016. In other parts of the world, declining rainfall trend had been reported. For instance, Praveen et al. (2020) reported a significant negative trend in both seasonal and annual rainfall in most parts of India between 1901 and 2015 and a significant variability in rainfall in North Africa was reported by Nouaceur and Murărescu (2016).

Fedorov et al. (2003) opined that the period and steadiness of ENSO depend on the atmospheric system and mean states of the Ocean of Tropical Pacific. This self-sustained oscillation (ENSO) mode is a stable mode put in motion by random forcing is not fixed. The catastrophic flooding impacts are significant on human health. The occurrences of heavy rainfall initiated flooding. Heavy rainfall, tropical storms and glacial melt water are some meteorological events that partnered with flooding. Heavy rainfall leads to flash flooding (such rainfall is heavy on the land such that it cannot be soaked up by the land, this may be as a result of drought). Glacial melt water is when there is a more rapid than usual annual melt of mountain glaciers. It occurs at the Highland regions where temperature affects ENSO, for example, Himalayas/Hindu Kush tropical storms, the flooding combined effects of both heavy rainfall and storm surge. It is the possible bridge (glacier melt) by which ENSO affects storm tracks (Wang and Picaut, 2004).

The United Nations Environment Program (UNEP) and World Meteorological Organization (WMO) in 1988 initiated Intergovernmental Panel on Climate Change (IPCC) to assess relevant information that are scientific about climate change for national policy formulation internationally. A change called anthropogenic climate was reported by IPCC Second Assessment to have started and that global climate consists of discernible human influence (IPCC, 2021). El Niño may be affected by climate change and may likely affect the intensity and the frequency of weather events all over the world. Furthermore, studies have shown that human health can be affected by global climate change (WHO/WMO/UNEP, 1996). The trend of rainfall in Africa from 1901 to 1985 is reported by Folland et al. (1986) to have been directly influenced by variations of sea surface temperature (SST) showing contrasting patterns anomalies on global scale.

Ati et al. (2010) reported that annual rainfall for 92% out of the ENSO years studied fell below long term mean. But during normal years, 25% has rainfall below the long term mean out of 12 years. He evidently showed that there are more ENSO and La Niña years with mean below long-term mean unlike the normal year.

METHODOLOGY

Study area

Nigeria covers an area of 923,768 km², out of which 910,768 km² is land, while water takes up 13,000 km². Nigeria has total boundary length of 4,047 km. The Benin land border with Nigeria is 773 km, the Cameroon land border is 1,690 km, while for Chad it is 87 km, and Niger is 1,497 km. The climate of Nigeria can be classified into latitudinal zones that progressively become drier as one moves north from the coast of the Atlantic Ocean (Olusina and Odumade, 2012). Nigeria is geographically located on the Gulf of Guinea in West Africa, bounded by Benin in the West and Cameroon in the East. In the North are Chad (North East) and Niger (North West) and in the West is the Atlantic Ocean.

Maiduguri, the capital city of Borno State, Nigeria is in the Sahel Savanna climatic region. This is a region which extends from Senegal eastward to Sudan Sahel semi-arid region of the western and the north-central Africa. It stretches eastward through northern Senegal from Atlantic Ocean and also through southern Mauritania. Maiduguri is hot most round the year with an average temperature of 37°C and an annual average rainfall of 1807 mm. The humidity is also very low most of the months (Figure 1).

Sources and types of data

Daily rainfall data from 1986 to 2019 for Maiduguri were collected from the headquarters of the Nigerian Meteorological Agency (NIMET), Abuja, Nigeria and monthly Sea-Surface Temperature (SST) data of South Atlantic Ocean (10° North-75° South, 70° West-25° East) were obtained from National Oceanic and Atmospheric Administration (NOAA), National Weather Service, Climate Prediction Center, USA for the same period.

Theory

The mean $(\bar{x})$ and standard deviation (SD) of yearly average of rainfall were calculated using Equations 1 and 2, respectively.

$$\text{Mean } \bar{x}, = \frac{\sum x_i}{n} \tag{1}$$

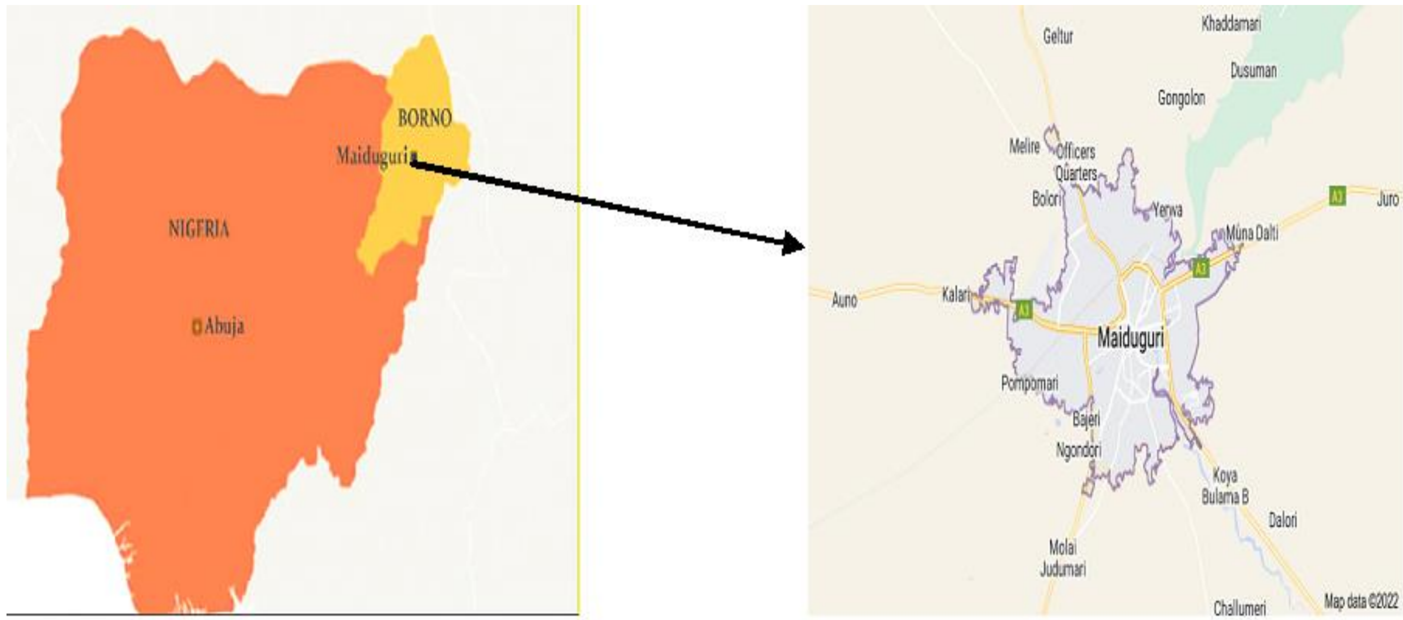
where x_i implies the yearly average value of rainfall, *n* is the total number of values.

$$\text{Standard Deviation, (SD)} = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} \tag{2}$$

where x_i represents each of the yearly average values of rainfall, $\bar{x}$ is the mean of the yearly averages; and n is the number of the values.

Mann-Kendall test

Mann-Kendall (M-K) test is a non-parametric statistic test used to analyze trend in climatology and hydrologic time series mainly



(A) Nigeria (B) Maiduguri

Figure 1. Map of Nigeria (A) showing Maiduguri (B).
Source: Google.

because it takes care of outliers in the very large values associated with climatology. Mann-Kendall test computation procedures are as follows:

$$S = \sum_{k=1}^{n-1} \sum_{J=K+1}^{n} \text{Sign}\,(X_j - X_k) \tag{3}$$

where Sign $(X_j - X_k) = 1$ if $X_j - X_k > 0$, Sign $(X_j - X_k) = 0$ if $X_j - X_k = 0$ and Sign $(X_j - X_k) = -1$ if $X_j - X_k < 0$.

The X_1, X_2, X_3, X_4……………X_n denotes *n* data points; X_j represents the data point at time J. A very high positive value of S shows that there is an increasing trend while the very low negative value is an indicator of a decreasing trend.

The *Z* value in M-K test is used to detect if the time series information is of increasing trend or not. The *Z* value is computed as follows:

$$Z = \begin{pmatrix} \frac{S-1}{\sqrt{\text{Var}\,(S)}} & \text{if} & S > 0 \\ 0 & \text{if} & S = 0 \\ \frac{S+1}{\sqrt{\text{Var}\,(S)}} & \text{if} & S < 0 \end{pmatrix} \tag{4}$$

where $\text{Var}\,(S)$ is the variance of Mann-Kendall test, the negative and positive value of *Z* is an indicator of decreasing and increasing trend, respectively.

The probability of shifting year (P) is a function of Z statistic. The $f(Z)$ is computed using:

$$f(Z) = \frac{1}{\sqrt{2\pi}} e^{\frac{-z^2}{2}} \tag{5}$$

The probability of shifting year (P) tells whether to accept or to reject the null hypothesis. If *Z* score is between –1.96 and +1.96, there is a confidence level of 95%. When Z score is between these range that is, -1.96 and +1.96), the P-value will be greater than the significant level ($P > 0.05$) and the result is said to be not significant. Thus, the null hypothesis (H_o) is accepted.

When *Z* score is between –2.5 and +2.5, confidence level is 99%, then P-value will be less than the significance level ($P < 0.05$), so the result is said to be significant. Therefore, the null hypothesis (H_o) is to be rejected, which implies the P-value (the probability of shifting year) is greater than the significant level ($\alpha = 0.05$ or 5%).

Method of data analyses

Equations 1 to 3 were utilized to calculate the yearly variation of the weather indices for the station throughout the 34 years studied. The Mann-Kendall (M-K) trend test was used to determine the trend and appropriate graphs where plotted.

The Mann-Kendall trend test works on two hypotheses: the alternate hypothesis and the null hypothesis. The alternate hypothesis states that a monotonic trend exists in a time series dataset while the null hypothesis states that no monotonic trend exists. This Mann-Kendall trend test has been widely used in hydro meteorological time series. A better trend was gotten if the time series data is large in size and that is why a period of 34 years was used in the analysis.

The results define the trend significance. The analyses are based on 0.05 or 5% level of significance. Based on this, if $P > 0.05$, the trend is not significant at 5%; this implies that there is no significant trend and the null hypothesis is accepted while the alternate hypothesis is rejected but if the value of $P < 0.05$; the trend is said to be significant; this shows that the alternate hypothesis is accepted while the null hypothesis is rejected.

Table 1. Descriptive statistics of Rainfall in Maiduguri.

Year	Year average (mm)	SD (mm)
1986	65.45417	103.9164
1987	55.78167	104.2217
1988	74.88667	103.9378
1989	57.63833	104.0668
1990	48.135	104.1247
1991	54.91417	104.1646
1992	54.91417	104.0748
1993	46.91833	104.276
1994	65.28083	104.3407
1995	72.24083	104.4111
1996	54.74167	104.287
1997	59.66167	104.4798
1998	46.85833	104.5394
1999	45.10667	104.6129
2000	33.35833	104.5304
2001	46.195	104.7368
2002	38.64417	104.7907
2003	41.41667	104.8069
2004	32.025	104.7307
2005	48.22333	104.9211
2006	37.90417	104.9755
2007	51.195	105.0288
2008	68.57167	104.9142
2009	40.73833	105.1221
2010	60.93583	105.1619
2011	50.43083	105.2216
2012	67.985	105.1158
2013	55.6175	105.34
2014	52.35417	105.3709
2015	34.60917	105.4608
2016	55.355	105.3904
2017	46.2175	105.6136
2018	50.51833	105.613
2019	47.03167	105.6679

Source: Author’s 2022

The null hypothesis being accepted means that there is no monotonic trend in the series but when alternate hypothesis is accepted; it implies that there is a monotonic trend in the series. This trend may be a positive (increasing) or negative (decreasing) trend depending on the value of Z statistic. An increasing/ decreasing trend will have a positive/negative value of Z, respectively.

RESULTS AND DISCUSSION

Descriptive statistics of rainfall and SST

Nigeria’s climate consists of two seasons; these are dry season and rainy season. Nigeria has climatic zones which can be categorized as Sahel savanna, Sudan savanna, Guinea savanna, rainforest and mangrove swamp. The Federal Republic of Nigeria is located on the Gulf of Guinea in West Africa. The mean ($\bar{x}$) and the standard deviation (SD) of rainfall of the years under study (1986 to 2019) are calculated using Mann-Kendall’s trend TEST.

From Table 1 and Figure 2 the minimum average rainfall of 32.025 mm in Maiduguri was in 2004 and the maximum average of 74.88667 mm was in 1988. It appears that there was no particular pattern of high, low or average rainfall but there was variability in rainfall. However, a negative slope of -0.325 shows rainfall has

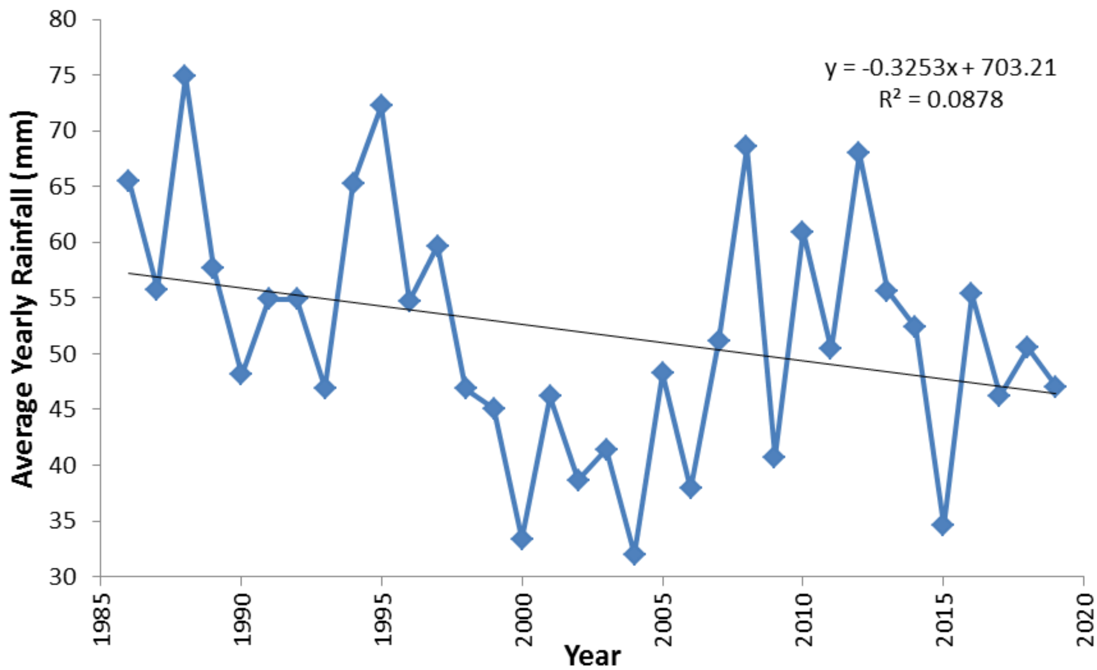


Figure 2. Plot of average rainfall recorded at Maiduguri station.
Source: Author's 2022

Table 2. Summary of Mann-Kendall test results for rainfall in Maiduguri.

Town	Climatic zone	P-value	Z-value	Trend	Trend/Level of significance	Null hypothesis
Maiduguri	Sahel Savanna	0.1463	-1.4528	No	Not significant/Rejected	Accepted

Source: Author's 2022

Table 3. Summary of Mann-Kendall trend test for sea-surface temperature.

P-value	Z-value	Trend	Trend/Level of significance	Null hypothesis
0.0011	3.2621	Yes	Significant/Accepted	Rejected

Source: Author's 2022

been on the decline within the period studied.

In Table 2, the hypotheses were tested at 5% or 0.05 level of significance (α). When $P < 0.05$, the alternate hypothesis is accepted and null hypothesis is rejected. The alternate hypothesis being accepted means that there is a significant trend in the quantity tested (rainfall, in this case). This trend may be positive (+Z that is increasing) or negative (-Z that is decreasing) depending on the value of Z. The P-value of 0.1463 is greater than the significant value hence there is no significant monotonic decreasing trend in the time series data.

Table 3 is a summary of the Mann-Kendall trend test for sea-surface temperature which shows that the probability of shifting year, P-value is far less than the level of significance, α ($P < \alpha$) and the Z value is positive. This implies that there is a monotonic increasing or upward trend in SST for the period under study and the alternate hypothesis is accepted. From Figure 3, the coefficient of regression is about 55% (≈55%) which explains that a little above half of the variability in SST is explained by the linear regression.

Conclusion

Statistical analysis of rainfall pattern in Maiduguri, North-

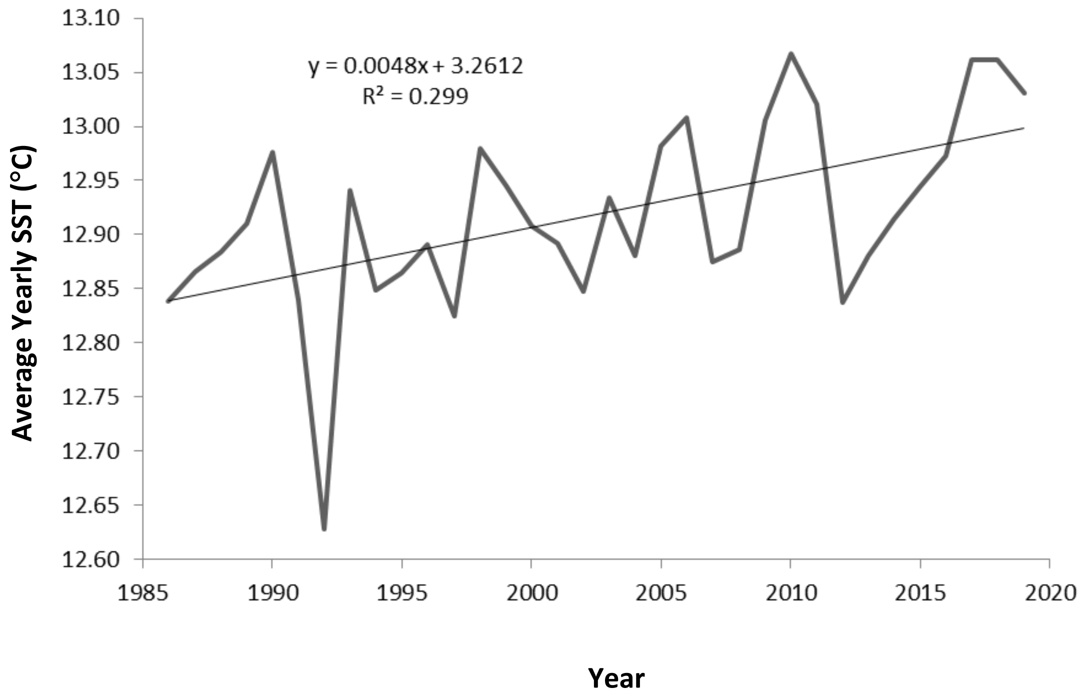


Figure 3. Graph of sea-surface temperature.
Source: Author's 2022

East of Nigeria and sea surface temperature has been carried out for a period of 34 years.

Sea-Surface temperature has been on a very high monotonic increase for the period studied. This may have affected the variability of rainfall in Nigeria.

The analysis has also shown that as the SST increases the rainfall decreases. Rainfall varied in terms of amount of rainfall and increased number of minimum rainfall years. This appears to be in agreement with the works of Adegboyega et al. (2016) and Itiowe et al. (2019) but at variance with the works of Bose et al. (2015) and Diagi (2018); though the times of study are different.

Based on our analysis, it is suggested that farmers should take into account the trends in Nigerian rainfall for optimum production. Also, this research work is a contribution to the ongoing discussions on climate change as it affects Nigeria.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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