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RESEARCH ARTICLE

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Trends and spatial analysis of temperature and rainfall patterns on rice yields in Nigeria

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Abstract
Trends and spatial analysis of temperature and rainfall on rice yield in Nigeria was carried out. Forty year of past trends (1970–2010) was conducted with climate data obtained from the International Institute of Tropical Agriculture, Ibadan, Nigeria while upland rice yield data were obtained from the Food and Agriculture Organization. Six cities, one in each of the six agro-ecological zones which were *Calabar*, *Enugu*, *Ikeja*, *Ilorin*, *Kaduna*, and *Maiduguri* were selected. Geographic information systems mapping for spatial analysis of temperature and rainfall over Nigeria was carried out. Mann–Kendall, Sens' tests, Pettitt's, and Buishand's tests and multiple linear regressions were used as statistical tools for analysis. Increasing rainfall trends in *Enugu*, *Calabar*, and *Ikeja* but decreasing trends were observed in *Ilorin Kaduna* and *Maiduguri* while temperature showed increasing trends in all the cities in the last four decades. Statistically significant positive trends of rice yield, rainfall, and temperature were observed in *Ikeja* and *Maiduguri* in the last four decades. Mann–Kendall tests showed that rice yield and temperature had generally statistically significant positive trends in *Calabar Ilorin Kaduna*, and *Enugu* while rainfall and yield were significant in *Calabar Enugu* but not significant in *Ilorin* and *Maiduguri* adaptation strategies to genetically modify rice varieties and effective water use strategies in areas of rainfall deficit are recommended to ensure food security.

KEYWORDS
climate variability, rainfall, rice yields, temperature, trends

1 | INTRODUCTION

Rice is a major food for millions of people in West Africa and the fastest growing commodity in Nigeria (Akinbile *et al* 2015). It is currently the staple food for over 4.7 billion people globally and demand is expected to continue to grow as population increases. Annual demand for rice in sub-Saharan Africa is increasing at the rate of 6% per year, fueled by rapid population growth and changes in consumer preferences (Akinbile *et al* 2016a). Rice is one of the few crops grown nationwide and in all the agro-ecological zones and could be cultivated in about 4.6–4.9

million ha of land in Nigeria, but the actual area under cultivation was only 1 million ha representing 22% of the total potential available area. This had increased to 1.6 million ha but still way below the required cultivation levels to attain self-sufficiency in production (Singh *et al* 1997). Although rice production in Nigeria has boomed over the years, there has been a considerable lag between production and demand levels with importation making up for the shortfall. Several importation figures had been reported by researchers since Nigeria started rice importation. In Nigeria, 413,000 tons was reported in 1997 which rose to 688,000 metric tons (MT) tons in 1999 and 1.3 million MT from 2000 up to 1.9 million MT in 2005 (Food and Agriculture Organization [FAO] 2007). Local production has also increased to 4 million MT (by June 2014) but the country still imports 2.1 million MT to meet the shortfall in local consumption, the cost which stood at a staggering 365 billion naira annually which implied that 1 billion naira is spent daily on rice importation. This justified the reason why Nigeria is the World's second largest rice importer after China, although the country is still the largest producer of the commodity in West Africa's subregion (Akinbile 2013). Most studies conducted on the factors responsible for costly imports despite a steady increase in local production suggested climatic factors like precipitation, temperature, and solar radiation as the most critical environmental factors affecting rice production (IPCC, 2007; Akinbile *et al* 2015). Climate is perhaps the most important of natural environmental resources, which affects growth, development, and adaptation of plants. This is apart from land and water resources which are predictable and can easily be manipulated for increasing rice production. Several researchers (Oguntunde *et al* 2011; 2012; 2017; Wassmann *et al* 2009; Saseendran *et al* 2000; Seino 1995 had reported the domineering influence of climate on crop yields in studies carried out from different parts of the globe. Similarly, Jagadish *et al* (2010) examined the effect of carbon dioxide (CO_2) and temperature on rice yield and found out that increase in temperature resulted in the large reduction in rice yield which was not compensated for by an increase in the CO_2. The grain yield decreased above critical temperature greater than 30°C. Similarly, Matsui *et al* (2000) found out that the combination of increased CO_2 and temperature resulted in a small increase in biomass and yield during the dry season and a small decrease during the wet season. This inferred that both Jagadish *et al* (2010) and Matsui *et al* (2000) agreed that increased maximum and minimum temperatures could decrease rice yield due to spikelet sterility and higher respiration loss. The consequences of continuous variation in meteorological conditions were severe reduction and deterioration in annual tonnage of rice yields. Solar radiation has a direct link with evapotranspiration and rainfall, which increases soil temperature and rainfall disparity triggers environmental problems such as flood, gully erosion, drought, and desertification, all of which have a serious impact on the tonnage of crops yield and biodiversity loss (Quirion and Quirion 2013). Therefore, the objective of this study is to carry out 40 years trends and spatial analysis (1971–2010) of temperature and rainfall patterns and effects on rice yields in Nigeria. Also, to develop spatial maps, using geographic information systems (GIS) tools to understand the effects of the two weather parameters on rice yields in Nigeria.

2 | MATERIALS AND METHODS

2.1 | Description of the study areas

Six cities, one from each of the six agro-ecological zones in Nigeria were selected for this study. Their selections were based on their strategic importance with respect to agricultural practices, especially cropping to their respective zones. The six cities and agro-ecological zones considered for this study were: Calabar (4°34′27″N, 6°58′32″E) (Mangrove), Enugu (6°26′0″N, 7°29′0″E) (Wooded Savannah), Ilorin (10°53′0″N, 4°1′0″E) (Guinea Sudan), Kaduna (10°31′23″N, 7°26′25″E) (Sudan-Sahel), Maiduguri (11°50′42″N, 13°9′35″E) (Sahel), and Ikeja (11°50′42″N, 13°9′35″E) (Rainforest). The predominantly grown crops in all these regions ranged from food (yam, cassava, rice) to cash (oil palm, kola nut, and coffee) crops and their respective locations are as presented in Figure 1.

2.2 | Data collection

Weather data on rainfall and temperature for the 40-year period (1971–2010) for the six agro-ecological zones study cities were obtained from the Nigerian Meteorological Services Lagos (NIMET) (2008) while that of the upland rice yields for the same period (1971–2010) were obtained from the FAO (2013) of the United Nations.

2.3 | Trends analysis of climate variability on rice yields

Trend analysis of climate (temperature and rainfall) variability throughout the 40-year period from 1971 to 2010 was carried out to recognize past trends in the six agro-ecological zones in Nigeria. An investigation was conducted to ascertain probable linkage between climate

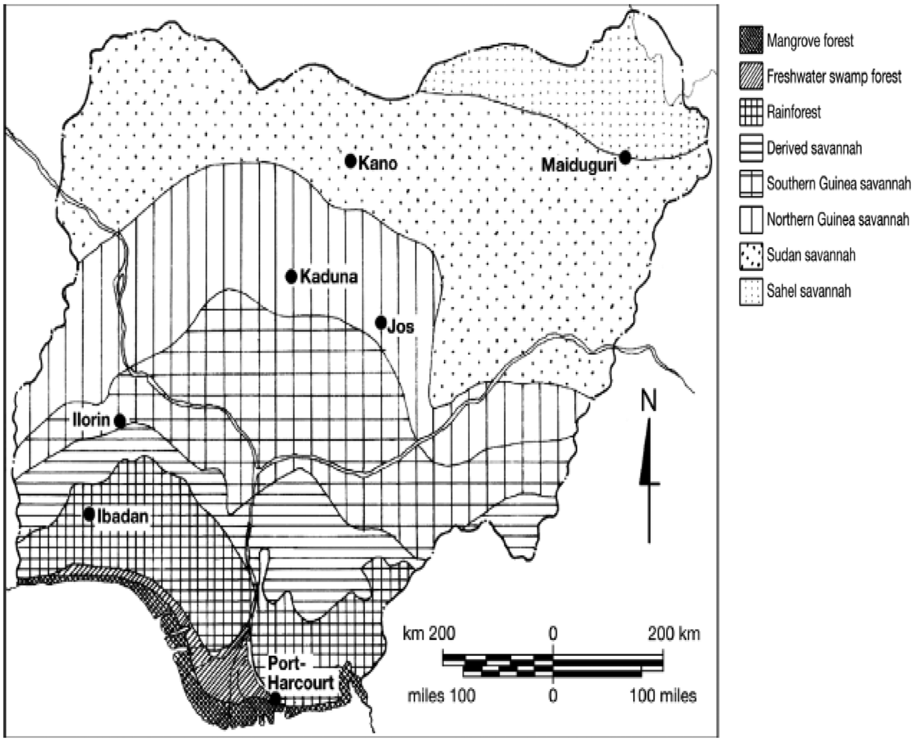


FIGURE 1 Six cities, one in each agro-ecological zone considered for the study

variability and trends in rice yield in Nigeria. Rice yield data obtained was correlated against variations in temperature and rainfall for the 40-year period.

2.4 | Data analysis

Statistical tools used for analyses include multiple linear regressions, cross-correlations analysis, Statistical Package for Social Sciences (SPSS) version 20, GISs version 9.2, analysis of variance, Pearson correlation, Mann–Kendall, and Sens' tests, and Duncan's multiple range test all at 95% level of significance. Also, homogeneity tests on the rainfall, temperature, and rice yield were conducted using the Pettitt's test and Buishand's test (Buishand 1982; Kang and Yusof 2012; Taxak *et al* 2014; Akinsanola and Ogunjobi 2017). The two tests are nonparametric tests that require no assumption of the distribution of the variable considered. The Pettitt's and Buishand's test use statistic K and Q respectively to identify if there is a shift in mean and the time at which the shift occurs.

$$\text{For } K, \text{ let } D_{ij} = \text{ if } (x_j - x_i) >$$
$$D_{ij} = \text{ if } (x_j - x_i) =,$$

$$D_{ij} = + \text{if } (x_j - x_i) >$$

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=i+1}^{T} D_{ij} \quad (1)$$

$$K_T = \underset{\leq t \leq T}{\max} |U_{t\,T}| \text{ for the two-tailed case}$$

For Q, let

$$S_o^* =$$

$$S_k^* = Z_1 = \sum_{i=1}^{k} (x_j - u), k = 1, 2, ..., T \quad (2)$$

$$S_k^{**} = S_k^* / \sigma$$

$$Q = \underset{\leq t \leq T}{\max} |S_k^{**}| \text{ for the two-tailed case}$$

The null and alternative hypothesis are expressed by H_0 is the variable data is homogenous; and H_a is the variable is heterogeneous and there is a date at which there is a change in data.

Akinbile *et al* (2015) and Koudahe *et al* (2017) reported that Mann–Kendall test a nonparametric method for trend analysis and used for analyzing temporal trends in annual monthly rainfall, ET_o, and aridity index, and a very useful tool in climatology and hydrology time series. Some of the advantages of using this test are that being a nonparametric test, it does not require the data to be normally distributed and the test has low sensitivity to abrupt breaks due to inhomogeneous time series (Koudahe *et al* 2017). According to the test, the null hypothesis (H_0) assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis (H_1), which assumes that there is a trend. The Mann–Kendall test statistic S is given as follows:

$$S=\sum_{k-1}^{n}\sum_{j=k+1}^{n} sign\left(x_j-x_k\right) \tag{3}$$

where x_i and x_j are the data values at time i and j, n is the length of the dataset and sign () is the sign function which can be computed as:

$$\text{sign}\left(x_j-x_k\right)=\begin{cases} \text{if } \left(x_j-x_k\right)> \\ \text{if } \left(x_j-x_k\right)= \\ -\text{if } \left(x_j-x_k\right)< \end{cases} \tag{4}$$

For $n > 10$, the test statistic Z approximately follows a standard normal distribution:

$$Z=\begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}, \text{ if } S>0 \\ 0 \quad \text{ if } S=0 \\ \dfrac{S+1}{\sqrt{Var(S)}}, \text{if } S<0 \end{cases} \tag{5}$$

in which $Var(S)$ is the variance of statistic S.

A positive value of Z indicates that there is an increasing trend while negative value indicates a decreasing trend. The null hypothesis, Ho, that there is no trend in the records is either accepted or rejected depending on whether the computed Z statistics is less than or more than the critical value of Z statistics obtained from the normal distribution table at the 5% significance level. If $|Z| > Z_{(1-\alpha/2)}$, the null hypothesis of no autocorrelation and trend in time series is rejected, in which $Z_{(1-\alpha/2)}$ is corresponding to the normal distribution with α being the significance level.

3 | RESULTS AND DISCUSSION

3.1 | Trends analysis of past of rainfall and temperature in all the six locations in Nigeria

Figure 2 shows the rainfall trends while Figure 3 showed the temperature trends of the six locations considered within the 40 years' duration (1971–2010) using Pettitt's and Buishand tests. This was with a view of identifying sudden shifts in the mean of the time series of the parameters considered. In Calabar, a fairly increasing trend of past annual rainfall which was not statistically significant at 7% linear variance was observed. The city experienced excess rainfall of over 2,000 mm in the last four decades except in 1973 with highest average rainfall of 3,490.9 mm in 1995 and lowest average rainfall of 1876.8 mm in 1973 (Figure 2). This indicated that Calabar experienced more rainfall than all the cities considered in this study especially in 1995. Mohammed and Tarpley (2009) reported that most cases of environmental degradation in Calabar are associated with serious rainfall anomalies. Too much rainfall leads to excessive flooding of low-lying areas and overflowing of river banks. Excessive rainfall experienced in Calabar do not in any way improved rice yields. Relating rainfall with yield in Calabar, a fairly increasing trend that was also statistically not significant at 6.9% linear variance was observed. A clear observation was that even in the years of moderate rainfall, higher yields were recorded when compared with years that had high rainfall. For instance, in 1987, a yield of 1.13 t/ha was recorded with an average annual rainfall of 2,740.9 mm while in 2009, an average yield of 2.25 t/ha was recorded with the rainfall average values of 2,271.7 mm. This observation agreed with the findings of Oguntunde *et al* (2011) in his rainfall studies over Nigeria for a century. For temperature scenario in the same region, that there was an increasing trend of 44.7% annual variance. 1975 recorded the lowest temperature value of 27.5°C while the highest temperature value of 30.2°C was recorded in 2003 (Figure 3a). This temperature range (28–30°C) with a mean value of 29°C is a boost to future rice yield in Calabar. A much higher mean temperature would reduce growth duration and accelerate flowering whereas a lower mean temperature would slow down vegetative growth and plants failure to flower at critical period of development (Wassmann *et al* 2009).

In Enugu, a very low increasing trend was observed in rainfall (1.4%) and rice yield (3.4%) which was statistically nonsignificant in the area. Enugu experienced the highest and lowest rainfall pattern of 2,212.4 mm in 1997 and 914.4 mm in 1983 respectively (Figure 2). Rice yields in those extreme years were 1.99 t/ha (1997) and 0.83 t/ha (1983) which showed that the high rainfall boosted rice yield for that year (Figure 4). Excess rainfall lower surface and soil temperature and but not high enough to constitute a serious problem to the tonnage of rice yield in Enugu. High rainfall resulted in flood and causes physical damage to farmland by eroding and sweeping away the topsoil, which is necessary for rice

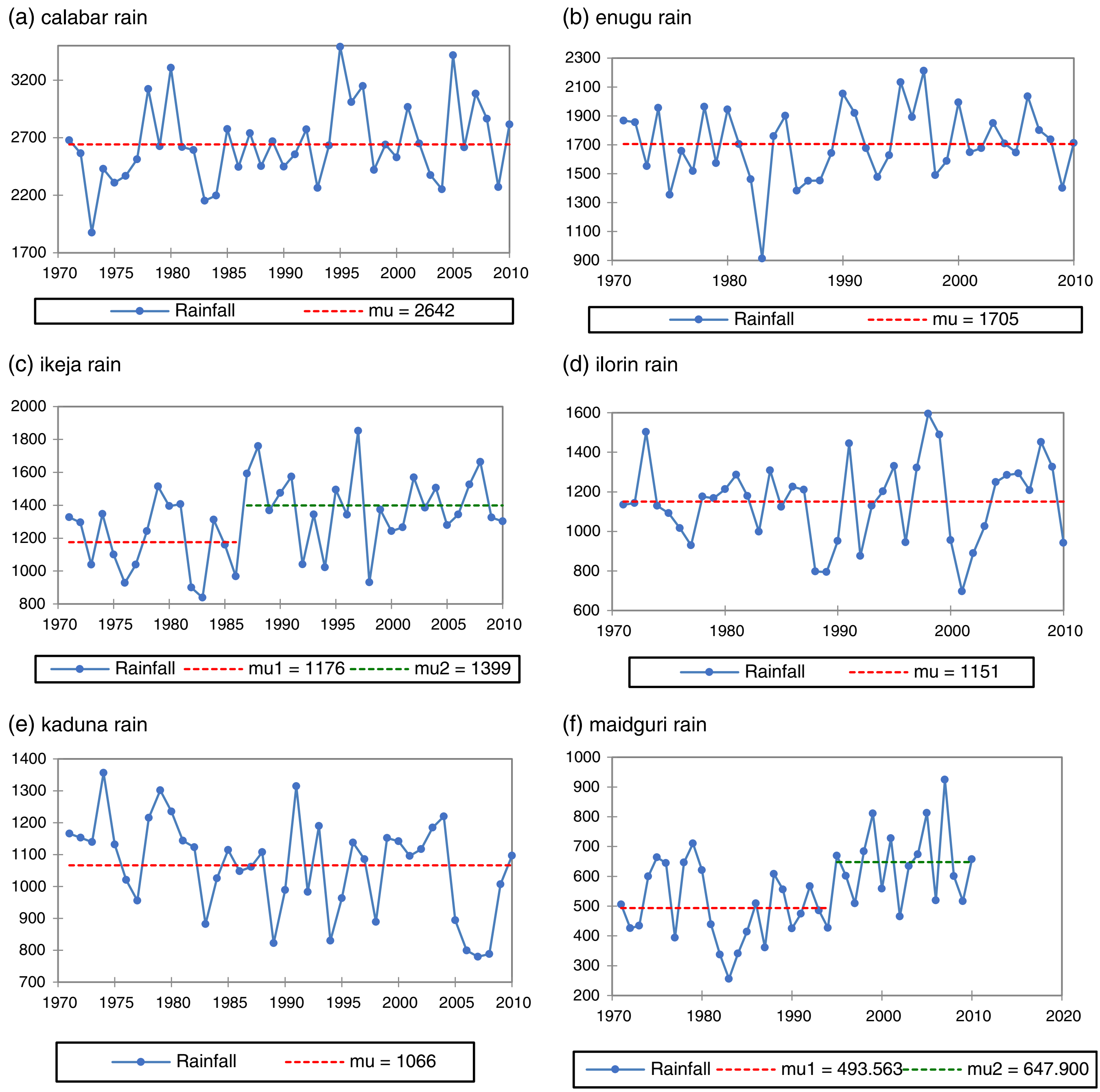


FIGURE 2 Rainfall trends for the six locations in Nigeria from 1971 to 2010 using Pettitt and Buishand tests

yield. This explained the presence of the highest number of gullies occasioned by torrential downpour leading to severe erosion in the southeastern part of Nigeria. Devastating flooding events in southern Nigeria has been linked with the progressive increase in rainfall over the region in the last five decades of the century (Akinbile *et al* 2015). The temperature scenario in Enugu for the 40-year period showed an increasing trend of 53.8% variance. Minimum temperature value of 29.5°C was recorded in 1975 while maximum value of 32.5°C in 2005 (Figure 3b). Similar observations as recorded by Wassmann *et al* (2009) could be the reason for this trend in Enugu.

Rainfall and temperature trends of Ikeja were as presented in Figures 2 and 3 respectively. A statistical nonsignificant linear increase of 11.3 and 47.9% were recorded for the two parameters respectively from 1970 through 2010. However, 13.8 and 50.7% linear increases were obtained for rice yield as compared with rainfall and temperature respectively, an indication that rainfall had a more pronounced effect on rice yield when compared with temperature at Ikeja. While rainfall was statistically significant on rice yield performance, the temperature was statistically nonsignificant. This inferred that rainfall played a significant role in the projected increase in rice yield in the next 40 years but temperature, which is clearly beyond the control of man. The effect of temperature and solar radiation having considerable influence on rice yield has been widely reported (Aggarwal and Mall 2002; Agrisnet 2011; Atul *et al* 2011; Akinbile *et al* 2016a; 2016b; Oguntunde *et al* 2017).

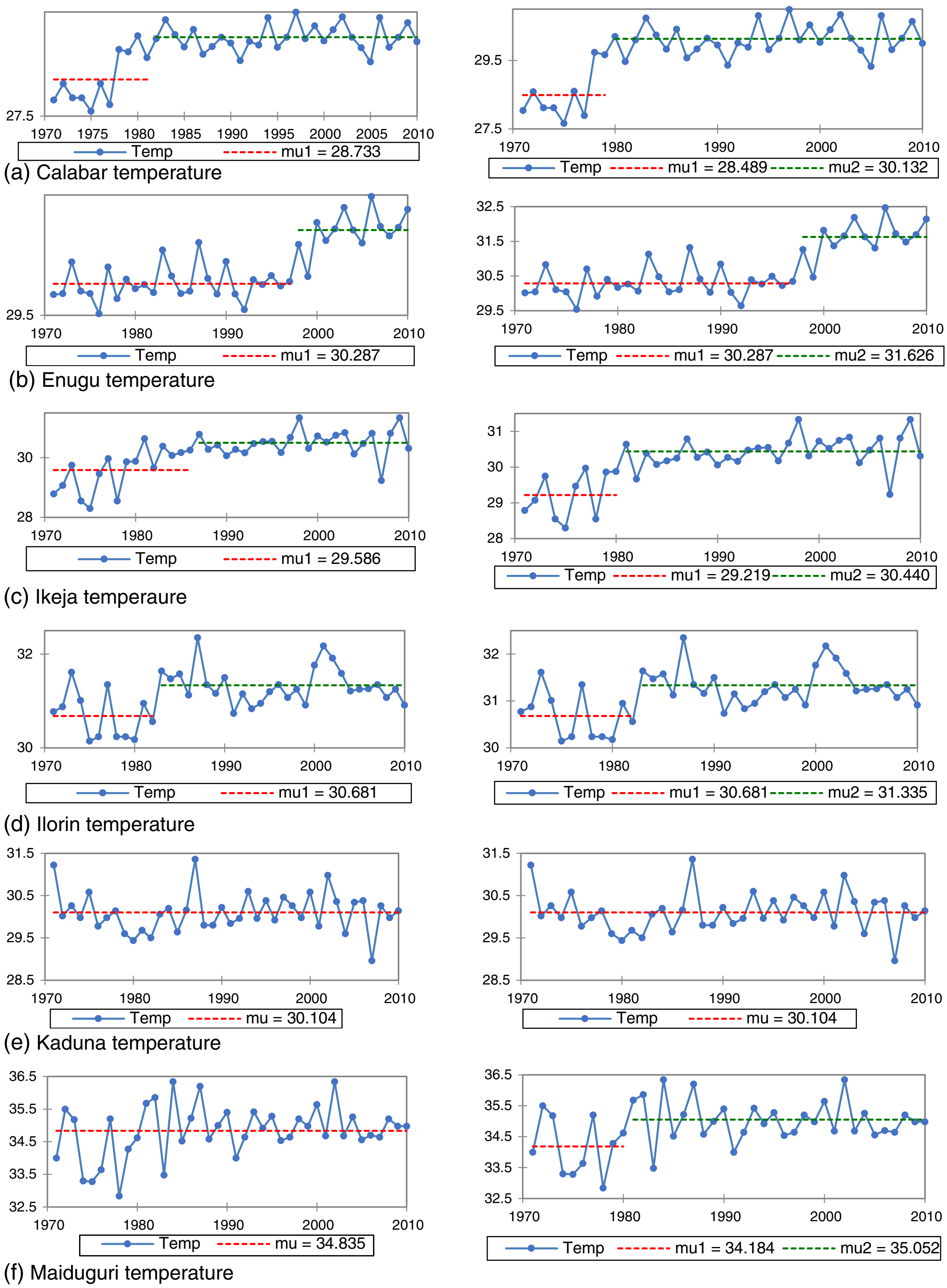


FIGURE 3 Temperature trends for the six locations from 1971 to 2010 using Petitit (left) and Bushiand (right) tests

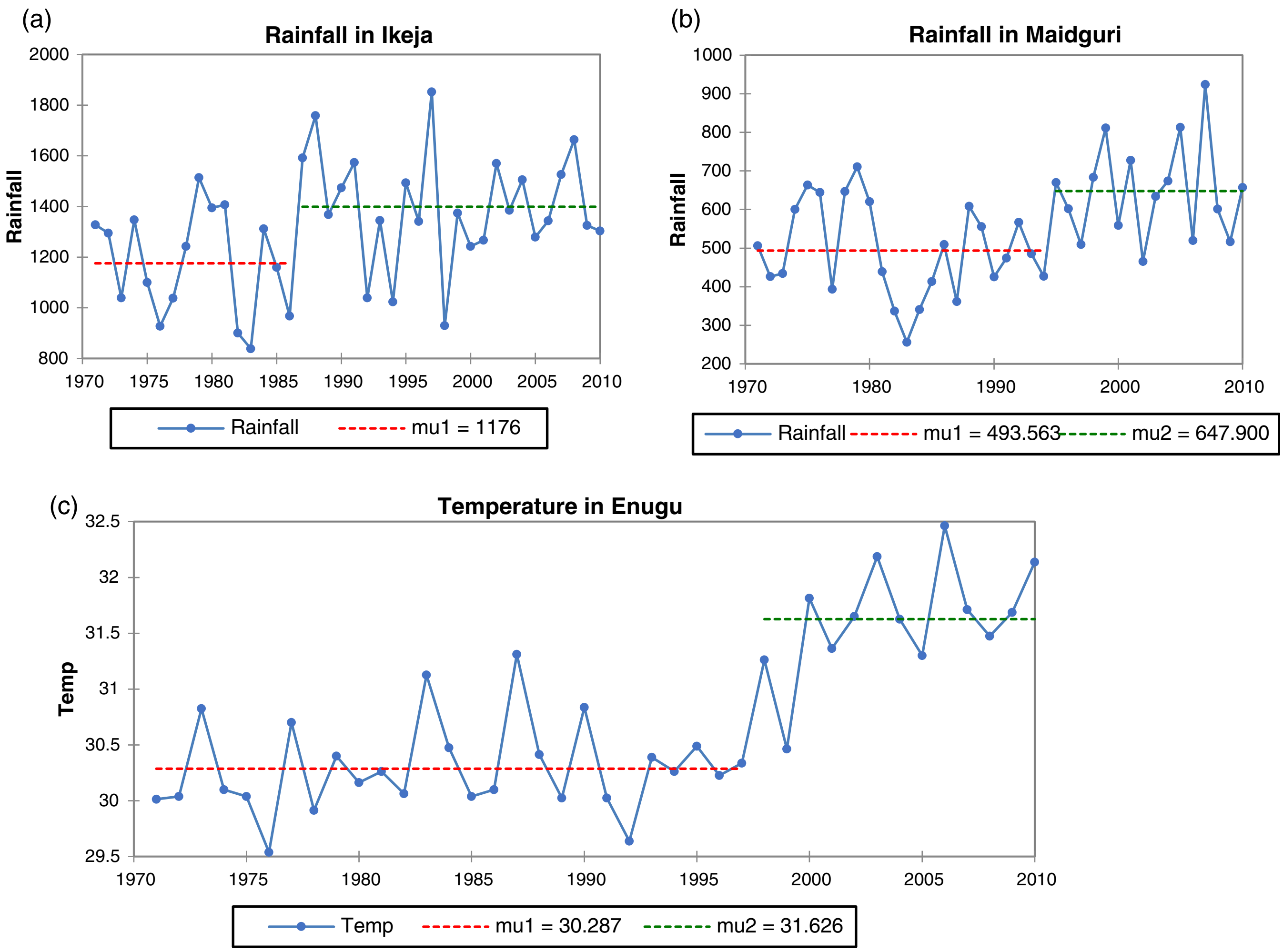


FIGURE 4 Rice yield trends for the six locations from 1971 to 2010 using time series analysis

The trend of Ilorin's variation weather is as presented in Figures 2 and 3. Temperature and rainfall trends were statistically nonsignificant at 15.1 and 0.3% respectively. Rice yield with rainfall and temperature were also statistically nonsignificant with linear increasing trends 0.3 and 11.1% respectively (Figure 4). This clearly demonstrated that temperature not rainfall affected rice yield in Ilorin along with other factors but not limited to soil type and fertility, soil moisture retention capacity, cultural practices, wind speed, and cultivar varieties grown in such region as reported by Poudel and Kotani (2013) in their studies. They reported that the described scenario exists in mild to moderately dry regions like Guinea and Sahel savannah which is a common feature in Nepal, the same agro-ecological region where Ilorin is located in Nigeria thus confirming the findings of this study.

The trends in rainfall, temperature, and rice yield pattern from 1970 through 2010 in Kaduna, a city in the north-central region of Nigeria is as shown in Figures 2–4 respectively. A statistically nonsignificant decrease of 15.9% was observed in the rainfall pattern while 2.1% linear increase was recorded for temperature for the same period of interest. Rice yield variation was weather-dependent as a 14.5% linear decrease was observed when compared with rainfall but 5.6% linear increase was observed when compared with temperature from 1970 through 2010 respectively. This decreasing trend in annual rainfall is a serious threat to rice yields in Kaduna as Nyang'au *et al* (2013)) reported that droughts have resulted into a total drop in the quantity and quality of rice grown. Das *et al* (2014) and FAO (2012) supported this in their respective studies on the threat of dwindling water supply to yields and seed abortion. Kaduna experienced the highest and lowest average rainfall of 1,356.3 mm in 1974 and 788 mm in 2008 in the last four decades (Figure 2). In order to make up for the rainfall shortfall for increased food production, artificial water application such as irrigation would be required to get water to rice farms in Kaduna state in order to minimize the threats of the future shortage of rainfall on rice yields across the state. Bouman (2009) underscored the importance of irrigation to global food survival and this is critical to have any realistic chance of reducing the impacts of food and water scarcity which is impending due to burgeoning population (IPCC 2007). Information on the trend analysis of temperature, rainfall, and rice yield in Maiduguri in the northeastern part of Nigeria in the last four decades (1970–2010) were as presented in Figures 2–4 respectively. A statistically nonsignificant linear variance of 8.3% was observed in temperature and also a 16.2% linear variation observed in rainfall between 1970 and 2010 respectively. As for rice yield, increasing linear variance of 6 and 13.1% were recorded in temperature and rainfall for the same period respectively. Deo (2011) and Lobell *et al* (2007)) reported that the impact of precipitation is very minimal and sometimes insignificant but when compared with the temperature in the northern part of Nigeria and especially Maiduguri, temperature had a great impact on rice yields than rainfall. Research had shown that the tonnage of rice yield is a function of rainfall variation in Maiduguri. Farmers at the onset of the season waiting for the rain to come which sparsely affects the soil. The inception of rainfall marks the beginning of farming activities in the area. Any year there is a delay in rainfall, the farming activities are also delayed. This could result in a reduction in the quantity of rice planted and invariably affects annual tonnage of rice yield. Hence, serious delay in the farming schedule shortens the farming period and reduces crop yield. The fundamental problem that could upshot from this serious delay in rainfall is drought (World Meteorological Organization 2007; Weerakoon Sheshu 2008; Patra *et al* 2012). The effect of this increase will be significant on rice yield in Maiduguri since Maiduguri depends majorly on rain-fed irrigation for rice production since soil temperature do increase the rate of seed abortion. Fricker *et al* (2013) recommended some climate prediction tools to enable farmers to embark on proper planning and optimally schedule irrigation for improved yield, that way, endless waiting for sparse rainfall which in most cases is insufficient to last an entire growing season and by extension increase food costs would be averted. This was supported by Lobell *et al* (2008) in their studies as one major adaptation strategy for coping with climate change especially if the first sustainable development goal of ending hunger is to be achieved by the year 2030.

3.2 | Summary statistics of rice yield and climatic factors

Table 1 shows the trend analysis for the two climatic variables, rainfall, temperature (maximum, and minimum) and rice yield on annual basis for the six locations considered in the study. Rice yield was significant at $\alpha = .001$ in all the locations (Ikeja, Ilorin, Calabar, Enugu, Kaduna, and Maiduguri) with a value of 7.35 while maximum temperature (T_{max}) was significant only at Ikeja, Calabar, and Enugu with values 4.85, 3.75, and 4.81 respectively. Generally, low significance was observed for rainfall in all the locations even in predominantly tropical rainfall zones where cities such as Calabar, Enugu, and Ikeja

TABLE 2 Correlation (R^2) values between rainfall and temperature and rice yield in each of the six locations

S. No.	Locations	Rainfall vs. yield	Temperature vs. yield
1	Calabar	0.46	0.66
2	Enugu	0.59	0.60
3	Ikeja	0.57	0.68
4	Ilorin	0.47	0.71
5	Kaduna	0.48	0.77
6	Maiduguri	0.44	0.80

TABLE 1 Trend test for climatic variables and rice yield on annual basis for the six locations considered

Time series	Ikeja		Calabar		Enugu		Ilorin		Kaduna		Maiduguri	
	Test *Z*	*Q*	Test *Z*	*Q*	Test *Z*	*Q*	Test *Z*	*Q*	Test *Z*	*Q*	Test *Z*	*Q*
Rice yield	7.35**	0.066	7.35**	0.066	7.35**	0.063	7.35**	0.052	7.35**	0.052	7.35**	0.063
Rainfall	1.83***	6.479	1.53	6.884	0.62	2.000	0.80	2.799	−2.41+	−4.706	2.53+	4.998
Max. temp.	4.85**	0.039	3.75**	0.043	4.81**	0.043	2.14+	0.014	1.93***	0.016	1.42	0.015
Min. temp.	0.85	0.020	−2.81*	−0.049	−2.40	−0.049	−2.07+	−0.036	2.98*	0.045	−3.23*	−0.072

*Trend is significant at $\alpha = .01$.
**Trend is significant at $\alpha = .001$.
***Trend is significant at $\alpha = .1$.
+Trend is significant at $\alpha = .05$.

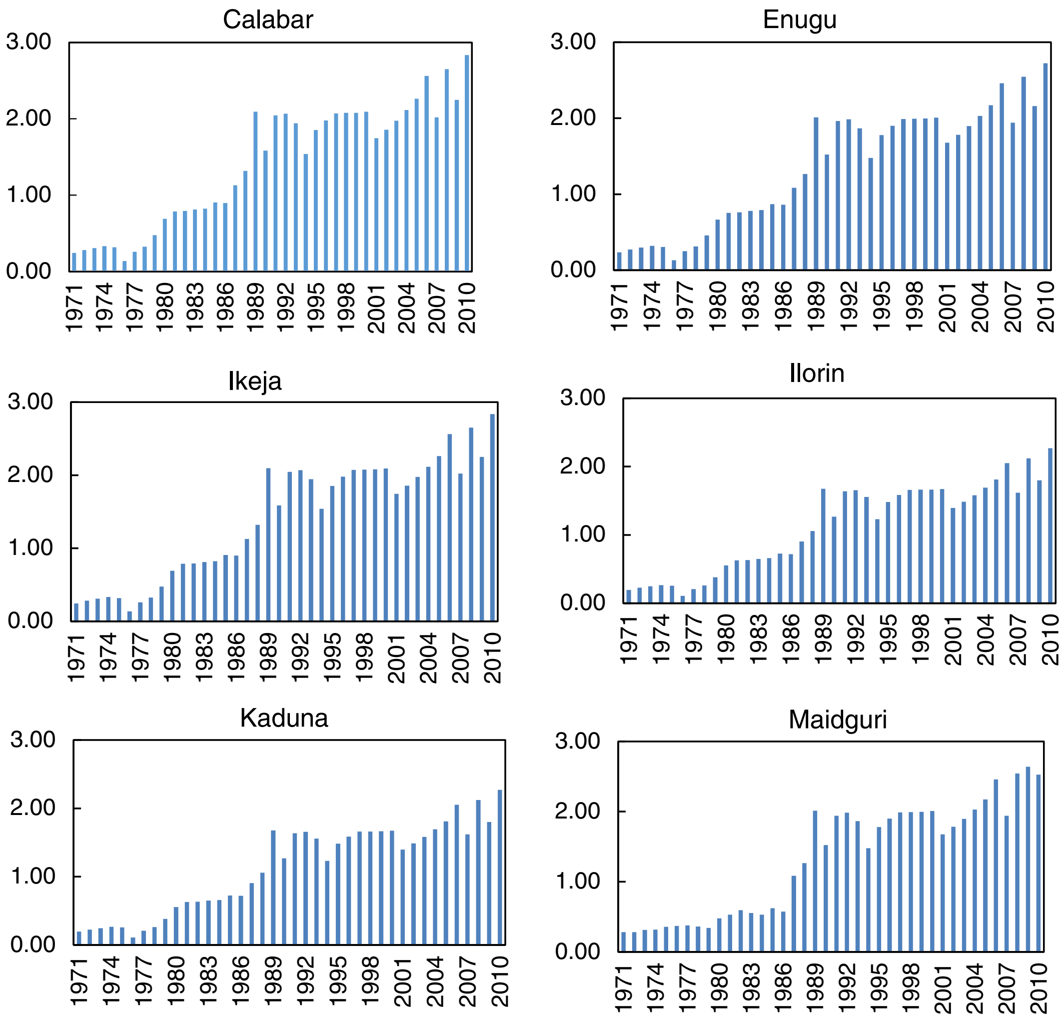


FIGURE 5 spatial analysis of rainfall distribution pattern across the six locations in Nigeria

were located. Table 2 shows the correlation (R^2) values between rainfall and temperature and rice yield in each of the six locations. An increasing trend high correlation values were recorded between temperature and yield with the lowest value of 66% recorded in Calabar, 68%, in Ikeja, and 80% for Maiduguri. As for the correlation between rainfall and yield, a generally reducing trend was observed from south to the north of the country. Calabar recorded 46%, Ilorin, 47% while Kaduna, 48%. These trends corroborated the spatial analyses of temperature and rainfall across as reported in Figures 5 and 6 which further justified the diverse influences of temperature and rainfall on rice yields from each of the regions in Nigeria. Matsumoto *et al* (2014)) reported a strong correlation between water and upland rice yield during their studies in a research institute in Namulonge, Uganda although under a controlled environment. Table 3 shows the results of the homogeneity tests conducted on the two climatic variables of rainfall and temperature using Pettitt's and Buishand's tests. Annual rainfall was heterogeneous in Ikeja and Maiduguri but homogenous in the remaining four locations for the Pettitt classification. Buishand's test also had the same locations as heterogeneous however with the inclusion of Kaduna. For annual temperature, Kaduna and Maiduguri were homogenous while all the other states were heterogeneous according to the Pettitt classification. Ilorin and Kaduna were homogenous when the Buishand's test was used. The most probable year of change for each of the states was also shown in Table 3. Both tests result converge that mean rainfall changed in Ikeja (Figure 7a) in 1986 and Maiduguri in the year 1994 (Figure 7b) while temperature changed in 1997 for Enugu (Figure 7c).

3.3 | Spatial analysis of rainfall and temperature within the six locations in Nigeria

Spatial distribution of annual rainfall and maximum temperature were shown in Figures 5 and 6 respectively. Rainfall values for freshwater swamp ranged from about

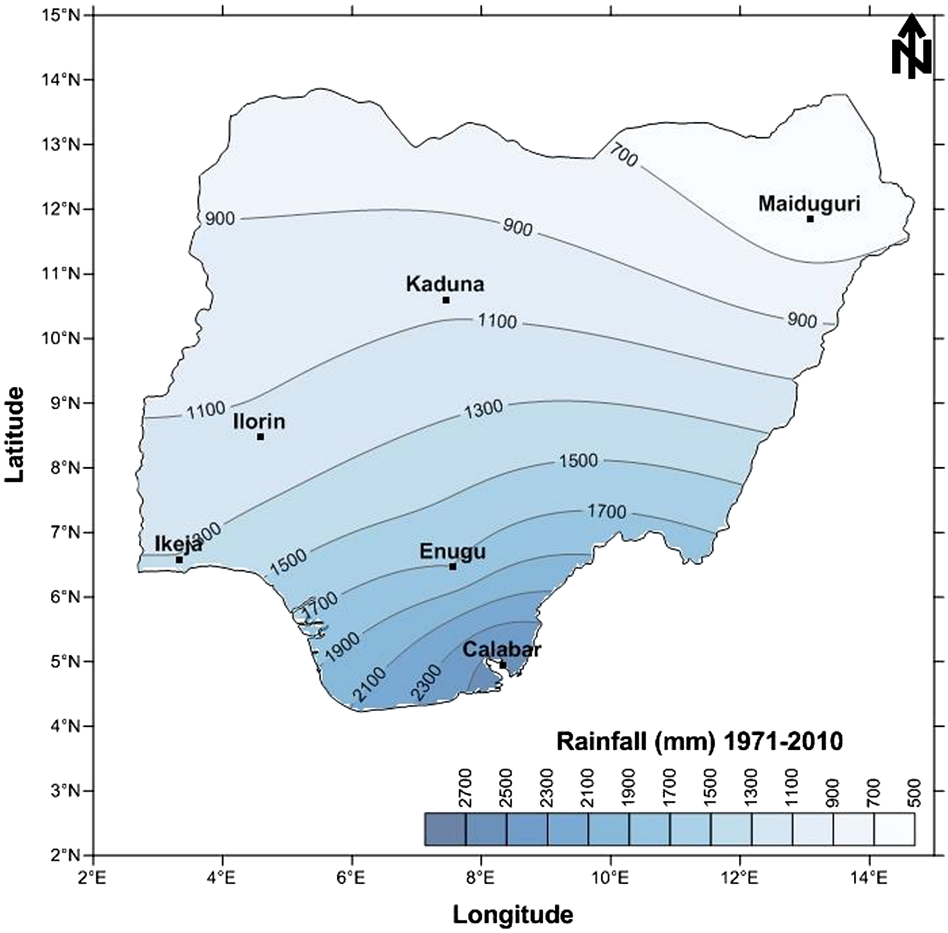


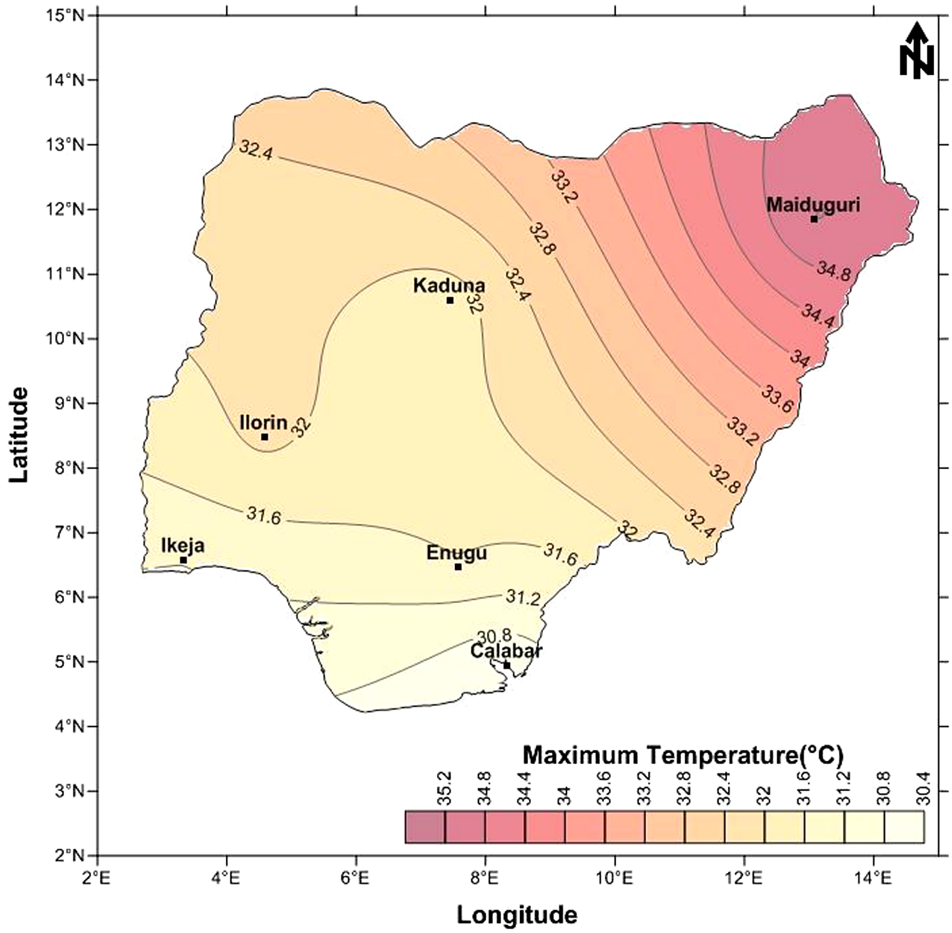
FIGURE 6 Spatial analysis of temperature distribution pattern across the six locations in Nigeria

TABLE 3 Most probable year of shift of mean by Pettitt's test and Buishand's test

	Pettitt's test			Buishand's test		
City	*K* value	Year	Hypothesis	*Q* value	Year	Hypothesis
Rainfall						
Calabar	139.000	1993	H_0	6.616	1994	H_0
Enugu	127.000	1989	H_0	5.944	1989	H_0
Ikeja	202.000	1986	H_a	9.061	1986	H_a
Ilorin	95.000	1993	H_0	3.399	2003	H_0
Kaduna	190.000	1982	H_0	7.830	1982	H_a
Maidguri	244.000	1994	H_a	10.493	1994	H_a
Temperature						
Calabar	265.000	1981	H_a	13.445	1979	H_a
Enugu	333.000	1997	H_a	15.484	1997	H_a
Ikeja	301.000	1986	H_a	12.912	1980	H_a
Ilorin	232.000	1982	H_a	10.879	1982	H_0
Kaduna	113.000	1992	H_0	3.362	1975	H_0
Maidguri	161.000	1980	H_0	8.181	1980	H_a

1,590 to 2,710 mm·year^{-1} which decreased with increasing latitude. Its value ranged from about 400 mm·year^{-1} around the Lake Chad in the northeast corner to over 2,500 mm·year^{-1} in the south around the Niger Delta area of Nigeria. This agreed with Oguntunde *et al* (2011)) who in similar studies reported that rainfall varied mostly

FIGURE 7 Time of change (year) in (a) rainfall series for Ikeja, (b) rainfall series in Maidguri and c. temperature series in Enugu (*mu*1 and *mu*2 represents mean before and after the year of change)



in the north with values ranging from 117 to 640 mm·year^{-1}. Comparing the results to the findings of Liu *et al* (2008) in the Yellow River Basin of China, the relationship between quantity of rainfall and latitude yielded a negative linear correlation suggesting that precipitation possesses the latitudinal zonality, which implies that rainfall decreases with increasing latitude away from the Atlantic Ocean and in line with reducing vegetal cover. A similar explanation could be offered for the GIS interpretation of the data showed that the mangrove savannah (Calabar) experienced the highest amount of rainfall over the course of the last four decades while Sahel savannah (Maiduguri) was the driest zone over the course of the last four decades. The findings here revealed that rainfall had more effect on rice yields in the Sudan-Sahel and Sahel ecological zones than in the rainforest and mangrove ecological zones. The fact that Calabar had over 2,300 mm value of rainfall over the course of the last four decades did resulted in high yield in the zone. Considering the spatial temperature analysis, it was observed that the mangrove savannah (Calabar) experienced the least maximum temperature which ranged between 30.4 and 30.8°C while Sahel savannah (Maiduguri) experienced the highest maximum temperature which ranged between 34.8 and 35.2°C in the last four decades respectively. From this study, it was discovered that rainfall had significant effects on rice yields than temperature in Calabar. The same influence was observed and reported in Enugu and Ikeja, though the trends decreased marginally. In Ilorin, temperature had significant effects on rice yields than the rainfall. The same trend but in increasing proportion played out in Maiduguri and Kaduna respectively. Maiduguri is one of the hottest cities in Nigeria, the high temperature did not result in high rice yields as Nyang'au *et al* (2013) reported that increase in both maximum and minimum temperature led to a decrease in Basmati 370 grain yields planted under system of rice intensification in *Mwea* irrigation scheme in Kenya.

4 | CONCLUSIONS

Climate variability in Nigeria has been recognized as major threats to food security especially rice production. The overall past trends (1971–2010) of rainfall scenarios showed increasing trends for Enugu (1.4%), Ilorin (0.3%), Calabar (7%), Ikeja (11.3%), and Maiduguri (16.2%) but a decreasing trend was observed for Kaduna (15.9%).

Similarly, the overall temperature scenario showed increasing trends for Calabar (44.7%), Enugu (53.8%), Ilorin (15.1%), Ikeja (47.9%), Kaduna (2.1%), and Maiduguri (8.3%) which would be a boost to future rice yield in these cities.

It was established that high rainfall experienced in Calabar and Enugu did not translate to high rice yield while high temperature experienced in Kaduna and Maiduguri also did not result in increased rice yield production. Development of water resources efficiently for optimal rice production is inevitable in order to supplement irrigation in areas of projected shortfall especially in Kaduna and Maiduguri and evolving adaptation strategies to accommodate changes in weather patterns for ensuring a continued increase in rice yield in order to match burgeoning population are suggested. Finally, investigation of other parameters such soils characteristics and tolerance as well as plants' ability to thrive in each of those regions are recommended for further studies.

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