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Research Article

Rainfall Variability and its Impact on Crop Production in Niger State, Nigeria

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Abstract

The net potential effect of severe changes in rainfall pattern disrupts crop production leading to food insecurity, loss of jobs, and poverty. Crop production in Niger State is predominantly rain-fed, thus, exposing this major livelihood activity to the variability of rainfall. The study examined the impact of rainfall variability and its consequences on crop production. This is to integrate climate change adaptation options into agricultural activities. Strategies for climate change adaptation options in the study area have often been made without experimental foundations placed on the level of rainfall variability and its implications on crop production. To achieve this, a climatic index (CI) analysis of rainfall was employed to ascertain the level of rainfall extremes occurrences resulting from rainfall variability using standard deviation as a tool for rationalization. The study also used crop yield to test the relationship between the yield and rainfall characteristics for thirty years (1990-2019). Rainfall data and crop yield (soybean, maize, and sorghum) were collected. The data were analysed using statistical and climatic index analyses. The results show that there were various degrees of rainfall extremes that occurred (from mild to severe dry spell and mild to severe wet spell). Moreover, the regression analysis shows that F-values > p-values. Consequently, the occurrences of severe wet spells and mild to severe dry spells impacted negatively on crop production, which undermines food security. Based on the findings, recommendations were made to mainstream the adaptation options.

Keywords: *Crop yield, Climatic Index, Rainfall variability, El Niño, La Niña*

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Introduction

Inter-annual rainfall variations in Nigeria are highly linked to the El Niño Southern Oscillation (ENSO), with more rain and flooding during El Niño and droughts in La Niña years, both having severe impacts on human habitation and Agriculture. Agriculture plays important roles in promoting economic growth and enhancing food security (World Bank, 2008). Agriculture can be a source of economic growth at the local and national level. It is also a provider of investment opportunities for the private sector and agriculture-related industries (Ellis and Freeman 2004). The agricultural sector accounts for a large share of national income, employment, and foreign trade in Africa. Despite the role of

agriculture in Africa, it has not helped significantly to reduce poverty or to alleviate hunger and malnutrition (Dercon and Gollin, 2014). Therefore, to achieve higher rates of agricultural growth, crop productivity needs to improve significantly (World Bank, 2008). However, scientific literature has been established empirically that in spite of recent technological advances, farmers in Africa still depend heavily on rain-fed agriculture (Ndamani and Watanabe, 2015; Tiarniyu *et al.*, 2015; Ezihe *et al.*, 2017; Eze *et al.*, 2018a). Thus, environmental factors, particularly, the climate is still the most important variable in crop production. Climate affects agriculture and determines the adequacy of food supplies in two major ways. One is through

climatic hazards (drought, flood) to crops and the other is through the control exercised by the environment on the type of crops feasible or viable in a given area (Shi *et al.*, 2013; Eze, 2018). Thus, climatic parameters (rainfall, temperature, relative humidity) have an influence on various stages of agricultural production chain including land preparation, sowing, crop growth and management, harvesting, storage, transport, and marketing (Ayinde *et al.*, 2011; Popova *et al.*, 2014). Rainfall is undoubtedly one of the most important climatic variables. It has far-reaching influences in agricultural production. The crucial role rainfall plays in crop production includes the supply of moisture to the soil to activate plant growth, the replenishment of water in rivers to make irrigation possible through seepage and percolation, and building of underground water resources which are later tapped by wells in drier areas (Tiamiyu *et al.*, 2018). The amount, incidences, variations and reliability of each of these roles rainfall plays go a long way towards explaining the differences in cropping patterns and livestock management practices in various ecological zones of Nigeria (Ayinde *et al.*, 2011). Jones and Thornton (2003) argue that climate change has a direct effect on crop yields and farm management and that variation in climatic parameters will have subsequent effects on the implementation of new economic policies and adaptation strategies. The most direct impact of climate change in Africa stems from growing water shortages or drought, leading to an increasing dependence on imported foodstuffs (Boubacar, 2010; Shittu *et al.*, 2017; Eze, 2018). Moreover, the changing climatic conditions are likely to impose additional pressure on water availability, reducing the length of the growing season and forcing large regions of marginal agriculture out of production (IPCC, 2007). Moreover, there will be a 50% reduction in yields by 2020 and a 90% reduction in crop net revenues by 2100 in areas that are already classified as marginal in Africa (IPCC, 2007).

Many scholars have carried out research on the impacts of drought on agriculture in various parts of the world (Gadgil *et al.*, 2002; Popova *et al.*, 2014; Van der Pol *et al.*, 2015; Tiamiyu *et al.*, 2015; Jin *et al.*, 2016; Kazemzadeh and Malekian, 2016; Ezihe *et al.*, 2017; Shittu *et al.*, 2017; Eze,

2018). Most of the studies concentrated on the impact of rainfall variation on agriculture, health, water resources, causes and effects on the land, households and the extent of drought occurrences. However, none of the above studies focused on the extent of deviation of rainfall from normal and its implication on agriculture. Therefore, the knowledge of the relationship between agriculture and rainfall facilitates an understanding of the various interactions and inter-relations required in areas of agricultural management and production (Shi *et al.*, 2013; Eze *et al.*, 2018a). This is to explain the variations in the yield and possibly formulate a predictive model for forecasting the future yield of the crop given certain environmental parameters (Shi *et al.*, 2013; Choudhury and Jones, 2014). The decline in the yield and production of Soybean in Nigeria has been a major problem of concern in recent years (Khojelyet al, 2018). Despite huge sums of money being spent on fertilizer, tractors and improved high-yielding grain hybrids, the problem still lingers on (Idoko and Sabo, 2014). This is because the real issue of environmental constraints against sustained agricultural production has not been adequately addressed. Moreover, Oladipo (1993) argues that the degree of impact of a particular drought on the environment and the extent to which it may affect agricultural production depend on the length of the period of the drought event. Moreover, Eze (2018) stated that there is a need for appropriate techniques to be used to determine drought occurrence in order to reduce its impact on the environment. Libanda *et al.* (2019) also argue that understanding the patterns of drought is essential because it informs decision-making processes for possible adaptive measures. Against this background, the study fills the gap by assessing the extent of deviation of rainfall from the normal and its implications on agriculture in Niger State, Nigeria, using climatic Index (CI). This has much to offer in terms of farm-level policy decision making on Agricultural production.

Materials and Methods

Rainfall data were obtained from the Nigerian Meteorological Agency, Abuja and National Cereals Research Institute, Badeggi for 30 years (1990-2019). Also, data on crop production (soybean, maize and sorghum) were collected

from the Niger State Agricultural Development Programme (NADP) for thirty years (1990-2019). Only 3 crops (soybean, maize and sorghum) were selected due to unavailability of complete data on other crops cultivated in the study area. Data collected were analysed using mean, standard deviation, regression analysis and climatic index. The analyses were carried out using Microsoft Excel. Rainfall data were analysed using the Climatic Index (CI). This index represents a quantitative expression of rainfall characteristics (Near-normal, Mild dry spell, Mild flood, Moderate dry spell, Moderate flood, Severe dry spell, and Severe flood)(Table 1) using standard deviation as a tool for rationalization. The climatic index can be expressed as shown in equation 1:

$$CI = \frac{Xi - \bar{X}}{\sigma} \dots\dots\dots 1$$

Where Xi = Total rainfall of a particular year or period; $\bar{X}$ = mean annual rainfall for the station for the period under study; σ = standard deviation

When the value of the climatic index (CI) is in the range as shown in Table 1, it indicates near-normal, mild, moderate and severe dry spell or flood. The regression analysis was employed to determine the degree of relationship between rainfall characteristics and crop production. Thus, the computation was carried out using linear regression as shown below;

$$Y = a + bX \dots\dots\dots 2$$

Where **X** is the independent variable (rainfall amount) and **Y** is the dependent variable (crop production). The slope of the line is **b** and **a** is the intercept (the value of y when x = 0).

To establish a conclusion, the hypothesis is posited, thus:

H₀: There is no significant relationship between rainfall characteristics and crop yield, at 0.05 significant levels

H₁: There is a significant relationship between rainfall characteristics and crop yield at 0.05 significant levels

Results and Discussion

The rainfall data collected for the period under study (1990-2019), indicate that the total annual

rainfall in the study area varies from year to year and from place to place resulting to near-normal, mild dry spell to severe dry spell and mild flood to severe flood (Table 2). For 30 years studied, the area was free from dry spell only in 1993, 1996, 1999, 2001, 2003, 2007, 2010, 2011, 2014 and 2018. Thus, other years experienced dry spell and severe flood either in some parts of the study area or in all the parts of the study area. This result is also in line with Anyadike (1993), who studied seasonal and annual rainfall variation over Nigeria for a 72 year period (1916-1987).

Table 3 shows the crop yield (soybean, maize, and sorghum) for 30 years (1990-2019). The results indicate that crop yield varies from year to year and from place to place. The highest soybean yield of 43.7 (000 metric tons) was recorded in the year 2013 with the lowest yield in 2015. The highest maize yield of 42.7 was recorded in 1992, the lowest yield of 7.2 (000 metric tons) was recorded in the year 2002 (Table 3). Moreover, the highest sorghum yield of 40.2 (000 metric tons) was recorded in 2010 and the lowest yield of 10.3 (000 metric tons) was recorded in the year 2015. The result also shows that in the last 30 years, the southern part (Badeggi and its environs) had the highest mean yield of 28.7 (000 metric tons). The lowest mean yield was recorded in the north-western part (Kainji and its environs) with 25.1 (000 metric tons).

Moreover, the results of the regression analysis on the crop yield and rainfall characteristics in the study area show that in Badeggi and its environs, the regression model yielded coefficient of determination of 0.29, an F-value of 11.45, and a p-value of 0.002. In Kainji and its environment, the model yielded a coefficient of determination of 0.35, an F-value of 14.96, and a p-value of 0.001. Also in Minna and its environs, the result of the regression model yielded a coefficient of determination of 0.32, an F-value of 13.20, and a p-value of 0.001. Since F-values > p-values in the 3 stations studied, H₀ is rejected. Thus, there is a significant relationship between rainfall characteristics and crop yield in the study area at 0.05 significant levels. Moreover, in Badeggi, the results indicate that a unit variation in rainfall results in 1.0, 0.9, 0.9, 1.5, 0.9, 0.5, 0.1, 1.4, 0.6, 1.4, 0.5, 0.2, 1.8 and 1.5 unit increase in crop

yield in 1992, 1993, 1998, 1999, 2000, 2003, 2008, 2009, 2010, 2011, 2014, 2015 and 2016, whereas, in other years, a unit variation in rainfall resulted in -0.1, -1.1, -1.2, -1.0, -1.2, -1.1, -0.2, -0.8, -0.9, -0.5, -0.6, -0.10, -1.1, -1.1, -0.7, and -0.8 unit decrease in crop yield in Badeggi (Table 4). Similar cases were recorded in Kainji and Minna stations (Table 4). Thus, some of the dry spells and severe floods that occurred during the period of the study had serious negative consequences on crop yields and other vital agricultural support systems (such as rivers, wetlands and rangelands) that provided means of livelihood to farmers. Abaje *et al.* (2013) argue that incidences of dry spell result in a decrease in farm output and weight loss in livestock. In addition, total losses in farm output, particularly in crop yield usually occur, during severe dry spell and flood. Severe dry spell and flood also results in increased mortality rates of farm animals.

Moreover, the result of the regression analysis on crop yield and rainfall characteristics in the study area shows a positive correlation. The result also shows that 29%, 35%, and 32% variations in soybean, maize and sorghum yields respectively are determined by variations in rainfall. This implies that 71%, 65% and 68% of the variations in soybean, maize and sorghum yields are due to other causes or reasons, such as soil type, application of fertilizers, farming methods etc. However, it was observed that the crop yields were mostly at best in those years characterised with Near-Normal rainfall and mild flood. On the other hand, the periods of dry spell and severe flood largely affected the crop yields. Exceptional cases were observed in Kainji station in the year 1997 and 2019 where production was very low during near-normal rainfall. This was attributed to pest and diseases attack. However, in Badeggi station (1997, 2008) and Kainji station (2012), there were records of high crop yield during mild dry spells. This was attributed to the availability of irrigation facilities at the time, which supplemented the shortfall in rainfall and also farmers' access to improved crop varieties (drought resistant and early maturing varieties), particularly in the year 2008. This result is validated by study conducted by Rangaswamy (2010) who used regression model and found a moderate correlation between rainfall variability

and yield of maize and rice. In addition, Ogbuene (2010) and Olanrewaju (2010) also found a correlation between rainfall and yield of rice which also corroborates with the present study.

However, Eze (2018) states that the most immediate consequence of dry spell is a reduction in farm output, due to inadequate rainfall. Therefore, insufficient rainfall causes poor pasture growth and may also lead to a decline in fodder supplies from crop residues. Furthermore, farmers in dry spell affected areas are usually faced with poor harvests that are too small to feed their families (Tiamiyu *et al.*, 2018). Where crops are badly tormented by dry spell, pasture production additionally seems to be reduced though output from natural pastures tends to be less liable to dry spell than crop production (Eze *et al.*, 2018a). Consequently, poor regions of the world, such as Africa, which depends on agriculture, have been described as one of the most vulnerable regions to the impacts of climatic and environmental changes (Vogel, 2005). The extent of rainfall deviation from its normal occurrences, therefore, has great implications for the crop yield and agricultural production in general.

Conclusion

In conclusion, the rainfall variability in Niger State is highly variable in time and space. The occurrences of dry spells and extreme floods have impacted negatively on agricultural production, particularly, crop yield in the study area. However, the crop yield and rainfall amount in the study area shows a generally weak positive correlation. Also, the study observed that the crop yield was mostly at best in those years characterised with Near-Normal rainfall and mild flood. On the other hand, the period of mild, moderate and severe dry spell and severe flood spell largely affected the crop yield. The extent of rainfall deviation from its normal occurrences, therefore, has great implications for the crop yield and agricultural production in general. Finally, the study has effectively used the climatic index to determine the extent of variation of rainfall from the normal and its implication on agriculture, particularly, crop yield. The result, therefore, has much to offer in terms of farm-level policy decision making on Agricultural production. The results can be used for the reduction of the

potential damage of climate variability and crop production, by integrating climate smart agricultural practices in crop production.

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Table 1: Classes of Climatic Index values

Index	Characteristics of Rainfall
0.40 to -0.40	Near-normal
-0.41 to -0.80	Mild dry spell
0.41 to 0.80	Mild flood
-0.81 to -1.20	Moderate dry spell
0.81 to 1.20	Moderate flood
< - 1.20	Severe dry spell
> 1.20	Severe flood

Source: Computed by the author

Table 2: Total Rainfall amount and Climatic Index (CI) and its Characteristics in the Study Area

Year	Badeggi Rainfall (mm)	CI	Rainfall Character	Kainji Rainfall l (mm)	CI	Rainfall Character	Minna Rainfall (mm)	CI	Rainfall Character
1990	1170.9	-0.17	N-normal	1059	-0.54	Mild-dry	1302	0.54	Mild-wet
1991	1152.9	-0.29	N-normal	1179	0.32	N-normal	1181.5	-0.53	Mild- dry
1992	1239.26	0.27	N-normal	1181	0.34	N-normal	1109.5	-1.17	Mod-dry
1993	1394.5	1.26	Severe-wet	1285	1.08	Mod-wet	1316.7	0.67	Mild-wet
1994	968.2	-1.47	Severe-dry	753	-2.72	Severe- dry	1241.9	0.00	N-normal
1995	1407.1	1.34	Severe-wet	1016	-0.84	Mod- dry	1069.4	-1.53	Severe- dry
1996	1193.7	-0.03	N-normal	1228	0.67	Mild-flood	1482.3	2.14	Severe-wet
1997	1123.8	-0.47	Mild- dry	1098	-0.26	N-normal	1279.3	0.33	N-normal
1998	1192.7	-0.03	N-normal	823	-2.22	Severe- dry	1274.3	0.29	N-normal
1999	1432.3	1.50	Mild-wet	1117	-0.12	N-normal	1245.1	0.03	N-normal
2000	1030.9	-1.07	Mod- dry	1350	1.54	Severe-wet	1532.7	2.59	Severe-wet
2001	1200.4	0.02	N-normal	1295	1.15	Mod-wet	1249.5	0.07	N-normal
2002	1238.6	0.26	N-normal	975	-1.14	Mod- dry	1274.5	0.29	N-normal
2003	1292.4	0.61	Mild-wet	1267	0.95	Mod-wet	1233	-0.08	N-normal
2004	1051.1	-0.94	Mod- dry	1286	1.09	Mod-wet	1294	0.47	Mild-wet
2005	1088.2	-0.70	Mild- dry	1288	1.10	Mod-wet	1314	0.64	Mild-wet
2006	1181.4	-0.10	N-normal	1121	-0.09	N-normal	1162.5	-0.70	Mild- dry
2007	1207.1	0.06	N-normal	1185	0.36	N-normal	1216.7	-0.22	N-normal
2008	1131.6	-0.42	Mild- dry	1053	-0.58	Mild- dry	1141.9	-0.89	Mod- dry
2009	1296.7	0.63	Mild-wet	1116	-0.13	N-normal	1169.4	-0.64	Mild- dry
2010	1340.4	0.91	Mod-wet	1248	0.81	Mod-wet	1282.3	0.36	N-normal
2011	1523	2.08	Severe-wet	1198	0.46	Mild-wet	1379.3	1.22	Severe-wet
2012	1287.5	0.57	Mild-wet	1023	-0.79	Mild- dry	1254.3	0.11	N-normal
2013	1168.1	-0.19	N-normal	1127	-0.05	N-normal	1145.1	-0.86	Mod- dry
2014	1158.6	-0.25	N-normal	1310	1.26	Severe-wet	1232.7	-0.08	N-normal
2015	899.7	-1.91	Severe-dry	995.7	-0.99	Mod- dry	1049.5	-1.71	Severe- dry
2016	953.4	-1.56	Severe-dry	1075	-0.42	Mild- dry	1074.5	-1.49	Severe- dry
2017	1032.4	-1.06	Mod- dry	1067	-0.48	Mild- dry	1133	-0.97	Mod- dry
2018	1503.1	1.95	Severe-wet	1216	0.59	Mild-wet	1394	1.35	Severe-wet
2019	1073.4	-0.80	Mod- dry	1088	-0.33	N-normal	1214	-0.25	N-normal
Mean	1197.8			1134.1			1241.6		
STD	156.2			139.9			112.5		

Source: Computed by the author:

N-normal = near-normal; mild-wet = mild flood; mild-dry = mild dry spell; mod-flood = moderate flood; mod-dry = moderate dry spell; severe-wet = severe flood; severe-dry = severe dry spell.

Table 3: crop yield s in the Study Area from 1988-2017

Year	Soybean yield in Badeggi & its environs (000 metric tons)	Maize yield in Kainji & its environs (000 metric tons)	Sorghum yield in Minna & its environs (000 metric tons)
1990	36.6	10.1	25.3
1991	35.4	39.1	15.6
1992	29.4	42.7	12.4
1993	26.3	23.6	26.2
1994	9.7	7.2	38.1
1995	27.3	16.8	11.3
1996	37.2	31.8	39.4
1997	39.8	15.4	38.9
1998	37.1	8.9	37.1
1999	26.9	41.7	36.8
2000	12.1	27.9	24.7
2001	33.5	31.5	36.1
2002	28.3	9.8	37.6
2003	33.2	34.5	35.8
2004	15.9	27.5	39.1
2005	16.4	33.8	24.6
2006	41.1	36.7	14.8
2007	34.7	40.1	39.1
2008	39.2	9.1	14.3
2009	36.8	41.8	15.2
2010	29.8	28.3	40.2
2011	35.7	36.9	25.8
2012	33.9	27.4	39.6
2013	43.7	39.7	14.2
2014	40.6	24.1	39.6
2015	8.9	8.2	10.3
2016	9.4	8.9	10.7
2017	12.8	9.6	13.5
2018	33.4	30.2	28.6
2019	16.9	10.6	36.8
Mean	28.7	25.1	27.4

Source: Niger State Agricultural Development Programme

Table 4: Estimated values of crop yield from the regression equation

Years	Estimated Y for Badeggi & its environs	Standard Residuals	Estimated Y for Kainji & its environs	Standard Residuals	Predicted Y for Minna & and its environs	Standard Residuals
1990	27.7	1.0	21.2	-1.1	30.8	-0.6
1991	27.1	0.9	27.5	1.1	24.0	-0.9
1992	30.3	-0.1	27.6	1.5	19.9	-0.8
1993	36.0	-1.1	33.1	-0.9	31.7	-0.6
1994	20.2	-1.2	16.7	-0.9	27.4	1.1
1995	36.5	-1.0	18.9	-0.2	17.6	-0.7
1996	28.6	0.9	30.1	0.2	41.1	-0.2
1997	26.0	1.5	23.2	-0.8	29.5	1.0
1998	28.5	0.9	8.7	0.0	29.2	0.8
1999	37.4	-1.2	24.2	1.7	27.6	1.0
2000	22.5	-1.1	36.5	-0.9	44.0	-2.1
2001	28.8	0.5	33.6	-0.2	27.8	0.9
2002	30.3	-0.2	5.0	0.5	29.3	0.9
2003	32.2	0.1	32.1	0.2	26.9	1.0
2004	23.3	-0.8	33.1	-0.6	30.4	0.9
2005	24.7	-0.9	33.3	0.1	31.5	-0.7
2006	28.1	1.4	24.4	1.2	22.9	-0.9
2007	29.1	0.6	27.8	1.2	26.0	1.4
2008	26.3	1.4	20.8	-1.2	21.7	-0.8
2009	32.4	0.5	24.2	1.7	23.3	-0.9
2010	34.0	-0.5	31.1	-0.3	29.7	1.1
2011	40.8	-0.6	28.5	0.8	35.2	-1.0
2012	32.1	0.2	19.3	0.8	28.1	1.2
2013	27.6	1.8	24.8	1.5	21.9	-0.8
2014	27.3	1.5	34.4	-1.0	26.9	1.4
2015	17.7	-1.0	17.8	-1.0	16.5	-0.7
2016	19.7	-1.1	22.0	-1.3	17.9	-0.8
2017	22.6	-1.1	21.6	-1.2	21.2	-0.8
2018	40.1	-0.7	29.5	0.1	36.1	-0.8
2019	24.1	-0.8	22.7	-1.2	25.8	1.2