Daily extreme rainfall indices and their impact on rice yield in parts of North-central States of Nigeria

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ABSTRACT

Recurrent extreme rainfall events create a severe threat to crop production across the globe. The study assessed daily extreme rainfall indices and their impact on rice yield in parts of North-central States of Nigeria.Thirty (30) years daily rainfall data were obtained from the Climatic Prediction Center Merged Analysis of Precipitation (CMAP) and Rice yield data from the Agricultural Development Project (ADP) Offices of four states and Federal Capital Territory (FCT) in Nigeria. Nine (9) extreme rainfall indices developed by Expert Team on Climate Change Detection and Indices (ETCCDI) under the World Meteorological Organization (WMO) were generated using the RClimDex Software. Mann-Kendall test for trend detection was used to determine a trend in the occurrence of the extreme rainfall indices during the study period. The Spearman Rho Rank Correlation Coefficient obtained indicates a non-significant correlation between Consecutive Dry Day (CDD) and rice yield across the stations at the same time, Consecutive Wet Day (CWD) shows significant negative correlation with Rice yield at (P< 0.01) and (P< 0.05) at Abuja and Ilorin stations respectively. The study revealed that maximum 1-day rainfall (R1D) and maximum 5-day rainfall (R5D) has no significant correlation with rice yield across the stations. Further, the study established that very wet day rainfall (R95T) has more impact on rice yield as it shows significant positive correlation at (P< 0.05) in Lafia while other stations depict positive but non-significant correlation during the study period. Generally, the study shows that optimal growth of rice crop in the study area requires moderate and continuous rainfall. The research also shows that correlation was more pronounced between extreme rainfall indices and rice yield at Minna, Abuja and Lafia stations compared to Lokoja and Ilorin stations during the study period. We recommend that continuous monitoring of rainfall distribution of the study area is essential in putting in place an informed climate change adaptation measures.

***Keywords:** impact, extreme rainfall, indices, rice yield, north central states, Nigeria*

1.0 INTRODUCTION

Intergovernmental Panel on Climate Change IPCC in its fourth assessment report (AR4) indicated with very high confidence (90% probability of being correct) that human activities since the beginning of industrial revolution have caused the planet to warm by about 1°C and future climate change is likely to affect agriculture, increase risk of hunger and water scarcity (IPCC, 2007). It has been acknowledged that climate change and associated extreme weather events have presented more constraints on agriculture production and negatively impacted the agricultural economy in many nations of the world (Piao*et al.*, 2010; Wei *et al.*, 2015). It is also projected that extreme (climatic) events are likely to intensify and become more frequent in several regions worldwide due to climate change (IPCC, 2012). Flood, droughts and heat-waves adversely impact on agricultural production and seriously affect the livelihoods and food security of communities. It is not only the areas that are directly experiencing the extreme events are affected but even those regions in other parts of the world, which may suffer from indirect consequences such as reduced exports of agricultural products and higher food prices (Puma *et al.*, 2015). Increased occurrences of heavy rainfall events have been found in places where total rainfall amounts have decreased. Based on observational and theoretical modelling studies, an increase in the frequencies of heavy rainfall events are likely to have occurred over most land areas within the late 20th century (Bates *et al.*, 2008). Recurrent extreme rainfall events have a devastating impact on rice growth and pose a severe threat to rice yield (Qin *et al.*, 2014). In both the developing and the developed worlds, extreme weather events and climatic anomalies pose a negative impact on crop yield and disease patterns. For instance, droughts that are followed by intensive rains can increase the potential for flooding, thereby creating conditions that favour fungal infestations of leaves, roots and tuber crops (Ajetomobi, 2016).

The world food system is more vulnerable to weather extremes for various reasons, the key one being that crop yield changes have not been keeping up with rising food demand worldwide (Ortiz *et al.*, 2008).; Boyer *et al.*, 2013). Yield growth rates have either collapsed or are stagnating in about 30%, 38% and 39% of the global harvested area for maize, rice and wheat, respectively (Ray *et al.*, 2012). Securing optimised yields in a changing climate requires understanding of the impact of climate extremes on crop yields in the past and present climate (Vogel *et al.* 2019). Understanding the variability of daily extreme rainfall indices and their impacts on rice yield will provide vital information for farmers and decision-makers. It is a fact that significant increases in the occurrence of heavy rainfall and their impact on crop production have been documented by researchers in different agro-ecological zones across Nigeria. However, virtually no research work that has adopted the classification of standardized extreme rainfall indicators by Expert Team on Climate Change Detection and Indices (ETCCDI) under the World Meteorological Organization (WMO) in a crop-rainfall relationship in the study area. Consequently, there is the need to apply the ETCDDI scheme in observing the effects of extreme rainfall events on rice yields in the study area. The objective of this study is to examine the impact of extreme rainfall event on rice yield in the North Central States of Nigeria.

2.0 MATERIALS AND METHODS

2.1 The Study Area

T he study area lies between Latitude 7° 48¹ N and 9° 36¹ N and Longitude 4° 32¹ and 8° 30¹ E (Fig. 1). It covers four states (Niger, Kogi, Nasarawa, Kwara) and the Federal Capital Territory (FCT) in Central Nigeria. The study area is situated within the Guinea Savannah ecological zone of Nigeria. In this zone, the continental Northeast trade wind and Southwest monsoon control the wet and dry period. More often the dry season is from December to March while the raining season is between May to October, with the two seasons regularly separated by somewhat transitional periods in April and November (Olayemi*et al.*, 2014).

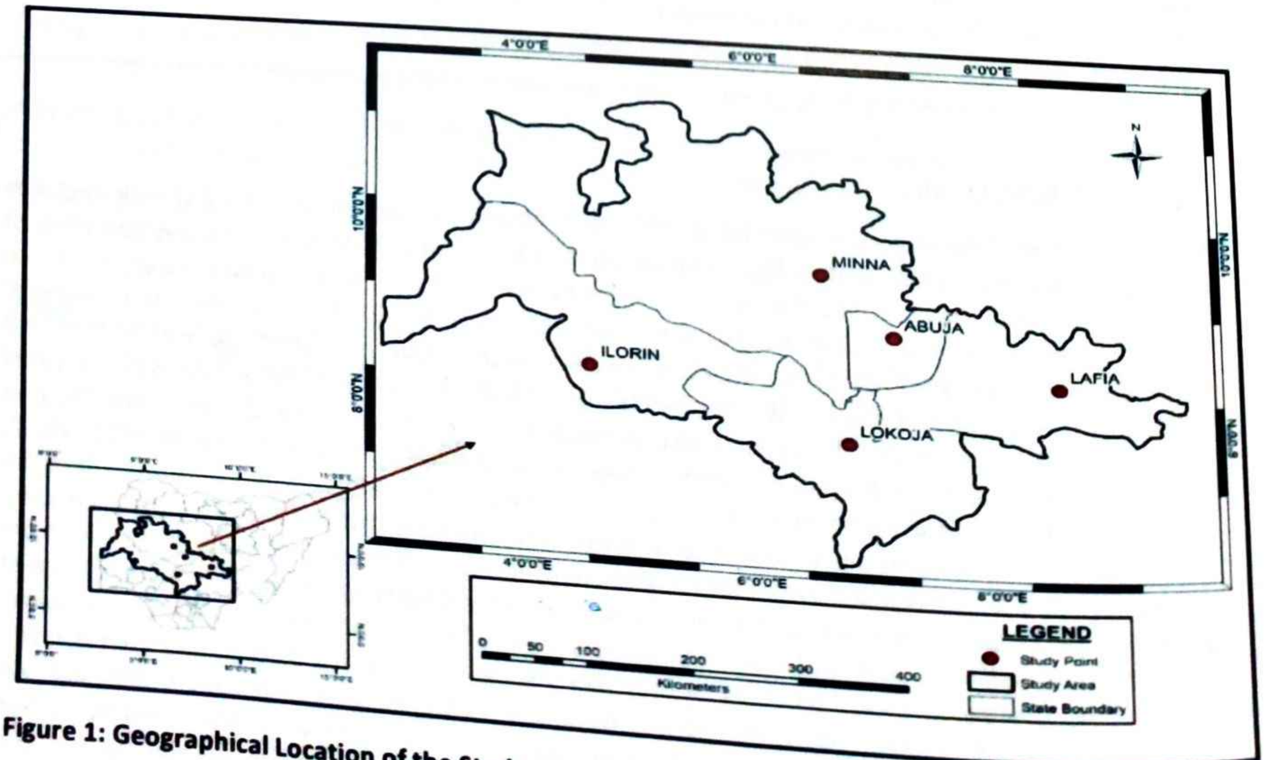

Figure 1: Geographical Location of the Study Area

2.2 Methods of Data Collection

This study collected daily rainfall data for thirty years (1989 to 2018) from Climate Prediction Center Merged Analysis of Precipitation (CMAP) and Rice yield for five stations (Minna, Lokoja, Abuja, Ilorin and Lafia). The spatial distribution and the number of years of data generated are presented in Table 1.

Table 1: Study Location, Coordinate and Number of Years of Data Generated

S/N	State	Weather Station	Coordinate	Duration of Generated Data
1	Niger	Minna	Lat 9^0 36^1 Long 6^0 32^1	1989 to 2018 (30 Years)
2	Kogi	Lokoja	Lat 7^0 48^1 Long 6^0 44^1	1989 to 2018 (30 Years)
3	Kwara	Ilorin	Lat 8^0 30^1 Long 4^0 32^1	1989 to 2018 (30 Years)
4	Nasarawa	Lafia	Lat 8^0 29^1 Long 8^0 30^1	1989 to 2018 (30 Years)
5	FCT	Abuja	Lat 9^0 31^1 Long 7^0 29^1	1989 to 2018 (30 Years)

2.3 Methods of Data Analysis

To improve a constant perspective on observed climate change and weather extremes, the Expert Team on Climate Change Detection and Indices (ETCCDI) has defined a core set of descriptive indices of extreme. The indices describe special characteristics of extremes including amplitude, frequency and persistence (Li *et al.*, (2017); Wei *et al.*, 2015; Azizzadeh and Jovan, 2018; Ibrahim, Emigilati, Kaoje&Aminu, 2020). The core set includes 27 extreme indices for precipitation and temperature. In this paper, nine (9) indices on extreme rainfall used are represented in Table 2. The RClimDex software was used to extract the selected extreme indices. RClimDex program operates in R software.

Table 2: ETCCDI rainfall-related extreme indices adapted for this study

Index	Description	Definition	Unit
CDD	Consecutive Dry Days	Maximum number of consecutive dry days	Day
CWD	Consecutive Wet Days	Maximum rainfall on wet days	Day
SDII	Simple Daily Intensity Index	Average rainfall on wet days	mm/day
R1D	Maximum 1-day rainfall	Annual maximum 1-day rainfall	Mm
R5D	Maximum 5-day rainfall	Annual maximum consecutive 5-day rainfall	Mm
R95T	Very wet day rainfall	Fraction of annual rainfall due to event s ≥95th percentile	%
R10	Number of heavy rainfall days	Number of rainfall days ≥10mm/day	day
R20	Number of heavier rainfall days	Number of rainfall days ≥20mm/day	day
R50	Number of rainstorm days	Number of days rainfall ≥50mm/day	day

To examine trends in extreme rainfall indices, we used the Mann-Kendall test with significance levels at α = 0.001, 0.01, 0.05 and 0.1 taken as thresholds to classify the significance of upward and downward trend. The equation (Mann-Kendall statistic) S is given as:

$$S = \sum_{k=1}^{n-1} \sum_{i=k+1}^{n-1} \text{sgn}(x_j - x_k) \quad (1)$$

x_j is a time series ranked from i = 1,2,.........n-1 and x_j, ranked from j = i +1,2,..........n.

Where

$$Sgn\,(x_j - x_k) = \begin{cases} +1\ if\ (x_j - x_k) > 0 \\ 0\ if\ (x_j - x_k) = 0 \\ -1\ if\ (x_j - x_k) < 0 \end{cases} \quad (2)$$

To calculate the variance of S. VAR(S) the following equation is use;

$$VAR(S) = \frac{n(n-1)(2n-5) - \sum_{i=1}^{m} t_i\,(t_i - 1)\,(2t_i + 5)}{18} \quad (3)$$

Where n = number of data points; t_i= are the ties of the sample time series; and m = number of tied value (a tied group is a set of sample data having same value)

Equation 2 and 3 were then used to compute the test statistics Z. The computation for normalized test statistics Z is given as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \quad (4)$$

A positive value of Z indicates an upward trend; a negative value indicates a downward trend, and a zero value indicates no trend.

The study used Spearman Rank Correlation method to examine the strength of association between the climatic variables and rice yield. The equation is given as:

$$r = 1 - \left(\frac{6\Sigma d^2}{n\,(n^2 - 1)}\right) \quad (5)$$

Where

d = variance between the two numbers in all pair of ranks

n = number of pairs of data

3.0 RESULTS AND DISCUSSIONS

Table 3 depicts the Mann-Kendall test result for Consecutive Dry Day (CDD), Consecutive Wet Day (CWD), Simple Daily Intensity Index (SDII), Maximum 1-day rainfall (R1D), Maximum 5-day rainfall (R5D), Very wet day rainfall (R95T), Number of heavy rainfall days (R10), Number of heavier rainfall days (R20) and Number of rainstorm days R50. Result shows upward trend for CDD in all the stations with a significant alpha value of 0.05 in Minna and Abuja stations. Result for CWD shows significant downward trends in all the stations during the study period. A significant upward trend at 0.05 and 0.001 was detected for SDII in Minna and Abuja stations while Lokoja station shows a significant downward trend at 0.05 alpha level.

Further findings show a significant upward trend for R1D at alpha values of 0.01, 0.05, 0.01 and 0.05 at Minna, Lokoja, Abuja and Lafia stations respectively. Also result for R5D shows a significant upward trend at 0.1 alpha value in Minna and Abuja stations while Lafia station depict a significant downward trend at 0.1 alpha value. A significant upward trend of 0.05 was detected for R95T in Abuja station. Further, result shows a significant downward trend for R10 at 0.1, 0.001, 0.1, 0.1 and 0.001 in Minna, Lokoja, Abuja, Ilorin and Lafia stations respectively. Result for R20 shows significant downward trend at 0.01 and 0.001 alpha values in Lokoja and Lafia stations respectively. R50 shows a significant upward trend at 0.05 in Abuja and Ilorin stations. Generally, the result shows varying downward and upward trends in extreme rainfall indices across the study area.

Table 3: Mann-Kendall Test Result Showing Trend in Extreme Rainfall Indices over the Study Area (1989 – 2018)

Stations	CDD	CWD	SDII	R1D	R5D	R95T	R10	R20	R50
Minna	2.20*	-3.46***	2.11*	2.89**	1.68+	1.55	-1.83+	0.34	1.52
Lokoja	1.34	-2.63**	-2.09*	2.16*	-1.39	-.05	-3.32***	-2.76**	1.37
Abuja	2.41*	-2.75**	3.39***	3.28**	1.86+	2.57*	-1.66+	0.52	3.03*
Ilorin	1.23	-1.80+	1.59	1.64	0.64	1.53	-1.86+	0.00	2.38*
Lafia	1.04	-3.18**	-1.50	2.00*	-1.89+	-0.71	-3.59***	-3.42***	-0.71

***Trend is significant at α = 0.001, **Trend is significant at α = 0.01, *Trend is significant at α = 0.05, +Trend is significant at α = 0.1 confidence levels.

Table 4 depicts the Spearman Rank Correlation coefficient between extreme rainfall indices and Rice yield in the study areas. The result shows a non-significant positive correlation in bulk of the stations. CDD shows a non-significant correlation with Rice yield in all the stations while CWD shows a significant negative correlation at ($P< 0.01$) and ($P< 0.05$) in FCT and Kwara stations respectively. SDII shows a significant positive correlation with Rice yield at ($P<0.05$) in Niger and Kwara stations. Result for R1D and R5D shows a non-significant correlation with Rice yield in all the stations. R10 shows significant positive correlation at ($P< 0.05$) and ($P< 0.01$) in FCT and Nasarawa stations and a significant negative correlation at ($P< 0.01$) in Kogi. Result for R20 shows a significant positive correlation at ($P < 0.01$) and ($P< 0.05$) in Niger and Nasarawa stations and a significant negative correlation at ($P< 0.05$) in Kogi station. R50 shows a significant positive correlation at ($P< 0.05$) in FCT while other stations showed a non-significant correlation. Generally, the result revealed that the correlation between extreme rainfall indices and Rice yield across the stations is not homogeneous. Findings also show stronger relationship between R10, R20 and Rice yield across the study area.

Table 4: Spearman Rank Correlation Coefficient between Extreme Rainfall Indices and Rice Yield

Station	CDD	CWD	SDII	R1D	R5D	R95T	R10	R20	R50
Minna	-.011	-.086	**.456***	.221	.211	.330	.237	**.471****	.072
Sig (2- tailed)	.952	.652	.011	.241	.264	.075	.207	.009	.705
N	30	30	30	30	30	30	30	30	30
Lokoja	.067	-.170	-.438	.307	-.068	.079	**-.483****	**-.403***	.169
Sig (2- tailed)	.725	.370	.016	.099	.721	.679	.007	.027	.371
N	30	30	30	30	30	30	30	30	30
Abuja	.236	**-.487****	.444	.361	.154	.340	**.473****	-.068	**.385***
Sig (2- tailed)	.209	006	.014	.050	.417	.066	.008	.720	.035
N	30	30	30	30	30	30	30	30	30
Ilorin	.094	**-.432***	**.362***	.205	.019	.256	-.296	-.045	.303
Sig (2- tailed)	.620	.017	.050	.277	.919	.172	.112	.812	.104
N	30	30	30	30	30	30	30	30	30
Lafia	.135	.348	.194	-.288	.249	**.154***	**.453***	**.433***	-.109
Sig (2- tailed)	.476	.059	.303	.123	.184	.416	.012	.017	.567
N	30	30	30	30	30	30	30	30	30

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

Figure 2 shows the distribution pattern of the result of correlation between extreme rainfall indices and rice yield in the study area. The figure shows more positive correlation between the extreme rainfall indices and rice yield at Minna, Abuja and Lafia stations compared to Lokoja and Ilorin stations during the study period. The finding could be as a result of station's specific physical characteristics.

Figure 2: Pattern of Correlation Coefficient between Extreme Rainfall Indices and Rice Yield in the Study Area.

4.0 CONCLUSION AND RECOMMENDATIONS

The study examined the impact of extreme rainfall event on rice yield for the period of thirty (30) years in the North Central States, Nigeria using daily rainfall data and rice yield record. The result showed varying significant and non-significant trends in the occurrence of the extreme indices during the study period. The varied trend could be as a result of the influence of locational specific physical characteristics. Result of the correlation analysis showed that there is moderate relationship between rice yield and extreme rainfall indices at Minna, Abuja and Lafia stations compared to Lokoja and Ilorin stations. The study established that very wet day rainfall (R95T) has more impact on rice yield as it showed positive correlation in all the stations during the study period. Findings from this study therefore underscore the need for continuous monitoring of the rainfall pattern of the study area so as to provide timely and effective adaptation measures.

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