Relationship between Rainfall Pattern in North Central and Southern Nigeria and Some Tropical Climate Systems

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Authors' contributions
Both authors was involved in the manuscript writing and analysis presented in the study. Both authors have read and approved the final manuscript.

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ABSTRACT

Monthly rainfall data from meteorological stations in Nigeria are analyzed from 1951 to 1992, to establish their relationship with some Tropical climate systems. The climate systems include Tropical South Atlantic (TSA) sea surface temperature index, North Atlantic Ocean (NAO) atmospheric index, Tropical North Atlantic (TNA) sea surface temperature index, Central India Precipitation (CIP) and and Outgoing Longwave Radiation Anomaly (OLRA)). The rainfall pattern was given in terms of the August break (quantified in terms of the monsoon break intensity (MBI) and annual rainfall anomaly index (RAI)). Partial correlation analysis was carried out to determine the effect of the tropical climate systems on the linear association between them and the stations in Nigeria. Our results show that the rainfall anomalies although sometimes intense do not have predictable patterns. The tele connection between CIP and total rainfall in Nigeria suggests that the rainfall patterns in Nigeria is likely to be modulated by the Tropical Easterly Jet (TEJ) connecting rainfall pattern in Central India to that in Nigeria. The August break is observed to be highly variable and does not show a clear discernable pattern of variability. Its variability may be connected with multiple forcings from ocean and mesoscale circulations.

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1. INTRODUCTION

Nigeria has witnessed series of episodes of climate extremes which have continued to pose serious threats to lives and properties. Floods and drought conditions across the country have had far reaching and devastating effect on her economy and food security. Nigeria depends largely on the vagaries of weather, especially rainfall for its rain fed agriculture. The monsoon over West Africa is a seasonal prevailing wind blowing from the South Atlantic Ocean. Monsoon systems affect more than one-third of world’s population in numerous and varied ways, from agricultural irrigation to catastrophic disasters on an enormous spatial scale, such as flood or drought [1]. The activity of this wind system has also been closely linked to Hydro power plants, infrastructural development, flood control dams, desert encroachment and visibility. Studies have linked the climate of Nigeria to various global systems such as: Intertropical Convergence Zone (ITCZ) [2,3], El Nino Southern Oscillation [4,5] and West African Monsoon [3]. Other vagaries include Sea Surface Temperature (SST) which affects rainfall patterns in the Sahel [6]. How these global and regional climate drivers interact and affect climate change is still not completely known. The ITCZ is the zone of contact between the Tropical Continental (CT) air mass and the Tropical Maritime air mass (MT) and sweeps across West Africa once every year. This region of contact between the two air masses at the surface is therefore a zone of moisture discontinuity and is also known as the Zone of Intertropical Discontinuity (ITD). The ITCZ is both a zonal and global phenomenon [7]. It is responsible for the rainy season in the tropics. Understanding, interpreting and exploring the dynamics of weather and climate extremes is still an active area of research today [8]. Nigeria (Latitude 4°-13°N and Longitude 2°-14°E) is located in the tropics and borders the Gulf of Guinea between Benin on the West and Cameroon on the East. It has an area of 923,765 square km. The country’s land mass extends from the Gulf of Guinea in the South to its boundary with Niger and Chad republics in the North [6].

Okeke et al. [5] used monthly precipitation data from meteorological stations in Nigeria from 1950-1992, to study the possible connection to sea surface temperature (SSTs) in the tropical Pacific and Atlantic Oceans. Their analysis analyses showed some indication that rainfall in Nigeria is associated with El Nino-related circulation and rainfall anomalies. Though the correlation values between rainfall anomaly indices (RAI) and different meteorological indices were not all significant. Camberlin et al., 2001 showed that a number of changes in East-West circulation patterns can be associated with ENSO variations. Over West Africa, El Nino events tend to result in enhanced north easterlies and reduced monsoon flow, coupled to weakened upper easterlies, and hence dry conditions over West Africa close to the surface position of the ITCZ, in July-September, as well as January-March. Most of the works on SSTs have focused on the South Atlantic Indices. In this work we focus on investigating the teleconnection between rainfall anomaly (including monsoon breaks) and other climate systems purported to drive the rainfall pattern in North central and Southern parts of Nigeria. Akinsanola et al. [2] showed that there has been a sequence of alternately decreasing and increasing trends in mean annual precipitation and air temperature in Nigeria during the period 1971-2000.

Bain et al. [9] used satellite fields of infrared (IR), visible (VS) and total precipitable water (TPW) with the Markov Random Field (MRF) model to determine the temporal and spatial evolution of the ITCZ in the East Pacific. Their results showed seasonal migration of the ITCZ and significant interannual variability. They also observed that the location and area of the ITCZ is closely associated with the anomalies from the Tropical Atlantic Sea Surface Temperatures. Many authors [10,11,12] also showed that the band of clouds that form the ITCZ which sometimes extend for many hundreds of miles, sometimes break into smaller line segments which results in irregular precipitation patterns in the tropics. Their work also suggests that the variability of the ITCZ is attributed strongly to the anomalies associated with sea surface temperatures. Which further strengthens the argument for a better understanding of the association between TNA and rainfall anomaly. The teleconnection of these atmospheric vagaries is currently an active area of research [13], Datwyler et al. 2019.

Chineke et al. [3] analysed daily series of rainfall data from 1983-2003 between the months of July-August for some sites in the Eastern humid
zone of Southern Nigeria. Their work shows that the August break may indeed be breaking. The August break was observed to have reduced to a period of 2-4 days instead of 2-3 weeks. Some authors [3,14] have linked these variations in the West African climate to differential changes in SSTs (Sea Surface Temperatures) of the Atlantic (both north and south) and the Indian Ocean as the primary drivers of climate change in the region. Some authors [15,16] have suggested that the standard precipitation index is suitable for examining breaks and active events in the monsoon rainfall over India. In his work on rainfall anomalies in Nigeria, Olaniran [4] observed that during the period 1921-2000, there was a countrywide occurrence of droughts during two periods: firstly from the 1930s to 1950 and recently from 1970 to the mid-1990s. He reiterated that during the last three decades each drought event persisted more in northern Nigeria than in southern Nigeria. His work shows that the possible drivers that could be associated with these anomalies are the ITCZ, Tropical Easterly Jet (TEJ), Tropical Atlantic Sea Surface Temperature Anomaly, El Nino Southern Oscillation (ENSO) and other teleconnections. However, not much work has been done to understand the teleconnection between the rainfall patterns/anomalies in Nigeria to other climate systems. In particular, the present study aims to find the possible link(s) between specific rainfall indices (monthly total rainfall, rainfall anomalies and monsoon breaks) in selected stations in Nigeria and some prominant climate systems.

2. MATERIALS AND METHODS

2.1 Sources of Data

Monthly rainfall data (mm/month) for the period 1951 - 1992 were collected at six meteorological sites (Warri, Enugu, Makurdi, Minna, Ondo and Calabar) from http://climexp.knmi.nl/ all stations. The stations are part of the Nigerian Meteorological Agency (NMA) network of surface stations measuring meteorological parameters like, maximum and minimum temperatures, rainfall amount, wind speed, solar radiation and sunshine hours.

![Fig. 1. Part of Map of Nigeria showing the locations of the stations used](image-url)

Table 1. Stations used and their abbreviations

| Station | Abbreviation | Latitude("n") | Longitude("e") |
|---------|--------------|---------------|----------------|
| WARRI   | WAR          | 5.52          | 5.73           |
| ENUGU   | ENU          | 6.50          | 7.00           |
| MAKURDI | MAK          | 7.70          | 8.60           |
| MINNA   | MIN          | 9.56          | 6.54           |
| ONDO    | OND          | 7.10          | 4.83           |
| CALABAR | CAL          | 4.97          | 8.35           |
Monthly data of climate indices (Tropical North Atlantic TNA), North Atlantic Oscillation (NAO), Central Indian (standardized) Precipitation (CIP) and Tropical South Atlantic (TSA). Sahel Standardized Rainfall (SSR), were obtained from the following website: National Oceanic and Atmospheric’s Earth System Research Laboratory.http://www.esrl.noaa.gov/psd/data/climateindices/list/; for the period 1951-1992.

We also obtained Outgoing Long Wave Radiation (OLR) monthly data from: National Oceanic and Atmospheric’s Center for Disease Control:http://www.cdc.noaa.gov/map/clim/olr.shtml/; for the period 1975-1992.

In order to study the association between monsoon break and various climate systems we quantified the monsoon break by a factor ε (after works by [17], which describes the intensity of the break in total rainfall expected around August. (Also known as August Break).

\[ \varepsilon = \left( \frac{H_1 + H_2}{2} \right) - H_3 \]

Where,

\( H_1 \) is the first rainfall Maxima,(which usually occur around June/July) see Fig. 2, \( H_2 \) is the second rainfall Maxima,(which usually occur around September/October) while \( H_3 \) is the minimum between \( H_1 \) and \( H_2 \) (\( H_3 \) usually occurs around August) see Fig. 1 (\( \varepsilon = 0 \) if the profile is unimodal i.e. no monsoon break).

To calculate the intensity of the monsoon break (\( \varepsilon \)), we plotted the rainfall profile for each year as shown in Fig. 1. \( H_1 \), \( H_2 \) and \( H_3 \) were identified from the plots. The intensities for each year were calculated. This was done for each station.

### 2.2 Derivation Scheme for Other Precipitation Factors from Monthly Data

The average monthly rainfall (AMR) was calculated as the average rainfall of each month from 1951 -1992. The plots of AMRs are presented in Figs. 3-8, while the summer monsoon rainfall (SR) was calculated as the sum of the monsoon rainfall in the months of June, July, August and September (JJAS). The total annual rainfall (TR) was calculated as the sum of the total annual rainfall from January to December. The long period average (LPA) was calculated as the mean of the TR. The anomalies are calculated by subtracting yearly TRs from the LPA. The plots of the anomalies are presented in Figs. 9-14.

### 2.3 Correlation Analysis

We assume that linear association exists between the anomalies from one station to another. Linear correlation between the monsoon break and annual rainfall anomaly of the stations was carried out using equation (2). Similarly we carried out the linear correlation between monsoon break intensity computed from equation (2), with different climate indices.

![Fig. 2. Rainfall data of Warri](image-url)
We also correlated the monthly rainfall data with the monthly data of the climate indices. The correlations are presented in Tables 2 and 3. The Pearson’s correlation coefficients $r_{xy}$ is given by:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2 \sum_{i=1}^{n}(y_i-\bar{y})^2}}$$

Where,

$x$ and $y$ are the dependent and independent variables respectively, and $\bar{x}$ and $\bar{y}$ are the mean of $x$ and $y$ respectively, while $n$ is the number of variables. All the correlations were performed at $p=0.05$ significance.

The first-order partial correlation was used which measure the linear relationship between two variables after removing the effect of or controlling for a single (third) variable. The first-order partial correlation is given by:

$$r_{xy.z} = \frac{r_{xy}-(r_{xz})(r_{yz})}{\sqrt{1-r_{xz}^2}}$$

We also conducted t-test to validate the significance of the correlations. The t-test is given as:

$$t = \frac{\bar{x} - \bar{y}}{\sqrt{\frac{\text{Var}_x}{n_x} + \frac{\text{Var}_y}{n_y}}}$$

Where,

$x$ and $y$ are the dependent and independent variables respectively, $\text{Var}_x$ and $\text{Var}_y$ are the variances of $x$ and $y$ while $n_x$ and $n_y$ are the number of variables of $x$ and $y$, $\bar{x}$ and $\bar{y}$ are the mean of $x$ and $y$ respectively.
Fig. 5. Average monthly rainfall profile for Calabar

Fig. 6. Average monthly rainfall profile for Ondo

Fig. 7. Average monthly rainfall profile for Makurdi
Fig. 8. Average monthly rainfall profile for Minna

Fig. 9. Time series of yearly rainfall anomaly for Warri

Fig. 10. Time series of yearly rainfall anomaly for Enugu
Fig. 11. Time series of yearly rainfall anomaly for Calabar

Fig. 12. Time series of yearly rainfall anomaly for Ondo

Fig. 13. Time series of yearly rainfall anomaly for Makurdi
Fig. 14. Time series of yearly rainfall anomaly for Minna

Table 2. Correlation of various climate indices with monthly rainfall intensities (1951-1992)

| Station/Index | WAR  | ENU  | CAL  | OND  | MAK  | MIN  |
|---------------|------|------|------|------|------|------|
| TNA           | -0.07| -0.06| -0.05| -0.03| -0.07| -0.08|
| NAO           | 0.22 | 0.24 | 0.21 | 0.2  | 0.24 | 0.21 |
| CIP           | 0.66 | 0.54 | 0.64 | 0.51 | 0.65 | 0.75 |
| TSA           | 0.02 | 0.04 | 0.02 | 0.02 | 0.03 | 0.03 |
| CIP*          | 0.65 | -0.37| 0.63 | 0.48 | 0.68 | 0.75 |
| OLRA*         | 0.11 | 0.01 | 0.16 | 0.15 | 0.13 | 0.11 |
| CIP*(OLRA effect removed) | 0.64 | -0.37| 0.61 | 0.47 | 0.67 | 0.74 |
| CIP (NAO effect removed) | 0.64 | 0.51 | 0.62 | 0.49 | 0.62 | 0.73 |
| CIP*(NAO effect removed) | 0.50 | -0.38| 0.62 | 0.48 | 0.67 | 0.74 |

*Data available for 1975-1992

Table 3. Correlation of various climate indices with monsoon break intensities (1951-1992)

| Station/Index | WAR  | ENU  | CAL  | OND  | MAK  | MIN  |
|---------------|------|------|------|------|------|------|
| TNA           | 0.05 | 0.07 | -0.06| 0.01 | -0.01| 0.04 |
| NAO           | 0    | -0.02| -0.05| 0.19 | -0.11| 0.06 |
| CIP           | 0.47 | 0.34 | 0.17 | 0.5  | -0.14| -0.03|
| CIP (NAO effect Removed) | 0.47 | 0.34 | 0.17 | 0.48 | -0.13| -0.03|
| TSA           | -0.29| -0.16| -0.12| -0.51| -0.1 | -0.16|
| CIP*          | 0.45 | 0.17 | 0.2  | 0.38 | -0.14| 0.36 |
| OLRA*         | -0.1 | 0.11 | 0.21 | -0.31| 0.04 | -0.17|
| CIP*(OLRA effect removed) | 0.5  | 0.15 | 0.16 | 0.48 | -0.16| 0.43 |
| CIP*(NAO effect removed) | 0.45 | 0.17 | 0.2  | 0.37 | -0.14| 0.36 |

*Data available for 1975-1992

Table 4. Percentage of summer to annual total rainfall with corresponding ranges

| Station | AASR | AATR | %AASR/AATR | RANGE |
|---------|------|------|------------|-------|
| WARRI   | 1643 | 2757 | 59         | 46-73 |
| ENUGU   | 988  | 1708 | 58         | 42-76 |
| CALABAR | 1586 | 2783 | 57         | 46-65 |
| ONDO    | 860  | 1563 | 54         | 42-76 |
| MAKURDI | 819  | 1250 | 66         | 46-77 |
| MINNA   | 882  | 1214 | 73         | 56-86 |

*Data available for 1975-1992
3. RESULTS AND DISCUSSION

3.1 Monthly Rainfall Pattern

Figs. 2-7 shows the seasonal (or monthly) rainfall pattern for all the stations. It is evident that Warri, Enugu, Calabar and Ondo had bimodal rainfall patterns while Makurdi and Minna had unimodal rainfall pattern. It is important to note that the figures (i.e. Figs. 3-8) were derived from the average of the monthly data for all years considered for each station, so it does not reveal the fine patterns observed on a year to year basis. There are some years (albeit few) with bimodal rainfall patterns in both Minna and Makurdi stations, similarly, there were years (also few) with unimodal rainfall pattern for Warri, Enugu, Calabar and Ondo. Southern stations Warri and Ondo showed the most distinct signatures of bimodal pattern. This observation may not be unconnected with their position not too close to the coastal region, and consequently should show greater fluctuations in response to the advancement of the ITCZ. The Calabar station rainfall pattern was particularly interesting. It exhibited a weak bimodal annual rainfall pattern but had the greatest amount of rainfall during the same period when compared with other stations; it is possible that other mesoscale circulation patterns could be affecting its ability to exhibit a stronger bimodal pattern. Moreover the advancement of the ITCZ northward which gives rise to the monsoon break will likely exacerbate the effect of such mesoscale wind structures which appear to predominantly sustain the lesser convections and rainfall during July and August. This observation is further supported by the range of the percentage ratio of the Average Annual Summer Rain (AASR) to the Average Annual Total Rain (AATR) for Minna is the highest (73%). This is due to the fact that most of the rain occurs during summer (June-September) months. This can also be seen with Makurdi station which has a percentage ratio of 66%. The least is that of Ondo which 54% is. These percentages do not differ much from the maximum value observed for the stations. The (AATR) for Calabar 2783 mm is the maximum even though its percentage is 57%. These values show that over 50% of the total annual rainfall occurred during the summer months for all the stations. The northern stations have the highest amount of their total rainfall during the summer months. This can be explained by the dominance of the ITCZ in that region during the summer bringing about the greatest amount of rainfall around August/September. This view is in line with earlier works by Houghton et al. [19].

From Figs. 9 - 14 it is observed that the signatures of the rainfall anomalies do not exhibit a definite pattern. The oscillations are sometimes intense as observed in Calabar, Ondo, Minna and Makurdi. The oscillations exhibited wide swings between the period 1971 and 1992 as reported in earlier works by Akinsanola et al. [2] and Okeke et al. [5]. Warri (Fig. 9) and Calabar (Fig. 11) experienced greater number of large yearly anomalies (>300mm), while Ondo station exhibited largest number of very extreme events (>700mm). The north central stations Minna and Markurdi experienced the least number of large anomalies within the period considered in this study.

3.2 Inter-stations Monsoon Break Intensity Teleconnectivity

The correlation of Minna and Makurdi which is ($r > 0.04$) is weak and not significant. Warri has a strong and direct correlation with Enugu. This correlation ($r > 0.66$) suggests a strong
teleconnection between the two stations. Also the teleconnection of Warri with Ondo and that of Enugu and Ondo which are \((r > 0.62)\) and \((r > 0.66)\) respectively are also strong and direct. It is evident that a special but strong correlation exists between these stations as compared to the other stations. These stations are all located in the southern region. The correlation of Calabar with these southern stations as seen in Table 5 is much weaker though they are all located in the south. This observation suggests some kind of fluctuations prevalent along that region which does not extend to Warri, Enugu and Ondo. This suggests a variability that could possibly stem from a mesoscale wind structure within that region. The correlation of CIP index with the
Fig. 17. Monthly rainfall for Calabar and CIP index

y = 0.094x + 156.1  
R = 0.63

Fig. 18. Monthly rainfall for Ondo and CIP index

y = 0.048x + 91.833  
R = 0.48
monsoon break intensity index (MBI) of Ondo station of \( r \approx 0.5 \) is the strongest, while that of Minna \( r = -0.03 \) is the weakest. We also observe that the correlation of Outgoing Long wave Anomaly (OLRA) with the (MBI) of Ondo station of \( r = -0.31 \) is the strongest while that of Makurdi; \( r = 0.04 \) is the weakest. The correlation of the MBIs with the other climate indices is not all so.
significant. This dispels the possibility of teleconnectivity between these climate indices with the MBIs in the North Central and Southern Nigeria rainfall pattern. On removing the effect of the OLRA and NAO from CIP, we observe a slight change which is not significant. This still leaves us with the conclusion that the effect of the CIP index on the MBI needs further analysis. The correlation of the MBI of the stations with Rainfall Anomaly Index (RAI) showed some level of association. Ondo station had a correlation of \( r \approx -0.48 \), while Minna station had \( r \approx -0.03 \). This suggests that the MBIs could possibly be driven by the RAI for Ondo station. For the other climate indices, we did not observe any significant association with the RAI.

3.3 Total Monthly Rainfall Teleconnection with Climate Indices

The correlation of North Atlantic Oscillation (NAO) index with the monthly rainfall index (MRI) for Makurdi (Fig. 19) and Enugu (Fig. 16) is \( r \approx 0.24 \). This observation dispels the idea of teleconnectivity between the rainfall pattern and NAO index in these stations. The atmospheric forcing over the mid-latitudes (Icelandic lows and Azores high) may not have reaching effect on the pattern of rainfall observed in this stations.

The linear association between the monthly rainfall index (MRI) for all the stations and the central Indian Precipitation is shown in Figs. 15-20. The correlation of the Central Indian Precipitation index with the MRI of Minna is \( r \approx 0.75 \), while that of Ondo is \( r \approx 0.51 \). Here it shows clearly from the 492 data points correlation that there is a strong association between the two indices. It is evident that the climate systems that drive the CIP could possibly be responsible for the fluctuations or irregularities associated with the monsoon rainfall pattern of these stations. The tropical easterly jet is one of such drivers as reported in the work of (Okechukwu, 2010) and [6]. These observations validates recent findings by Nnamchi et al. [8], that atmospheric dynamics (such as East African Jet Stream) are more likely to drive changes in climate variables than ocean forcing. On further removal of the effect of NAO and OLRA from the CIP index , only but slight changes are observed which are not significant.

We further observe that the correlation of OLRA with the MRI for all the stations is weak. Calabar has the strongest but inverse correlation of \( r \approx 0.16 \). The weakest amongst the stations is Minna with a correlation of \( r \approx 0.11 \). Also the correlation of the MRI with the OLRI gave us a correlation of \( r \approx 0.31 \) for Ondo station and \( r \approx 0.04 \) for Makurdi. This also suggests that there is a weak teleconnection between the OLRA with the MRI for Ondo station.

4. CONCLUSION

We have investigated the rainfall anomalies in six location in the Nigeria. The rainfall anomalies although sometimes intense do not have predictable patterns. The teleconnection between Central Indian Precipitation and total rainfall in Nigeria suggests that the rainfall patterns in Nigeria is likely modulated by the Tropical Easterly Jet (TEJ) connecting rainfall pattern in Central India to the pattern in Nigeria. The northern most stations appear to be more associated with Central Indian Precipitation. The August break is highly variable and does not show a clear pattern of variability. Its variability may be connected with multiple forcings from ocean and mesoscale circulations. These results have important implications for modelling of the climate system in Nigeria and West Africa. Considering the strong correlation we observed between the amount of rainfall recorded in these stations with the Central Indian Precipitation data, we suggest that further work be carried out to establish the possible drivers for such high correlation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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