

## Cointegration analysis of rainfall onset and cessation in rainforest of Nigeria

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### Abstract

This study investigates the autocorrelation patterns, tests for stationarity, and applies cointegration analysis to explore the existence of long-term relationships among rainfall characteristics in selected states in Southwestern Nigeria. It utilizes 38 years of rainfall data (1986–2024) for Ibadan and 34 years (1990–2024) for Akure, focusing on three key indices: onset, cessation, and length of rainy season. The data were sourced from the Nigerian Meteorological Agency (NiMet) and analyzed using time series techniques, including unit root tests, the Augmented Dickey-Fuller (ADF) test, and cointegration analysis. The results reveal no significant cointegration between rainfall cessation and length, and between rainfall cessation and onset in the study area. A weak cointegration relationship was observed between onset and length of rainy season, while stronger long-term relationships are evident between rainfall onset and cessation, and onset and length in Ibadan. In contrast, these relationships appear weaker in Akure, suggesting that rainfall patterns in Ibadan are relatively more stable and predictable, likely influenced by its tropical weather system. These findings underscore the need for location-specific adaptation strategies to address climate change and variability. Moreover, the use of cointegration and causality analyses provides a robust framework for understanding long-term climatic interactions, offering valuable insights for enhancing climate resilience in Nigeria. Future research is recommended to expand on these findings by integrating additional climatic variables such as temperature, humidity, and evaporation, and by assessing the potential impacts of urbanization and land use changes on rainfall dynamics within the rainforest.

**Key words** – long run, fluctuations, casualty, adaptation.

### Introduction

Rainfall variability is a critical determinant of agricultural productivity, hydrological

planning, and ecosystem stability in tropical regions. In West Africa, and particularly in Nigeria, the timing and distribution of rainfall, marked by onset, cessation, and length of rainy season significantly influence food security and water resource management (WMO, 2021). As the impacts of climate change intensify, understanding the temporal dynamics of these rainfall variables becomes increasingly urgent, especially for climate-sensitive sectors like agriculture. In the southwest Nigeria, the cities of Ibadan and Akure exhibit distinct climatic behaviors despite their geographical proximity. Rainfall onset and cessation dates vary between these locations, influencing the length of the rainy season and subsequently, the agricultural calendar (Adejuwon, 2023). Given these spatial disparities, a comparative analysis can provide insights into regional climatic dynamics and their implications. Similarly, as climate variability intensifies, traditional approaches to analyzing weather data are no longer sufficient. This has led to the increasing use of econometric techniques like cointegration analysis in agrometeorological research (Adetayo and Dauda, 2021). Cointegration offers a robust framework for identifying long-term equilibrium relationships between non-stationary climatic time series—such as rainfall onset, cessation, and length—that may fluctuate in the short term but exhibit stable interactions over time. Such insights are critical for improving seasonal forecasting and guiding policy makers in formulating adaptation strategies for climate-smart agriculture.

Two or more time series are said to be cointegrated if a particular linear combination of them is stationary, even though each individual series is non-stationary (Hualde, J. and Olmo, J. 2025). This indicates that the variables share a common stochastic trend and maintain a stable long-run equilibrium relationship, so they do not drift apart indefinitely over time.

Formally, let  $X_t = (X_{1t}, X_{2t} \dots X_{pt})'$  be a  $p \times 1$  vector of time series variables. Suppose each component of  $X_t$  is integrated of order  $d$ , denoted  $I(d)$ . If there exists a non-zero coefficient vector  $\beta$  such that the linear combination  $z_t = \beta'X_t$  is integrated of order less than  $d$  (typically  $I(0)$ , meaning stationary), then the components of  $X_t$  are said to be cointegrated, and  $\beta$  is referred to as the cointegrating vector.

This condition implies that although the individual series may exhibit stochastic trends, their movements are linked in such a way that deviations from the long-run equilibrium

are temporary and mean-reverting. Recent agrometeorological studies have adopted cointegration models to analyze the linkage between climate parameters and agricultural productivity. Edaba *et al.* (2023) applied the Johansen cointegration and Vector Error Correction Model (VECM) to demonstrate a long-run relationship between climatic variables and oil palm production in Nigeria. Their findings emphasized how persistent shifts in rainfall patterns could have lasting effects on crop yields.

Similarly, cointegration studies help assess the predictability and interdependence of meteorological variables, thus aiding the development of agroclimatic indices for early warning systems and risk assessment. In this study, cointegration analysis is employed to examine the interrelationships among rainfall onset, cessation, and duration in two agriculturally significant cities—Ibadan and Akure. These locations, though geographically close, may experience different climatic rhythms, potentially affecting their agricultural calendars differently. This study aims to examine the statistical properties and long-term interrelationships among rainfall onset, cessation, and length of the rainforest agro-ecological zone of Nigeria. Specifically, it is to determine the existence and strength of long-run equilibrium relationships among the variables. The overarching goal is to provide insights that support climate-resilient agricultural planning and localized adaptation strategies in response to rainfall variability.

## **Methodology**

The Rainforest agro-ecological zone in Nigeria is crucial for tree crop production, particularly cocoa and oil palm, which contribute significantly to Nigeria's agricultural export. It plays a significant role in food security, biodiversity conservation, and carbon sequestration. The region is predominantly located in the southern part of the country, including parts of Lagos, Ogun, Ondo, Oyo, Edo, Delta, Cross River, Akwa Ibom, Abia, Imo, Bayelsa, and Rivers States. Akure and Ibadan was chosen for this study. Akure, the capital city of Ondo State, is located in the Yoruba Highlands and has a tropical wet and dry climate. The city is part of the humid tropical rainforest belt of Nigeria and has a dense forest, hardwood trees, and various shrubs and climbers. Urbanization and agricultural activities have led to significant deforestation. Ibadan, the capital city of Oyo State, is a

major urban and historical center in the southwestern part of Nigeria. It is part of Nigeria's Southwest geopolitical zone and is the largest city in this zone in terms of landmass. Ibadan is located on rolling hills and ridges, with elevations ranging from 150 to 275 meters above sea level. It has both tropical wet and dry climates, with rainy seasons occurring from March to October and dry seasons from November to February. This study utilizes 38 years (1986-2024) rainfall data (onsets, cessation and length) for Ibadan and 34 years (1990-2024) rainfall data for Akure. The data were obtained from the Nigeria Meteorological Agency (NIMET) and were screened for existence of possible outlier. The data were subjected to time series plots, graphical analysis of means and variance of the monthly rainfall, descriptive statistics, variance-covariance analysis, stability test (stationary and unit root test), Granger causality test and cointegration analysis.

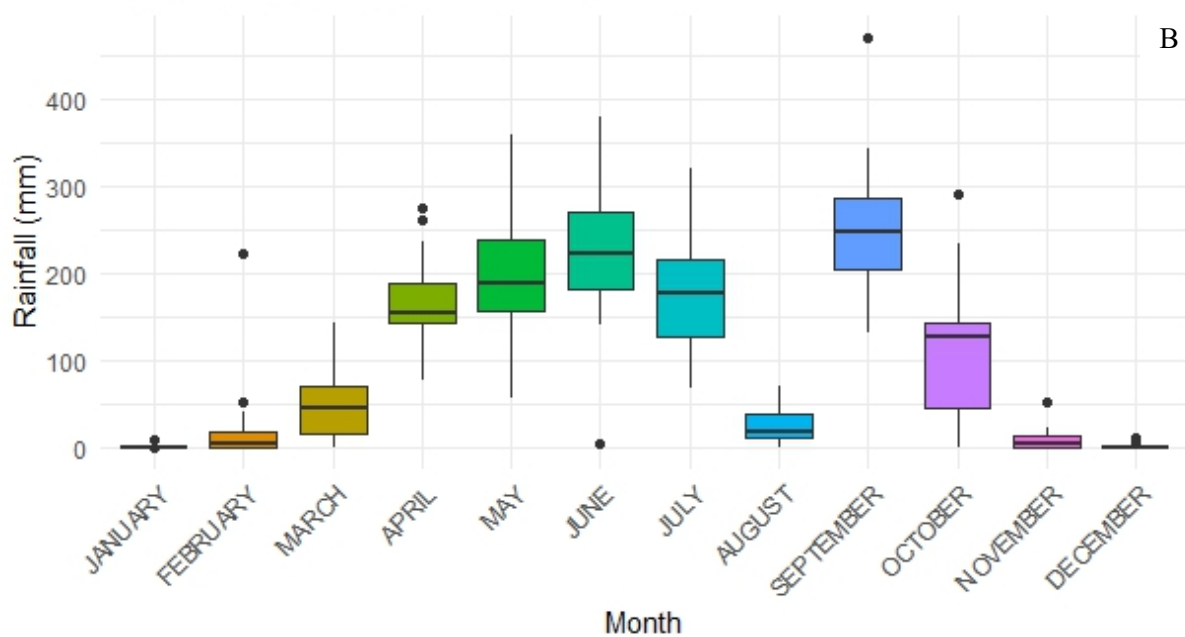
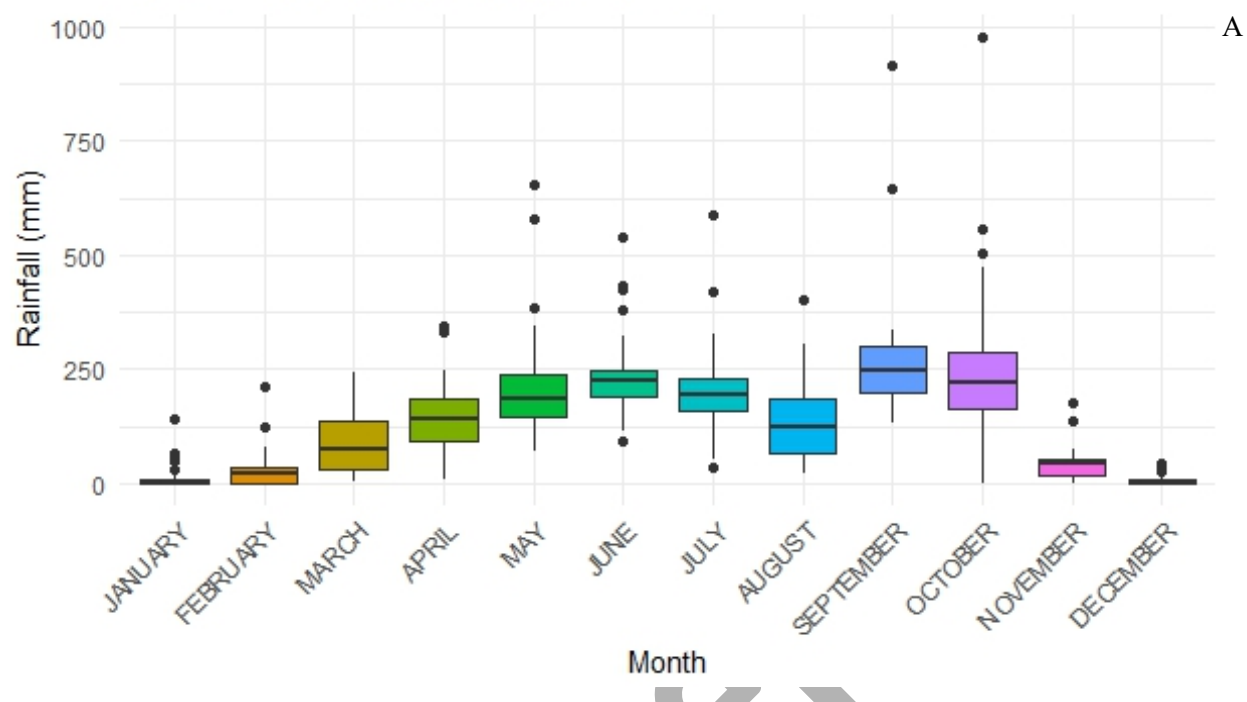
## **Results and discussion**

The box plots of monthly rainfall for Ibadan (Figure 1A) and Akure (Figure 1B) clearly illustrate seasonal variability, dispersion, and extreme precipitation patterns in southwestern Nigeria. By showing medians, interquartile ranges (IQRs), and outliers, the figures provide a concise view of intra-annual rainfall dynamics. Both cities display the typical bimodal rainfall pattern of the region: an early rainy season (March–July), a short August break, and a late rainy season (September–November). Wider IQRs during peak months indicate substantial seasonal concentration and increasing variability, influenced by the Inter-Tropical Discontinuity and Atlantic moisture systems. Recent studies confirm growing unpredictability in rainfall onset and cessation (Ayanlade & Ojebisi, 2021), while the IPCC (2021) and WMO (2023) report intensified precipitation extremes across West Africa. Such variability heightens risks of flooding, soil erosion, and crop damage. The FAO (2024) further notes that climate instability threatens smallholder productivity, underscoring the urgent need for adaptive agricultural strategies in the region. Mean monthly rainfall for Akure followed an irregular increasing trend which drops in the month of June (first peak) and it also increased till September (second peak). The pattern for Ibadan is similar to that of Akure. The variability of mean monthly rainfall for Akure are less than the variability of the mean monthly rainfall for Ibadan and it ranged from

3.012 (January) to 5512.51 (October). It is explicit from the mean monthly rainfall of the two sites that two rainfall peaks can be noticed in June and September (Figure 2). Significant variability in onset/cessation have been established to impact maize yield in Akure in earlier study (Mosunmola et al. 2020). Variability patterns in terms of late onset and early cessation differ from those observed in Ngamdu and Goni (2024).

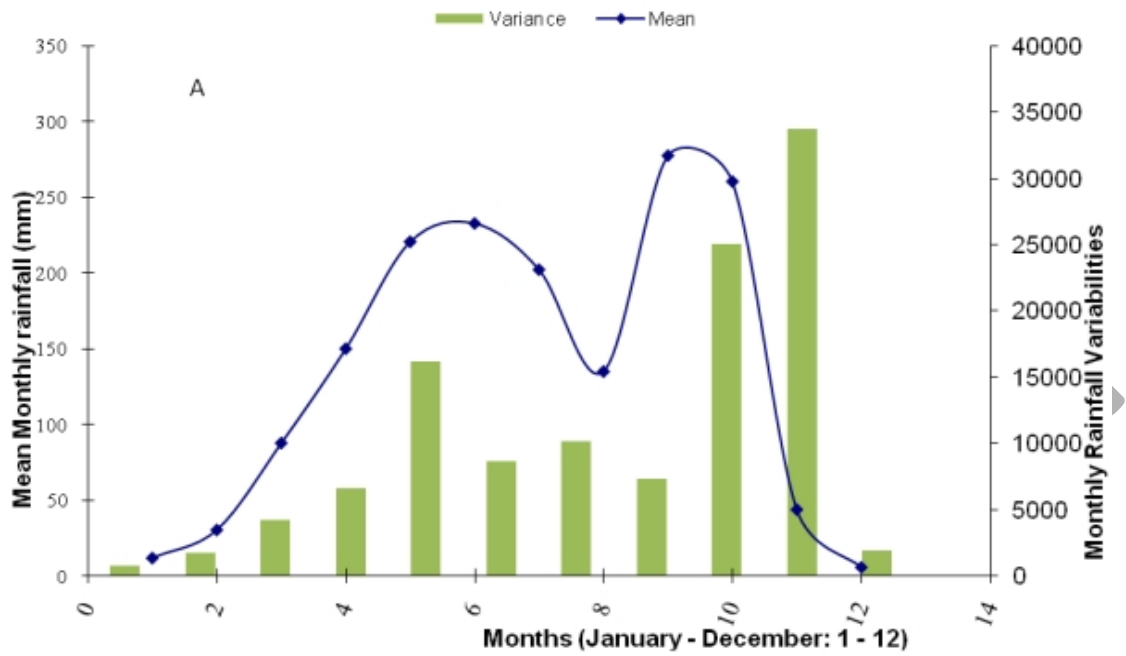
### **Descriptive statistics**

The mean onset day, cessation day and length of rainfall for Ibadan are 91.629, 320.143 and 235.314 (Table 1). The variance accordingly is 61.417 (onset), 209.479 (cessation) and 52.692 (length). Across the minimum, maximum, and cumulative measures, a consistent numerical pattern was observed, with rainfall onset day recording the lowest values, followed by rainfall length, while rainfall cessation day exhibited the highest values (Table 1). Mean rainfall onset days, cessation days and rainfall length for Akure were lesser than those of Ibadan for the same periods. The means rainfall onset of 86.629, cessation days of 315.8 and rainfall length of 237 were obtained for Akure. The variance, minimum and maximum of these variables followed the trend of rainfall onset less than rainfall length and less than rainfall cessation (Table 1). The number of items (years) involved in each of the parameters are equal ( $N = 35$ ) for both stations. Both sites (Akure and Ibadan) followed the trend of *rainfall onset < rainfall length < rainfall cessation* in quantity. This is consistent with Mosunmola *et al* (2020) but differs from Adeyefa (2022) which clearly showed that *rainfall length < rainfall onset < rainfall cessation*.



**Figure 1. Monthly rainfall distribution for Ibadan (A) and Akure (B)**

Ibadan



Akure

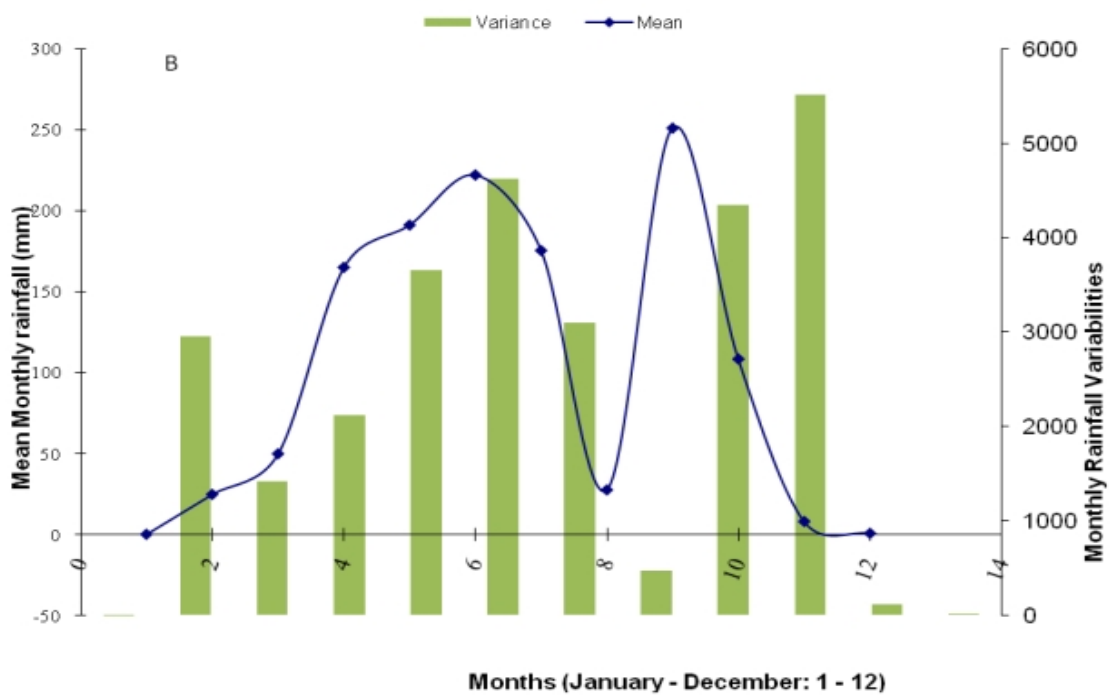


Figure 2. Mean monthly rainfall and monthly rainfall variability for Ibadan (A - 1986-2024) and Akure (B - 1986-2024)

**Table 1. Descriptive statistics of rainfall variables**

| Ibadan     | Onset    | Cessation | Length   |
|------------|----------|-----------|----------|
| Mean       | 91.62857 | 320.1429  | 235.3143 |
| S.E.M.     | 1.324676 | 2.446449  | 1.226987 |
| Variance   | 61.41681 | 209.479   | 52.69244 |
| Coef. Var. | 0.085529 | 0.045209  | 0.030848 |
| Minimum    | 76       | 283       | 223      |
| Maximum    | 103      | 342       | 250      |
| Sum        | 3207     | 11205     | 8236     |
| N          | 35       | 35        | 35       |
| Akure      | Onset    | Cessation | Length   |
| Mean       | 86.62857 | 315.8     | 237      |
| S.E.M.     | 1.577193 | 2.967272  | 1.941151 |
| Variance   | 87.06387 | 308.1647  | 131.8824 |
| Coef. Var. | 0.10771  | 0.055588  | 0.048456 |
| Minimum    | 71       | 279       | 215      |
| Maximum    | 101      | 344       | 260      |
| Sum        | 3032     | 11053     | 8295     |
| N          | 35       | 35        | 35       |

Similarity in the pattern of the variability of the rainfall parameters of the 2 areas. Although rainfall variables' variabilities were higher in Akure compared to Ibadan, with stronger covariance for cessation and length in Akure the rainfall length in the 2 regions however fall within the same range. The mean rainfall onset in the 2 regions falls within the Nigeria Meteorological Agency's prediction (Adetayo and Dauda, 2021). Aweda *et al.* (2024) reported that rainfall in Ibadan and Akure significantly deviates from a normal distribution ( $p < 0.05$ ), whereas temperature follows a normal pattern. This suggests irregularities in the timing of rainfall onset and cessation, as well as variability in distribution. This is consistent with the observed descriptive statistics and non-uniform monthly rainfall patterns in the present study. The Nigerian Meteorological Agency (NiMet) predicted near-normal to earlier-than-normal rainfall onset for 2020, with onset dates ranging from February 24 in coastal areas to June 2 (55 – 154) in the northern fringes (Yahya, 2020).

The covariance matrix of the Ibadan rainfall variables (IRV) could be partitioned into 3 distinct classes, the weak, negative/inverse and strong covariance. The covariance value of 21.25

rainfall cessation and rainfall onset) is relatively low though positive and this suggests a slight direct relationship between the variances (Table 2). A later onset may be weakly associated with a later cessation. High covariance of 74.73 suggests a moderate positive relationship between cessation and length and this implies that a later cessation might be associated with a longer length. A negative covariance (between onset and rainfall length) indicates an inverse relationship. This suggests that an earlier onset could be associated with a longer duration (length). Similarly, the covariance matrix of Akure rainfall variables (ARV) could be partitioned into 3(the weak, negative/inverse and strong covariance) distinct classes. A higher covariance value of 145.97 ( $Cov_{cessation, length}$ ) suggests a strong positive relationship (Table 2). This implies that a later cessation is associated with a longer duration more strongly in Akure than in Ibadan. Also, with a covariance of 28.10 ( $Cov_{cessation, onset}$ ), a weak positive relationship similar to that of Ibadan, indicating that later onsets are slightly associated with later cessations was obtained. The covariance of - 41.97 ( $Cov_{length, onset}$ ) here is more negative than in Ibadan, indicating a stronger inverse relationship. This implies that earlier onsets tend to be associated with longer durations more strongly in Akure than in Ibadan. It is evident from the ongoing that the co-variability of Akure is higher than those of Ibadan. This is in consonance with Atedhor (2020) where heteroscedasticity of the rainfall parameters was established.

These findings also highlight regional differences in the relationship between rainfall onset, cessation, and length. It however contrasts with variability established in Ngamdu and Goni (2024) where rainfall variability patterns led to late onset and early cessation and which in turn shortened the growing season. Thus, variability adversely affected crop production in the region (Ngamdu and Goni, 2024). Similarly, research conducted in Akure, Ondo State, evaluated the impact of rainfall onset and cessation on maize yield (Mosunmola *et al*, 2020). The study found that while the mean onset date was March 8 and cessation was October 21, there was significant interannual variability.

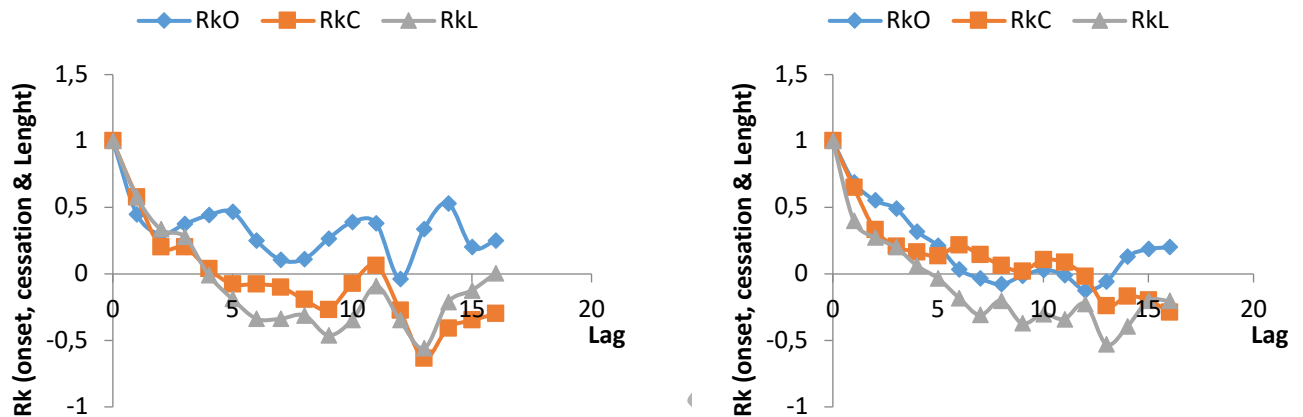
**Table 2. Variance covariance analysis of the rainfall parameter**

|                            |           | Cessation | Length | Onset  |
|----------------------------|-----------|-----------|--------|--------|
| <b>Covariance (Ibadan)</b> | Cessation | 203.49    | 74.73  | 21.25  |
|                            | Length    |           | 51.19  | -17.71 |
|                            | Onset     |           |        | 59.66  |
| <b>Covariance (Akure)</b>  | Cessation | 299.36    | 145.97 | 28.10  |
|                            | Length    |           | 128.11 | -41.97 |
|                            | Onset     |           |        | 84.58  |

All covariance values between paired variables ( $\text{cov}(x, y)$ ) were lower than their respective variances, except for the covariance between length of the rainy season and cessation. Notably, the covariance between length and onset was negative at both stations, suggesting an inverse relationship—as the variability in onset increases, variability in season length tends to decrease, and vice versa (Table 2). These findings underscore the presence of regional differences in how onset and cessation dates influence the length of the rainy season. This aligns with the observations of Ocher and Tomuter (2024), who identified shared or compensatory mechanisms among these variables (onset, length, and cessation) across different ecological zones.

The correlogram of the rainfall variable for Ibadan indicated that at lag 0,  $Rk_O$  (onset) shows a strong positive correlation ( $\sim 1$ ), suggesting a strong and direct relationship with the dependent variable at that point (Figure 3).  $Rk_C$  and  $Rk_L$  also start with positive correlations but are somewhat lower than  $Rk_O$ . For all the three variables, the correlation decreases as the lag increases. Around lag 5,  $Rk_O$ ,  $Rk_C$ , and  $Rk_L$  all show a trend towards zero or negative correlations. Around lags 5 to 15,  $Rk_C$  and  $Rk_L$  exhibit negative correlations, indicating an inverse relationship at these lags while  $Rk_O$  fluctuates slightly, but it remains close to zero and above the others, suggesting a weaker influence in the negative range. After lag 15, all three variables begin to rise slightly, with  $Rk_O$  and  $Rk_L$  showing some minor positive correlations again (Figure 3). These correlogram findings for Ibadan and Akure (strong lag-0 correlations,

mid-lag negative dip, and late re-emergence) are well-aligned with the recent descriptive and autocorrelation studies across Nigerian meteorological stations (Mosunmola *et al*, 2020, Ngamdu and Goni, 2024 and Ishaku *et al*. 2024).



**Figure 3. Autocorrelation  $R_k$  for the rainfall parameters for Ibadan (A) and Akure (B)**

It is evident that the strong negative correlation of  $R_{kL}$  at intermediate lags (5–15) suggests that the length (lag) exerts a delayed and inverse effect on  $R_k$  (autocorrelation). In other words, as the lag increases within this range, the autocorrelation tends to decrease, indicating a delayed but opposite relationship. This might represent a scenario where a longer lag (e.g., duration of an event) has a negative effect after a certain period, such as a prolonged dry or wet season impacting future events in the cycle.

### Stationarity and unit root test

The results of the stability test for Ibadan rainfall variables (IRV) returned unit root for rainfall cessation (-3.05), rainfall length (-2.84), and rainfall onset (-3.49) that are statistically significant ( $P < 0.05$  – Table 2). It is therefore advisable to reject the null hypothesis of a unit root (stationarity). The result of the stability test for Akure rainfall variables (ARV) indicated that the values are slightly varied, with Cessation at -2.65, Length at -3.69, and Onset at -2.25 potentially suggesting stationarity for both cessation and onset. This indicates that it is advisable to reject the null hypothesis of unit root. The unit root test value for rainfall length is specially low (-3.69), while those of both Cessation and Onset are closer to the threshold, which may imply that these segments are less stationary or marginal. The Augmented Dickey-Fuller (ADF) values for

Ibadan were 3.07 for Cessation, 2.83 for Length, and 3.53 for Onset. The values for both cessation and onset are significant thus it is advisable to reject the null hypothesis of stationarity of both cessation and onset data at lag 1 while the data for rainfall length can be said to be stationary at lag 1 (Table 3). The results of the ADF for Akure returned statistics (2.67, 3.68 and 2.30) that are significant for rainfall cessation, rainfall length and rainfall onset (Table 3). The results of the ADF for Akure returned statistics (2.67, 3.68 and 2.30) that are significant for rainfall cessation, rainfall length and rainfall onset (Table 3). It is obvious that these rainfall variable data are suitable for cointegration analysis even at the first lag (lag 1). The significance of the unit root test results in the present study aligns with recent findings that highlight the stationarity of rainfall-derived seasonality indices in southwestern Nigeria (Ilori *et al.* 2025). The fact that the time series became stationary after removing the unit root through first differencing further supports this pattern. This outcome indicates that even when the Augmented Dickey-Fuller (ADF) test suggests non-stationarity at level 1, stationarity can still be achieved at first difference, which is consistent with the findings of He *et al.* (2022) and Ilori *et al.* (2025). While temperatures have exhibited a significant upward trend across parts of West Africa, rainfall series have generally remained statistically homogeneous, with no significant long-term increases or decreases. This absence of systematic change suggests that the rainfall regime is stationary, meaning that its statistical characteristics, such as mean and variance, have remained relatively constant over the period of observation (Ilori and Ajayi, 2020).

**Table 3. Augmented dickey fuller unit root tests for stationarity of rainfall parameters**

|               | Options                 | Cessation | Length  | Onset  |
|---------------|-------------------------|-----------|---------|--------|
| <b>Ibadan</b> | Unit root Test          | -3.05     | -2.84   | -3.49  |
|               | Augmented Dickey Fuller | 3.05*     | 2.83    | 3.53** |
|               | Mean                    | 320.14    | 235.31  | 91.63  |
| <b>Akure</b>  | Unit root Test          | -2.65     | -3.69** | -2.25  |
|               | Augmented Dickey Fuller | 2.67*     | 3.68**  | 2.30*  |
|               | Mean                    | 315.80    | 237.00  | 86.63  |

\*, \*\* significant at  $p < 0.05$  and  $p < 0.01$  respectively

Vector Error Correction Models (VECM) are used to analyze the dynamic relationship (short term fluctuation and long-term equilibrium) between multiple time series that are cointegrated. The three (3) multi cointegrated variables in the present study are the rainfall onset, rainfall cessation and rainfall length. The granger causality test of the Ibadan rainfall variables (IRV) indicated that all the rainfall variables are cointegrated except rainfall onset that does not granger cause rainfall length because the  $F_{(33; 0.05)} = 3.670$  is significant ( $P < 0.05$  – Table 4). The least significant cointegration for IRV (0.936) was obtained for “length does not granger cause rainfall onset” which implies that it is advisable to accept the alternative hypothesis. Similarly, the result of the granger causality test for the Akure rainfall variables (ARV) indicated that none of the multi cointegration analysis returned significant results for all (Table 4). Significant cointegration between rainfall variables (onset, length and cessation) established in the present study confirm the applicability of VECR in capturing both dynamic and equilibrium effects in environmental time series analysis. This is compatible with Sheu *et al* (2024) which established significant cointegration between climate variables and waste output.

**Table 4. Granger causality test**

|                                         |     | <b>Ibadan</b> |        | <b>Akure</b> |        |
|-----------------------------------------|-----|---------------|--------|--------------|--------|
| Null Hypothesis:                        | Obs | F-Statistic   | Prob.  | F-Statistic  | Prob.  |
| LENGTH1 does not Granger Cause CESSATN1 | 33  | 0.13911       | 0.8707 | 1.19218      | 0.3185 |
| CESSATN1 does not Granger Cause LENGTH1 |     | 0.75776       | 0.4781 | 0.79644      | 0.4609 |
| ONSET1 does not Granger Cause CESSATN1  | 33  | 0.67625       | 0.5166 | 0.61147      | 0.5496 |
| CESSATN1 does not Granger Cause ONSET1  |     | 0.2329        | 0.7938 | 0.3677       | 0.6956 |
| ONSET1 does not Granger Cause LENGTH1   | 33  | 3.66973       | 0.0384 | 0.12041      | 0.887  |
| LENGTH1 does not Granger Cause ONSET1   |     | 0.93625       | 0.404  | 1.70018      | 0.201  |

## Cointegration analysis

The results of the Johansen Cointegration analysis of the Ibadan Rainfall variables indicated that there is no cointegration between rainfall cessation and rainfall length at 5% significance level. This is due to the maximum eigenvalue (11.458) and trace statistics (13.180) that fall below the critical values ( $P > 0.05$  – Table 5). The cointegration analysis results of rainfall cessation and rainfall onset shows the existence of cointegration ( $p\text{-value} < 0.05$ ) for both "None" and "At most 1" hypotheses in the trace test, indicating a significant long-term relationship between these variables. Both the maximum eigen value (18.525) and the trace statistics (6.0599) were significant ( $P < 0.05$  – Table 5). Johansen Cointegration Analysis of rainfall onset and rainfall length indicated that cointegration is confirmed ( $p\text{-values} < 0.05$ ) in both trace and max-eigenvalue tests, indicating a strong relationship between onset and length. The Trace statistics and maximum eigen values obtained for the cointegration were both significant ( $P < 0.05$ ). The results of Johansen Cointegration analysis of the Akure Rainfall variables (ARV) also indicated no cointegration at 5% significance level. Both maximum eigenvalue (13.18) and trace statistics (15.495) fall below the critical values ( $P > 0.05$  – Table 5). The maximum eigenvalue (9.927) and trace statistics (13.054) obtained for the cointegration fall below the critical values ( $P > 0.05$  – Table 5). No significant cointegration is found between rainfall cessation and rainfall onset for Akure because both the trace statistics (12.750) and maximum eigen values (9.275) obtained for the cointegration were not significant ( $p\text{-values} > 0.05$ ). A weaker cointegration relationship is observed between rainfall onset and rainfall length for Akure because both the trace statistics (16.09) and maximum eigen values (12.47) were significant but close to 0.05 (Table 5). It is noteworthy to stress that Ibadan shows stronger evidence of cointegration, particularly in cessation-onset and onset-length interactions, meaning these rainfall characteristics have a stable long-term relationship. The weaker or no cointegration obtained for Akure implied that its rainfall fluctuate more independently over time. Disparity in the cointegration pattern of both Akure and Ibadan may indicate different climatic or environmental influences between the two locations, possibly due to geographical or topographical differences. Recent studies have employed similar methodologies to explore the impact of climate variables on agricultural productivity in Nigeria. Edaba *et al.* (2023) utilized Johansen cointegration and Vector Error Correction Model (VECM) techniques to assess the implications of climate change on oil palm production

trends from 1981 to 2020. Their analysis revealed a long-run relationship between oil palm production and climatic factors, emphasizing the significant impact of climate variability on agricultural outputs.

The disparities in cointegration trends suggest differing climatic or environmental influences, possibly due to geographical or topographical differences between the two locations (Akure and Ibadan). Research by Ogunbode *et al.* (2022) in Iwo, a city in southwestern Nigeria, indicated a general decline in rainfall over a 30-year period (1989–2018). This declining trend may influence the stability of long-term rainfall relationships, as observed in the cointegration analysis for Akure. Sobowale *et al.* (2016) examined the onset and cessation of rainfall in southwestern Nigeria, including Ibadan and Ondo (a city near Akure). The study found that Ibadan experienced an earlier onset of rains compared to other locations, while Ondo had a later cessation. This extended rainy season in Ibadan could contribute to more stable long-term relationships between rainfall variables, aligning with the stronger cointegration observed in the Johansen analysis.

Recent studies have highlighted the complex and dynamic nature of rainfall patterns across southwestern Nigeria. The Johansen cointegration analysis of the current study reflects these complexities, highlighting the need for location-specific strategies to address the challenges posed by rainfall variability.

Table 5. Johansen cointegration analysis of rainfall variables

|                                                                                             | Hypothesized<br>No. of CE(s) | Eigenvalue | Ibadan                      |                             |         | Akure      |                             |                             |         |
|---------------------------------------------------------------------------------------------|------------------------------|------------|-----------------------------|-----------------------------|---------|------------|-----------------------------|-----------------------------|---------|
|                                                                                             |                              |            | Max-<br>Eigen<br>Statistics | Critical<br>Value<br>(0.05) | Prob.** | Eigenvalue | Max-<br>Eigen<br>Statistics | Critical<br>Value<br>(0.05) | Prob.** |
| <b>Unrestricted Cointegration Rank Test<br/>(Trace - CESSATioN*LENGTH)</b>                  | None                         | 0.2933     | 13.1803                     | 15.4947                     | 0.1084  | 0.2598     | 13.0538                     | 15.4947                     | 0.1129  |
|                                                                                             | At most 1                    | 0.0509     | 1.7227                      | 3.8415                      | 0.1893  | 0.0904     | 3.1265                      | 3.8415                      | 0.0770  |
| <b>Unrestricted Cointegration Rank Test<br/>(Maximum Eigenvalue -<br/>CESSATioN*LENGTH)</b> | None                         | 0.2933     | 11.4576                     | 14.2646                     | 0.1327  | 0.2598     | 9.9273                      | 14.2646                     | 0.2167  |
|                                                                                             | At most 1                    | 0.0509     | 1.7227                      | 3.8415                      | 0.1893  | 0.0904     | 3.1265                      | 3.8415                      | 0.0770  |
| <b>Unrestricted Cointegration Rank Test<br/>(Trace - CESSATioN*ONSET)</b>                   | None *                       | 0.3146     | 18.5251                     | 15.4947                     | 0.0169  | 0.2450     | 12.7496                     | 15.4947                     | 0.1243  |
|                                                                                             | At most 1 *                  | 0.1678     | 6.0599                      | 3.8415                      | 0.0138  | 0.0999     | 3.4744                      | 3.8415                      | 0.0623  |
| <b>Unrestricted Cointegration Rank Test<br/>(Maximum Eigenvalue-<br/>CESSATioN*ONSET)</b>   | None                         | 0.3146     | 12.4652                     | 14.2646                     | 0.0944  | 0.2450     | 9.2752                      | 14.2646                     | 0.2640  |
|                                                                                             | At most 1 *                  | 0.1678     | 6.0599                      | 3.8415                      | 0.0138  | 0.0999     | 3.4744                      | 3.8415                      | 0.0623  |
| <b>Unrestricted Cointegration Rank Test<br/>(Trace - ONSET*LENGTH)</b>                      | None *                       | 0.3708     | 19.3963                     | 15.4947                     | 0.0122  | 0.3146     | 16.0882                     | 15.4947                     | 0.0407  |
|                                                                                             | At most 1 *                  | 0.1170     | 4.1069                      | 3.8415                      | 0.0427  | 0.1039     | 3.6205                      | 3.8415                      | 0.0571  |
| <b>Unrestricted Cointegration Rank Test<br/>(Maximum Eigenvalue -<br/>ONSET*LENGTH)</b>     | None *                       | 0.3708     | 15.2893                     | 14.2646                     | 0.0343  | 0.3146     | 12.4678                     | 14.2646                     | 0.0943  |
|                                                                                             | At most 1 *                  | 0.1170     | 4.1069                      | 3.8415                      | 0.0427  | 0.1039     | 3.6205                      | 3.8415                      | 0.0571  |

\*, \*\* significant at  $p < 0.05$  and  $p < 0.01$  respectively

## Conclusions

The stationarity and autocorrelation analyses indicated that some rainfall variables demonstrate temporal stability, making them suitable for further modeling. Notably, the Johansen cointegration tests revealed stronger long-term relationships between rainfall onset and cessation, as well as onset and length in Ibadan, while such relationships were weaker or absent in Akure. This suggests that rainfall patterns in Ibadan are more predictable over time, possibly due to localized climatic or topographic factors. These findings have significant implications for agricultural planning, early warning systems, and water resource management. The variability and weaker rainfall association in Akure highlight the need for adaptive, location-specific strategies in response to climate variability. Furthermore, the application of cointegration and causality analysis provides a robust framework for understanding long-term climatic interactions, contributing valuable insights to climate resilience efforts in Nigeria.

Future research could expand on these findings by incorporating other climatic variables such as temperature, humidity, or wind patterns, and by analyzing the potential impact of urbanization and land use changes on rainfall behavior.

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