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ARTICLE

Space-Time Oscillations in Rainfall Onsets and Their Implications on Sustainable Staple Crop Production in Imo State, Nigeria

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ABSTRACT

This study investigates the influence of space-time oscillations in rainfall onsets on sustainable staple crop production in agro-ecological zones from 1981 to 2023 in Imo State. The study area was stratified into three agro-ecological zones, comprising Imo East, Imo West and Imo North using stratified sampling techniques to ease data extraction. Data on rainfall onsets were obtained from NASA native resolution daily data PRECTOTCORR MERRA-2 using a gridded method 43 climatic years and analyzed using SPSS. The descriptive assessments of the monthly mean distributive patterns reveal that Imo East recorded the highest mean value of 369.2 mm in September, while Imo North recorded the lowest value of 15.19 mm in December. Also, the highest annual mean value of 68.419 mm is associated with Imo North, while the most dominant standard deviation and variance scores of 13.159 mm and 173.169 mm occur in Imo West agro-ecological zone. The time series with regression models of oscillations in rainfall onsets offered the generalized negative trends, but at varying rates. Comparatively, Imo West gives the highest predictive power of $-0.244x + 70.59$ and a corresponding highest R^2 value of 0.054 in the sequence, while the ANOVA model gives a low value of 0.466. The results led to a conclusion that variations in agro-ecological zones have no statistically significant effects on rainfall onsets. This study recommends an urgent need to boost farmers' adaptation capacity through proactive climate change education and training by agro-extension officers to

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increase crop production and sustainable food security in Imo State.

Keywords: Climatic Indicator; Rainfall; Planting Season; Onset; Sustainability; Crop Production

1. Introduction

The persistent will to increase staple crop production per land area in the humid Tropics and particularly in southeast Nigeria is sometimes frustrated by extreme climatic fluctuations of rainfall indices and temperature during the planting season. The aforementioned factors and lack of farmers' responsiveness to adapt or manage the extreme rainfall onset at different locations comprise a significant research gap. Time and money are needed to provide weather and climate information. In fact, more than 24 billion US dollars were spent on global climate information services while a comparable amount was spent on weather services with emphasis on near real-time [1]. But such information is either coarse-scaled or inaccessible to farmers.

The indices of the rainy season, in particular, onset, growing season length, cessation date and precipitation, are useful information for agricultural and water-related applications [2], but they can show variations in different places and years. Furthermore, the rainfall onset is a key variable for subsequent research on seasonal characteristics, such as the difference in rainfall between seasons such as the wet and dry periods [3]. Recent studies show that variations in rainfall onsets are associated with different methods applied and there are differences in the choice of onset dates [4–6].

Variabilities in rainfall onset have been reported as a major source of inconsistency and discrepancies of seasonal characteristics, such as rainfall season length, rainfall and dry days [3]. Therefore, different methods have been used to estimate the rainfall onset. These methods include the rain-based Agronomy method (also referred to as an adaptive method due to the constant adjustment of its parameters, according to the local climatic conditions) with wide usage [7,8]. One research simply lists three methods of onset estimation: agronomy, anomalous accumulation and a modified local [3]. Although all of the methods are widely used in geographical studies, their applications may vary depending on the researcher's focus and application.

The Precipittion-based Agronomy method adopted a general definition. Examples of past studies were the adoption of 5 days for the wet spell (w-days), 40 mm for the total precipitation during the wet spell (r) and 30 days for the time span (c), but various values had been adopted for the consecutive dry days (d-days) (e.g., Robertson et al. [7]; Moron et al. [8]). Particularly, this method had been used with ranges of 3, 40, 30 and 10 for the w-days, r, c and d-days respectively [3,8]. Second, is the method of Anomalous accumulation that aims at the flexibility of dealing with local issues without determining fixed parameters and thresholds such as Liebmann et al. [9]. Third is local accumulation of the rainfall as it is evident and explicit from Marjuki et al. [6].

Amidst the differences in approach to determining rainfall onset, the nature of information in farming decision-making has been reported in terms of how local knowledge; crop management; and the use of technical information have been used to mitigate agricultural risks. However, the seasonality of the forecast is typically produced from national weather services and the World Meteorological Organization (WMO) regional climate centres [10], which are mostly unavailable to farmers. The lack of farmers' ability to access and use the right information is a vulnerability to extreme variations in rainfall onset that can affect farming.

A recent study revealed that when farmers have access to timely weather forecasts, in-season risk management such as moving planting dates can be undertaken, and when farmers have access to seasonal forecasts, ex-ante risk management such as selecting crop varieties and crop type can be made [11]. Recently, it has been seen that lethargy, lack of location-specific rainfall data and/or technical competence in forecasting rainfall in the region are significant limiting factors in effective and sustainable people-centered agro-land policy settings [12]. Similarly, rain-fed cultivation of staple crops in southeast Nigeria is the norm because of the recent decades of meagre or diminished investments in regional irrigation and dam construction. This in turn inversely affects farmers' land preparatory practices and planting of varieties of cereals, legumes, vegetables, root and tubers that are reliant on the start of rainfall, to avoid the ravaging consequences of extreme events (like meteorological drought) and diseases.

Farmers' response to the oscillation in the onset of rainfall can be either planned or unplanned based on farmers' experiences and current conditions [13]. Such factors, particularly economic, cultural, political, financial, educational, traditional, geographical, ecological, and/or institutional conditions can influence farmers' perception and responsiveness to oscillations in rainfall onset in a farmland. It tends to create challenges at the local level to United Nations Sustainable Development Goal 1, Target 5, which states: "By 2030, in building for the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social, and environmental shocks and disasters" [14].

In contrast, in Nepal, the monsoonal period accounts for 80% of the rainfall in a year [15], but the longest periods of rainfall in Southeast Nigeria (Imo State) are registered during the long rainy season. Likewise, analysis of oscillation in Nepal reveals that the rainfall variability is an important factor in Nepal's drought and wet states [15,16]. Also, while 60% of the irrigable area relies on rainfall during monsoons in Nepal, more than 95 percent of staple food crops are rain-fed. Lack of adequate meteorological, hydrological and water resource infrastructure is also reported to make drought management difficult [17].

Similarly, subsistence farmers highly dependent on natural resources are highly prone to rainfall impacts, as observed by Hubertus et al. [18]. Likewise, research attention is basically concentrated on the linearized concept of trend in rainfall onsets and totals; Allen et al. [19] argued that slow onset changes in rainfall pattern, temperature and associated climate extreme events have led to a decline in food production and food security. In the flood of ideas, studies in East Africa are ignoring changes in extreme events, and the length and onset of rainy seasons [18].

In West Africa, Rauch et al. [20] used the Sudan-Sahel for rainfall variability. The circulation pattern model offers a wide range of positive economic impacts favouring decision-making in terms of various cost-loss scenarios as envisaged by Rauch et al. [20] and Bliefernicht et al. [21]. The trial of different new models, conventional forecasting techniques and approaches provided a new paradigm for validating and confirming seasonal rainfall variation.

In Mali, it is reported that there is an increasing period of rainy season from north to south [22], while a significant variability in the onset of the rainy season, with a trend towards increasingly delayed starts in Guinea-Bissau, is reported in the studies by Mendes et al. [23] and Mendes and Fragoso [24]. Overall, it is reported that there is a continuous increment in rainfall from the north (Sahelian zone) to the south (Guinea coast) by Diatta et al. [25], using CHIRPS data.

In a comparative analysis the use of rainy days is considered to be more effective, as the dates of onset and retreat of rainfall are more reasonable than those derived from rainfall amounts [26]. With respect to better quantification, several authors, such as Odekunle [26], Mason and Chidzambwa [27], and Pirret et al. [28], use WARCOF, SEAS5 TP and CP-based logistic regression approach to provide a better understanding of the different skills and weaknesses of each predicting rainfall variability model in the Sudan-Sahel zone. So, it is imperative to prioritise research focus from inter-annual rainfall predictions to onset only in the humid Tropics.

In the Coastal belt of Akwa Imo State (Nigeria), it is known that the mini farming settlements experienced a slight agricultural drought (R^2 = 0.0239–0.0568) [29]. This suggests the possibility of crop production for food security in the locale if the crops are selected based on rainfall pattern (i.e., water requirement). It is against the backdrop of the aforementioned that this research is germinated to examine the extreme scenarios of rainfall oscillations in the onsets in order to offer a better scope for the understanding and adaptation for sustainable agriculture in the diverse agro-ecological zones in Imo State.

Aim and Objectives

The aim of this study is to investigate the oscillations in rainfall onsets in the three distinct agro-ecological zones of Imo State, Nigeria. To actualize the aim, the following specific objectives were investigated.

1. To compare and assess the annual distributions of rainfall onsets across the Imo (North, East, and West) agro-ecological zones.
2. To determine the oscillations in annual rainfall onsets from 1981 to 2023 (43) climatic years in the three distinct agro-ecological zones.
3. To evaluate the patterns of oscillations in rainfall onsets for 43 climatic years in the three distinct agro-ecological zones.

4. To determine whether oscillations in geographical locations have statistically significant effects on annual rainfall onsets among the distinct agro-ecological zones of Imo State.

2. Materials and Methods

2.1. Location and Climate

Imo State is located at the heart of Southeast Nigeria. It is currently juxtaposed on the North and West by Anambra State while Abia State (with the much popular Imo River) is on the South and East. Moreover, it is also separated by Rivers State on the western flank as shown in **Figure 1**. In other words, the State stretches between Longitudes 6°7′13″ and 7°28′10″ East of Greenwich Meridian and Latitudes 5°10′00″ and 6°02′00″ North of the Equator as illustrated in **Figure 1**. The State is subdivided into three senatorial zones (Imo North, Imo West, and Imo East agro-ecological zones. The study area, as in 2016, is made up of 27 Local Government Areas and about 640 independent communities that are not even geographically spread [30], owing to the varying population distributions, socio-economic activities and geographical coverages respectively.

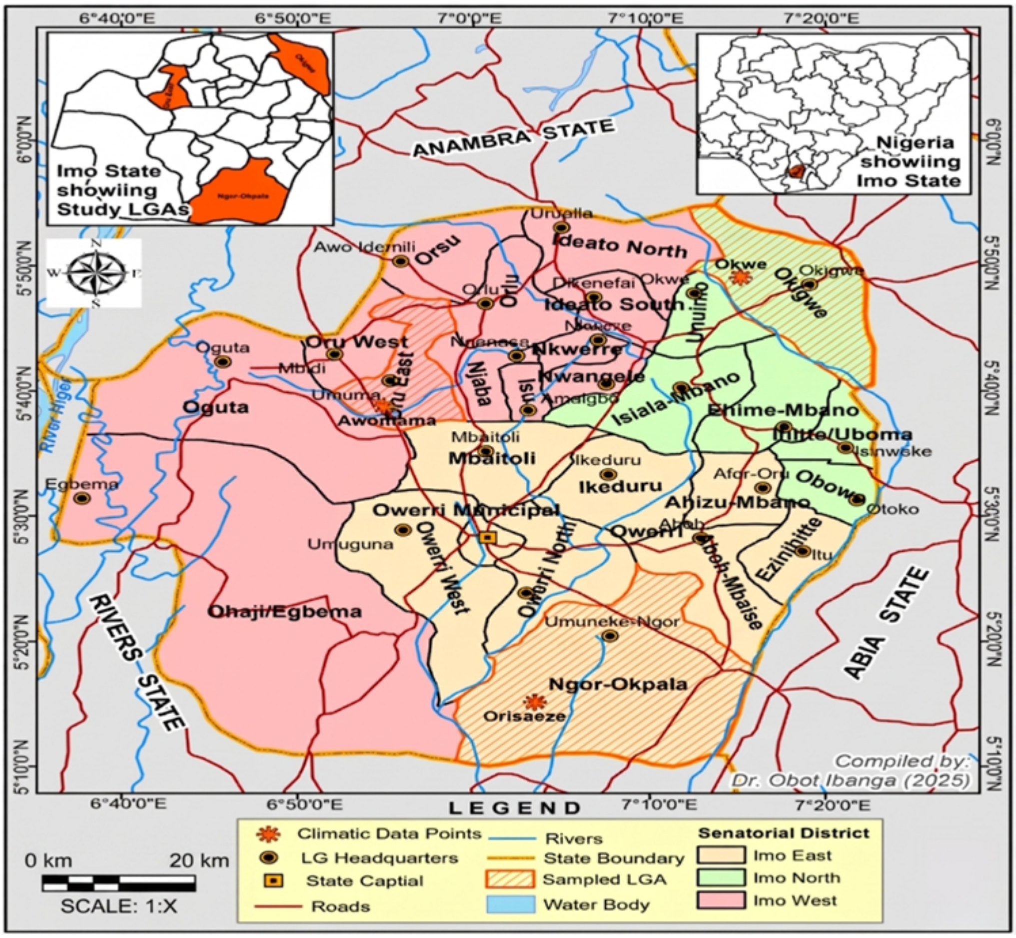


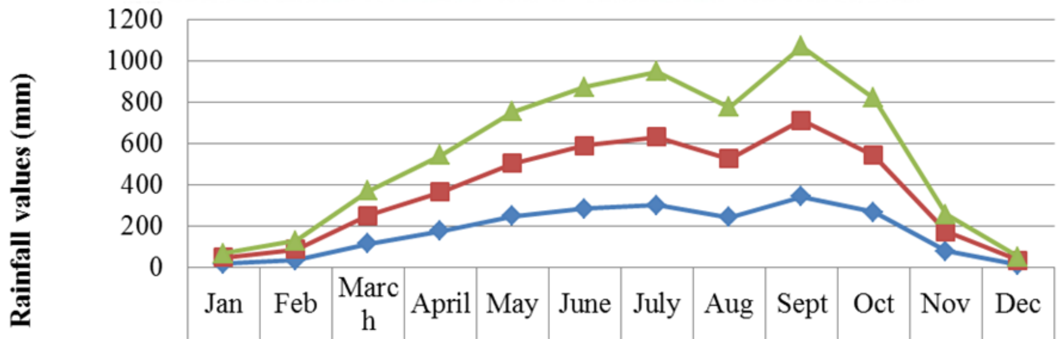
Figure 1. Imo State showing Agro-ecological Zones and Climatic Data Points.

Source: Compiled from authors' Fieldwork using GIS Version 10.3 (2025).

The weather and climate of Imo state are mostly humid tropical (Af) in Köppen's classification system [30,31]. Weather and climatic variables are differently distributed among the agro-ecological zones. The mean annual temperature measured is around 26.8 °C, accompanied by diverse cloud cover during long and short rainy seasons. But, synoptic scale weather thunderstorm and lightning affects the long rainy season. On the other hand, the study area often has a very clear sky and a quite calm night, but frequently higher sunny days in the long dry season. December and January suffer from the presence of harmattan, clouds and sun.

2.2. Rainfall Characteristics

The statistics of the temporal (monthly) distributions of rainfall for the period 1981–2023 (43 climatic years) are shown in **Figure 2** for the three agro-ecological zones, such that a comparative analysis can be made. As observed in the figure, there are variations in both space and time, with traces of uniformities. In terms of spatial monthly variability (in Imo North (Okwe)), the result showed that the mean monthly value of 345.3 mm is associated with the month of September, followed by 301.5 mm for July, while the lowest monthly mean rainfall value of 15.19 mm is recorded for December.



	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Imo West	21.24	41.59	119.3	179.1	247.4	282.8	317.3	250.1	357.2	276.7	83.37	17.55
Imo East	29.23	52.44	135.7	188.3	254.8	304.9	331	282.3	369.2	274.2	95.64	21.67
Imo North	20.65	37.46	116.3	178	251.5	287.6	301.9	243.9	345.3	270.7	80.53	15.19

Figure 2. Descriptive Analysis of Mean Monthly Rainfall Dynamics in Imo State.

Source: Data Analysis by the Researcher (2025).

In terms of Imo East (Orisaeze), the temporal analysis shows that the highest temporal value of 369.2 mm is recorded for the month of September, also a value of 331.0 mm for July; while the lowest value of 21.67 for the month of December followed by a value of 29.23 mm for January. In realm of the Imo West (Awomama) agro-ecological zone, the finding indicates that a highest mean monthly rainfall value of 357.2 mm is recorded in the month of September, followed by 317.3 mm is recorded in July, while a lowest monthly mean rainfall value of 17.55 mm is associated with the month of December followed by 21.24 mm is recorded for the month of January.

This is almost certainly replicated by the Imo West (Awomama) agro-ecological zone with the exception of the climatic month of October. On the second front, Imo North (Okwe) maintains fairly consistent lowest monthly rainfall totals in the series, with the exception of the climatic months of May and June, whose rainfall total of 251.5 mm and 287.6 mm respectively, shows considerable variations greater than Imo West in the sequence. The distributive features and seasonal duration of rainfall in the three agro-ecological zones of Imo State demonstrate the influence of the fluctuations and position of the Tropical Continental Convergence Zone, and Tropical Maritime Air Mass.

2.3. Area Demarcation and Data Extraction

The State of Imo was stratified into three (3) Agro-ecological zones of Imo North, Imo East and Imo West with Agriculture and political boundaries as indicators of Farming Systems (**Figure 1**). A strategic spot in each stratum was purposely chosen for the extraction of rainfall data, paying particular attention to areal differences and geospatial (locational) spread (**Table 1**). Primary and secondary sources of data were used for this study. Firstly, sources of data include direct measurement of locational coordinates (longitude and latitude) and altitude using Global Positioning System (GPS) and the result in **Table 1** and focus group discussion. By contrast, secondary data comprises rainfall data, published and unpublished reports from the internet and library sources respectively.

Table 1. Data Sources and Extraction Methods.

Ecological Zones	Data Site Extraction	Longitudes	Latitudes	Elevation	Durations
Imo East	Orisaeze	7.0803	5.2708	52.43 m	1/1/1981–31/12/2023
Imo West	Awomama	6.9329	5.6896	62.54 m	1/1/1981–31/12/2023
Imo North	Okwe	7.2173	5.7757	105.73 m	1/1/1981–31/12/2023

Source: Authors' Compilation (2025).

The methods adopted in identifying rainfall onsets vary from one researcher to another, due to their interests, choices, contents, contexts and ideologies. But, in this study, the precipitation-based Agronomy method was adopted due to its flexibility and adaptability to rainfall onsets in Imo State. With regard to context, it provides one of the unpretentious threshold values of the rainfall onset that is compatible with the specified climatic years and farmland management for the seasons.

Rainfall onsets for the 43 (1981–2023) climatic years were extracted using a gridded method. The gridded data were generated with the size of the grid cells 0.5° × 0.5° to extract timely rainfall onset at three different agro-ecological zones. This was extracted from the Climatic Research Unit (CRU) at the University of East Anglia [32], using CRU time series version 4.05 high-resolution gridded dataset between January 1st, 1981 and December 31st, 2023 (43) climatic years. The main reason is to circumvent the limitations of the location specificity of rainfall data archival from different locations of the Nigeria Meteorological Agency (NiMet's) in Imo State and Nigeria.

To ensure the validity tests of the rainfall data from NiMet Station (sites at Imo Cargo Airport) and rainfall data from the CRU site (Imo East Orisaeze) were conducted using quality control of data and coefficient of variation respectively. This is to avoid outlier/missing data (and results revealed a very high (0.92) coefficient. It is important to note that the raster data from CRU were prepared monthly and the annual sum was computed with the help of a raster calculator as recommended and adapted in recent studies from Abaneme et al. [12], Okoro et al. [33], Chen et al. [34], and Ezemonye et al. [35].

2.4. Method of Data Analysis

The descriptive statistics such as, mean, standard deviation and variance were used to scrutinize and compare trends of oscillations in rainfall onsets across agro-ecological zones of Imo state. Inferentially, linear regression time series was used to measure the trends; and to model/predict annual oscillations of rainfall onsets in Imo State. The multiple effects of variations in locations of the three agro-ecological zones were assessed using linear regression analysis. The analysis of variance was modified to test for multiple effects of variations in locations on the distribution patterns of rainfall onsets in Imo State.

3. Presentation of Results and Discussion

The statistical analyses of the annual monthly and annual features in rainfall onsets, annual rainfall trends and differences exhibited by different Agro-ecological zones of Imo State are presented and discussed chronologically in the following discourses.

3.1. Assessments of Monthly and Annual Oscillations in Rainfall Onsets

Descriptive analyses of annual rainfall onsets for 43 climatic years in Imo State, the results as presented in **Table 2** show that a maximum value of the mean score of 68.419 mm belongs to Imo North, relatively similar mean scores of 65.233 and 65.209 mm are associated with Imo East and Imo West respectively. Contradictorily, a minimum standard deviation of 11.276 mm is recorded at the Imo North (with a maximum recorded at the Imo West (13.159 mm) and a mean at Imo East (12.489 mm) agro-ecological zone. In retrospect, the spatial variances in rainfall onsets at the three agro-ecological zones are consistent with the minimum rainfall to qualify the precipitation agronomy method, however, there are sharp increases in Imo North.

The results of the occurrence of rainfall onsets in the different sampled agro-ecological zones presented in **Table 3** show spatial and temporal patterns. In terms of spatial homogeneity of similarities, Imo East and Imo West agro-ecological zones recorded the earliest onset of rainfall on the same date of 10th February 2014, while that of Imo North and Imo West recorded the late onset dates of 1st April, 2004 respectively. On the basis of differences, Imo North recorded early rainfall on 15th February 1982 and 2003 in successive years while Imo East recorded late rainfall on 1st April 1998. The evaluations of rainfall onsets as shown in **Table 3** also reveal the general patterns of homogenous convergences on climatic month of 8th March for Imo East and Imo North agro-ecological zones, but on 5th March for Imo West agro-ecological zone.

Table 2. Descriptive Analyses of Rainfall Onsets in Imo agro-ecological Zones.

Ecological Zones	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Imo_West	43	41.00	92.00	65.209	13.159	173.169
Imo_East	43	41.00	91.00	65.233	12.489	155.992
Imo_North	43	46.00	92.00	68.419	11.276	127.154

Source: Authors' Analysis (2025).

Table 3. Descriptive Analysis of Characteristics of Rainfall Onsets in Imo State.

Ecological Zone	Data Points	Early Onset	Late Onset	Mean Onset
Imo North	Okwe	15th February, 1982, 2003	1st April, 2004	8th March
Imo East	Orisaeze	10th February, 2014	1st April, 1998	8th March
Imo West	Awomama	10th February, 2014	1st April, 2004	5th March

Source: Data Analysis by the Researchers (2025).

3.2. Linearized Modellings of Space-Time Oscillations in Rainfall Onsets

In order to reveal the trends in rainfall onset variations in the three agro-ecological zones of Imo State, a regression model with time series was used and the results delineated under the following figures for Imo North, Imo East and Imo West respectively display dynamics in rainfall onsets, but with a consistent decrease. The intra-specific assessment of the results (**Figure 3**) for Imo North reveals that 17 climatic years converge above the line of best fit (average line) and this suggests an increase in annual rainfall onset.

In contrast, a relatively large number of 22 climatic years converge below the average line which implies the trends decrease in rainfall onset in the Imo North agro-ecological zone. The consequences of very high uncertainties in the outlier climatic years are delayed planting, death of exotic crops and poor yield. But, only the remaining 3 climatic years converge above the average line in the series. Similarly, the further comparison s of the results in **Figure 3** show that the highest magnitude of 92 mm rainfall onset occurred in 2004, followed by 91 mm in 1998 climatic years. Conversely, the lowest rainfall onset of 40 mm was recorded in 1982 and 2003 consecutive climatic years and 53 mm in 2018 climatic year.

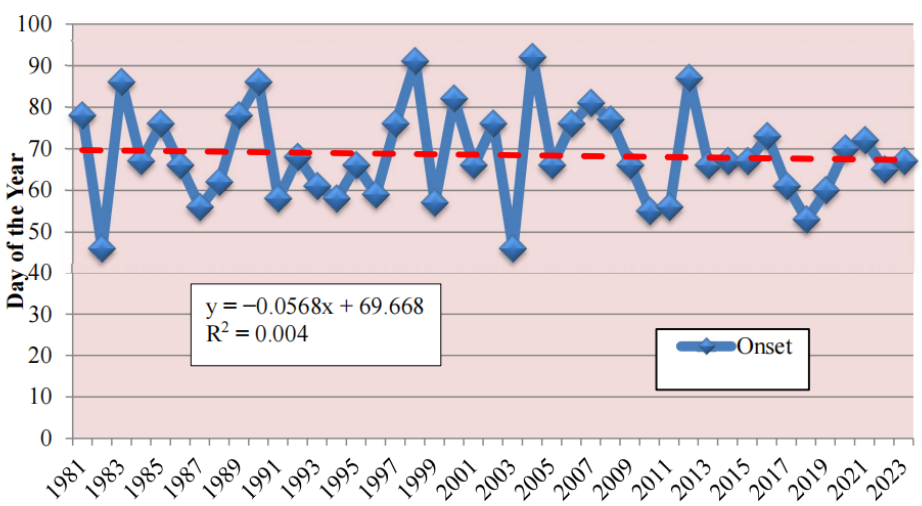


Figure 3. Analysis of Temporal Trend of Rainfall Onset in Okwe (Imo North).

Source: Data Analysis by the Researchers (2025).

The oscillatory nature of the linearized model of the dynamics in rainfall onsets is shown in **Figure 4** for the Imo East agro-ecological zone. The numerical analysis of the model shows that the total of 15 climatic years exhibits positive trends and convergence above the line of best fit (regression line) of rainfall onset. Conversely, the dominance of 19 climatic years' events converges below the model line of best fit. But the remaining 7 climatic years' events converge on the average line. At the event level, the results depict a highest positive onset of 91 mm in 1998 and 2001 climatic years, followed by a value of 86 mm for 1983 climatic year; with a lowest onset of 41 mm in 2014 climatic year, and a constant onset value of 46 mm on average in 1982 and 2001 climatic years.

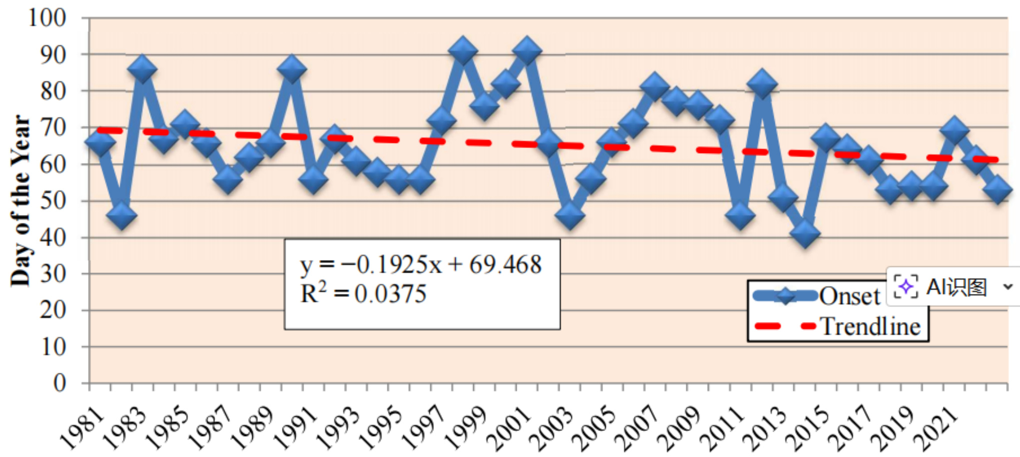


Figure 4. Analysis of Temporal Trend of Rainfall Onset in Imo East (Orisaeze).

Source: Data Analysis by the Researchers (2025).

At the Imo West agro-ecological zone the regression model with time series analyses of the temporal trends of annual rainfall onset highlighted in **Figure 5** reveals variations. The site-specific observations show that a cumulative total of 16 climatic years shows converging trends with values above the line of average, whereas a total value of 21 climatic years exhibits oscillations in annual rainfall onsets converging below the regression line. However, a total of 5 climatic years only show rainfall onsets in the average value.

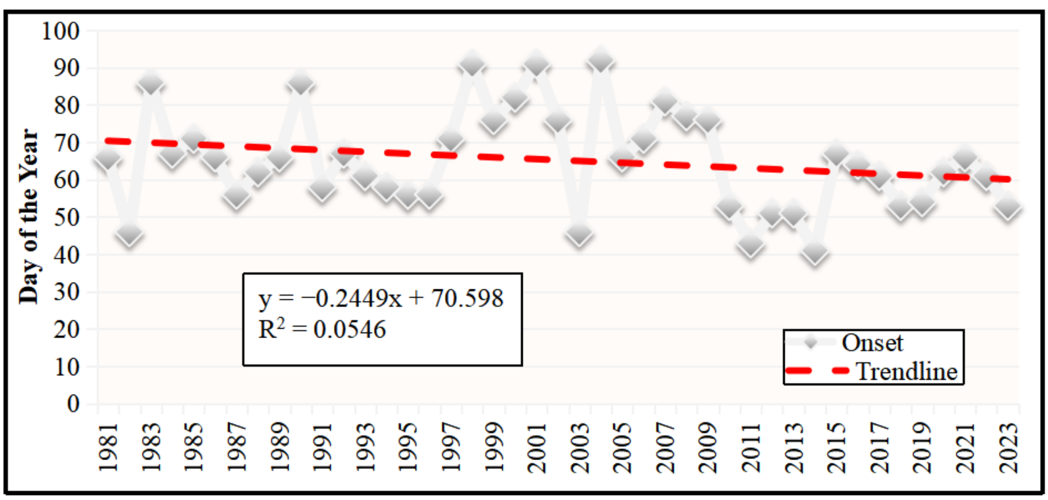


Figure 5. Analysis of Temporal Trend of Rainfall Onset in Awomama (Imo West).

Source: Data Analysis by the Researchers (2025).

The basis of specific annual trends, the result in **Figure 5** shows a highest value of positive trend for 92 mm is recorded in the 2004 climatic year, and followed by a value of 91 mm, which is recorded again in the 1998 and 2001 climatic years, respectively. In contrast, the minimum, the rainfall onset value of 41 mm was observed during the 2014 climatic year with an accompanying value of 43 mm recorded in Imo West during the 2011 climatic year. The outcomes of **Figures 3–5** confirmed Fitzpatrick et al.[5] and Marjuki et al.[6] that the oscillations in rainfall onsets between the sites are linked to the methodology and method of choosing the onset dates.

3.3. Predictive Models of Trends and Patterns in Rainfall Onsets

The comparative assessment of the spatial-temporal models of oscillations of rainfall onsets in the three agro-ecological zones of Imo State is shown in **Table 4** and the regression models vary. The Imo North result of the regression model offers the lowest desirable predictive pattern of −0.056x + 69.66, and a subsequent lowest positive coefficient of −0.004, which explains a total of 4% of the proportion of variance in rainfall onset. In the Imo East, the model gives a moderate fit −0.192x + 69.46 series in the rainfall onset. The result varies from what was reported by Rauch et al.[20] and Pirret et al.[28] in the Sudan-Sahel region partly because of the variability in the models, locational characteristics and the influence of the Inter-Tropical Convergence Zone.

The regression model also provides a relatively comparatively lower coefficient of 0.037 that explains a 3.7% of the total variance in the annual rainfall onset in Imo East agro-ecological zone. Finally, in the order of magnitude, the regression model of the rainfall onsets suggests Imo West has the highest predictive value of −0.244x + 70.59 in the model series and the highest regression coefficient of 0.054 which accounts for a 5.4% of the proportion variance of rainfall onset in the study area (**Table 4**). The findings are in line with reports of Isaiah et al.[29,36] in Ikot Ekpene that point to an indication of a meteorological drought, but with high potential for crop production without the need for irrigation.

Table 4. Spatiotemporal Trend in Rainfall Onset in Imo Agro-ecological Zones.

Ecological Zones	Data Points	Regression Equation	Pattern of Trend
Imo North	Okwe	$y = -0.056x + 69.66, R^2 = 0.004$	Decreasing
Imo East	Orisaeze	$y = -0.192x + 69.46, R^2 = 0.037$	Decreasing
Imo West	Awomama	$y = -0.244x + 70.59, R^2 = 0.054$	Decreasing

Source: Data Analysis by the Researchers (2025).

3.4. Evaluation of the Effect of Locations on Space-Time Oscillations in Rainfall Onsets

An attempt to analyse the impacts of variation in locations using a multiple linear regression and ANOVA as a proxy to assessing the effects on the linear combination of rainfall onset in the selected agro-ecological zones in Imo State, the results in **Table 5** reveal a corresponding low regression coefficient. Specifically, a multiple coefficient of determination exhibited a value of 0.186 which infers that a total of 18.6% changes in the rainfall onset across the different agro-ecological zones have been associated with oscillations in locations.

A juxtaposition of the results also shows that the regression square gives a corresponding very low coefficient of 0.035 while the coefficient of the adjusted regression square offers a corresponding very low negative coefficient of −0.040; hence suggesting very weak locational influence on rainfall onset in the distinct agro-ecological zones in the State. The review of farmers' experiences evidently established a fairly consistent negative impact of extreme rainfall onset on planting and yield within the different climatic years.

Table 5. Summary of Regression Model of Multiple Effects Variance among Parameters.

Model	R	R-Square	Adjusted R Square	Std. Error of the Estimate
1	0.186[a]	0.035	−0.040	0.84692

Note: [a] Predictors: (Constant), Onset_Okwe, Onset_Orisaeze, Onset_Awomama. Dependent Variable: Location.
Source: Authors' Analysis (2025).

A comparison of the model outputs presented an agreement with Mugalavai et al.[37] who observed in Kenya a weak positive correlation between the onset and cessation date. In this regard, it is inferred that a variance in the location of the agro-ecological zone in Imo State is likely not to affect farmers' perception towards planting and cultivation in the study area. Jointly, the focus group discussions showed that respondents' farming practices are hinged on rainfall seasonality within these zones. As a result, negative shifts in rainfall events have drastic negative impacts on various staple crops like cassava, maize and yams caused by short-term and long-term meteorological drought.

In an attempt to find multiple effects of variability of location on the linear combinations of rainfall onsets, ANOVA is used. The table below (**Table 6**) shows that variance of regression squares gives 1.003 as a sum of regression squares and 27.974 as a sum of residual squares (which contribute to a variance of total squares of 28.977). Similarly the mean squares are 0.334 and 0.717 (regression and residual respectively). The results of the ANOVA model give a low positive value of 0.466, statistically insignificant at 0.05 confidence levels; hence, contradicting reports in the same morpho-climatic zone of Nigeria[38,39] show a high variability in terms of the statistical content and context.

Table 6. ANOVA Model of Effect of Variations in Location on Rainfall Onsets.

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	1.003	3	0.334	0.466	0.708[b]
Residual	27.974	39	0.717		
Total	28.977	42			

Note: Dependent Variable: Location. [b] Predictors: (Constant), Onset_Okwe, Onset_Orisaeze, Onset_Awomama.
Source: Authors' Analysis (2025).

This study, therefore, revealed that the changes in locations have no significant influence on rainfall onset among the agro-ecological zones in Imo State. In spite of the variations in variables of rainfall indices, the results confirm Abaneme et al.'s[12] finding that differences in locations have no statistically significant effect on rainfall distributions during the length of growing seasons among the different agro-land zones in Imo State.

4. Implication of Findings on Sustainable Staple Crop Production

Our preceding discussions of the findings on rainfall onsets in Imo State's agro-ecological zones reveal variations within and between different climatic years and unit areas. The largest rainfall onset scenario of 92 mm was recorded at the same time in Imo North and Imo West agro-ecological zones of the 2004 climatic year. On the other hand, the smallest rainfall onset of 41 mm was also recorded homogenously in Imo East and Imo West agro-ecological zones of the 2014 climatic year. The distributional patterns of rainfall onsets across the different agro-ecological zones matched with the standard criteria and protocols defined under our choice option, with the capacity to enhance a relatively homogenous period of cultivation and crop planting to suit climatic influences.

The dimensional evaluations of trending with linearized models in our three agro-ecological zones confirm the negative homogeneous patterns. However, the patterns and differences in the predictive powers are observed, where the Imo West agro-ecological zone (**Figure 4**) has the highest value and is followed by the Imo East agro-ecological zone (**Figure 3**). The findings indicate that the two zones of agro-ecology are liable to experience early onset of the rainfall and start farm preparation for staple crop cultivation and production comparatively earlier than those in the Imo North agro-ecological zone.

This supports a belief that timing of rainfall onset is important for studying the characters of season, such as variations in rainfalls of a wet and a dry seasons[3], particularly with respect to uncertainties resulting climate variability and change The uncertainties in rainfall onsets have direct relationship with the onset of the relative northward movement of Inter-tropical Convergence Zone (ITCZ) this support dominance of Topical Maritime Airmass whilst strong relationship with local geographical factor, nature type of vegetation, topography, availability of water bodies, industrialization, urbanization and population.

The multiple effects of variations assessment demonstrate a very low regression coefficient of 0.040 to 0.035, which indicates that differences do not exist in the State, in terms of location of agro-ecological zones and the timing of rainfall for land preparation and the timing of rainfall onset for planting of staple crops among farmers. The observed uniformities in rainfall onsets prevailed in the State as a direct corroboration of Umos' [39] notion of relatively homogeneous temperature and rainfall regime in the tropics. So the location of agro-ecological zones has almost zero variance in rainfall onset. Also, test for multiple effects of locations in time and space oscillations in rainfall onsets showed statistical insignificance (**Tables 5** and **6**) and thus negated the reports of high levels of statistically significant differences in diverse parameters across regions [17,27,29,40].

This means that despite the study area's rainfall onset showing homogenous negative trends at varying levels, farmers' decisions-making and response in staple crop growing and farm management for sustainable crop production and food security may have been influenced by complex factors [38,39,41] including choice of crop, farmers' knowledge/experiences through the years, availability/accessibility/use of effective incentives and farmers' adaptive capacity to extreme stressors and rainfall onset.

5. Conclusion

This study reveals that farmers' knowledge and understanding of rainfall onsets are crucial for land preparation for staple crop cultivation (e.g., cassava, yams, maize, and sorghum) in various parts of Imo agro-ecological zones as all crops in the study area are rain-fed. The description of oscillation dynamics and trend confirms the diminishing order of negative predictive model of scenario in each of the zones. Specifically, extreme scenarios have impacted negatively on sustainable staple crops (such as cassava, maize, and yams) production in the State because of low levels of responsive/adaptive capacities.

Likewise, the FGD suggests contrasting negative impacts on the crop production as well as uncertainties in planting season due to scarcity of raindrops (resulting in the presence of drought after planting) resulting in losses. These losses are sometimes aggravated by weak adaptive measures (specifically relating to zero farm irrigation, non-avialbility of drought-resistant species and lack of capital among some farmers in the different agro-ecological zones).

Effects of location on oscillations of rainfall onset, the ANOVA test in this study showed a conclusion that changes in location have statistically insignificant effects on annual rainfall onsets among the different agro-ecological zones of Imo State. Thus, temporal and spatial variations of annual rainfall onsets do not have an impact on farmers' timing and responsiveness to staple crop farming in Imo State as a result of the assumption of thermal and rainfall uniformity in the Tropics. As a result, crop farmers prepare land, sow and cultivate crops in the state almost simultaneously. Failure to undertake preparatory activities and adapt to extreme rainfall onset and related situations influences farmers' unresponsiveness to cultivation and yield per farming land in each zone and vice versa.

5.1. Recommendations

In light of the results and conclusions made in this study, we recommend that:

(i) Intermediate stakeholders and stakeholders invest more in farmers' education on climate change response and adaptation to the major drivers of change in the timing and responsiveness to the optimal cropping in the State to ensure food security and reduce losses.

(ii) Ensure supplies and encourage cultivation of adverse weather and disease-resistant crop cultivars to farmers and other land users for increased productivity and yield. Several types of interventions such as the direct supplies of seedlings and farm inputs, interest-free loans etc., to farmers from government ministries/agencies, farmers' cooperatives, and other international agencies, will promote food security and stability. Similarly, such proactive approaches will increase the youth and women's participation in agricultural production and boost the level of United Nations Sustainable Development Goal I, Target 5 [14] from the community level to the state and regional level.

(iii) Despite heavy investments in power, road infrastructure, and social infrastructure by the Imo State Government to increase compliance with some of the United Nations Sustainable Development Goals and Targets, recent individual and group efforts to reduce the effects of climate change-induced rainfall uncertainties on the production of staple food crops are also partly limited by low capacity building. There is a dire need for the building of mega dams and irrigation projects in the three agro-ecological zones of Imo State and other States in the Southeast and South-south Nigeria. Such multiplier effects of infrastructure projects will encourage location-people-based adaptation strategies, support sustainable crop productions, diversify food bowl, alleviate poverty, lessen youth employment issues, deter insecurity and support economic diversification.

5.2. Limitations and Suggestions for Further Studies

This work has dealt with onset of rainfall using only three different meteorological units in Imo State, thus presenting a gap for future researchers to add more meters to two or three meteorological sites in each region of the State. This will then provide a different method for a more robust linear and non-linear statistical modelling and results generalization on the rainfall onset.

Furthermore, this study is unified with a descriptive design in which an overall picture of the phenomenon - the rainfall onset - has been constructed. Future research will need to consider a cross-sectional/ longitudinal design in data collection using rainfall, temperature and farmers' perception on rainfall onset with more quantitative and geospatial analyses to enable regional crop production.

Also, the influence of natural factors of rainfall change (e.g., elevation, distance from the river, plant, land use, population) was not discussed. Efforts should be made to include natural and human factors influencing rainfall pattern in the area.

Author Contributions

Writing of original manuscript, resources, analysis, methodology, data curation, I.S.U.; conceptualization, I.S.U. and A.O.A.; editing, A.O.A. and I.G.U.; investigation, A.O.A., I.G.U., and C.E.O.; review, I.S.U., A.O.A., and C.E.O.; project supervision, funding acquisition, A.O.A.; visualization and software, I.G.U.; validation, C.E.O. All authors have read and agreed to the published version of this manuscript.

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Data Availability Statement

The data for this article were extracted from the University of East Anglia Climatic Research Unit (Harris, Jones, Osborn & Lister, 2020), CRU time series version 4.05 of high resolution gridded. Details can be obtained from the authors.

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Conflicts of Interest

The authors declare no conflict of interest.

AI Use Statement

The authors declare that no artificial intelligence (AI) tools were used in the preparation of this manuscript.

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