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Spatio-Temporal Analysis of Rainfall Variability and Growing Season Dynamics in Nasarawa State, Nigeria

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Abstract

Rainfall variability has implications for agricultural planning and water resource management in Nasarawa State, Nigeria. This study examined rainfall trends, interannual variability, and growing-season dynamics over the 27-year period from 1997 to 2023. Monthly rainfall and rainy-day data obtained from the Nigerian Meteorological Agency were used to assess annual rainfall totals, rainy-day counts, rainfall onset and cessation, and length of growing season (LGS). Variability was examined across two subperiods, 1997–2010 and 2011–2023, while trends and statistical significance were assessed using linear regression and Student's t-test. Mean annual rainfall increased by 95.4 mm in 2011–2023 relative to the mean of 1,189.6 mm recorded in 1997–2010. Mean annual rainy-day counts increased slightly from 177 to 179 days, whereas mean LGS declined from 187 to 186 days. Across the full study period, mean annual rainfall was 1,235.5 mm, with a coefficient of variation of 0.12. Rainfall anomalies shifted from −64 mm during 1997–2006 to +29.8 mm during 2007–2016 and +49.6 mm during 2017–2023. Rainy-day counts varied slightly across these intervals, while LGS remained comparatively stable. Regression analysis indicated upward trends in annual rainfall and rainy-day counts amid interannual fluctuations. Overall, the findings indicate a changing rainfall regime characterized by increasing rainfall totals without a corresponding extension of the growing season. The study provides evidence to inform agricultural and water resource planning and highlights the need for improved seasonal forecasting and stronger climate adaptation strategies to support resilience in the state's predominantly agricultural economy.

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Keywords: Rainfall Variability; Rainfall Trends; Growing Season Length; Climate Adaptation; Nasarawa State

INTRODUCTION

The rising rate of radical weather and the changing weather patterns across the world, especially as they are being experienced through changes in rainfall, have been an issue of concern in environmental sustainability and socio-economic development. The change in the distribution, intensity, and duration of rainfall has a significant impact on the rain-based agricultural systems and the water resource management, particularly in the developing areas with livelihoods that are highly climate sensitive (Abubakar et al., 2024). In sub-Saharan Africa, the variability of rainfall has become one of the most important climate change indicators that affects crop yield, hydrology, and the stability of ecosystems.

The rainfalls in Nigeria are getting more complex, with certain areas registering a decrease in the rainfall amounts in a year, whereas others register increased rainfall. These opposing trends pose environmental threats as well as the opportunities of planning agriculture and optimizing the use of the water resource (Salami, 2024). The localized nature of the rainfall distribution patterns in the ecological zones also makes it challenging to adapt to such conditions, and thus localized analyses are also necessary. These dynamics are of special interest, especially in states that are located in transitional ecological belts with climate systems that are interacting and are highly variable.

Nasarawa State is found in the main Nigeria in the Guinea savanna ecological region, and the main farming economy is rain-fed, making it highly affected by the rainfall changes. Recent climatic evaluations have reported statistically significant changes in minimum temperatures and maximum temperatures in certain parts of central Nigeria, with changes in some instances of increased rainfall or decreases or variations in rainfall amounts. This forms the direct effects of such combined temperature and rainfall change on the balance of soil moisture, the evapotranspiration rate, and crop performance, which have dire consequences on agricultural productivity and food security (ABDULLAHI et al., 2025; AYANLADE et al., 2023). The new trends indicate the necessity of constant observation and thorough study of rainfall properties on a state basis.

Variability in rainfall is not just about the sum of rainfall per season but also the time and distribution of the rainfall. Parameters like onset and cessation of rains, intensity, duration, and periodicity are important determinants of the success of agriculture. Late germination has the capacity to reduce the duration of the planting period, and early termination can lower the duration of the growing period and, hence, crop maturity and yield potential. This means that an all-inclusive spatio-temporal study on rainfall changes and growing seasons will be necessary in the planning of agriculture sustainability (Fayose, 2025).

Analytical methods, in particular the spatio-temporal ones, facilitate the concurrent evaluation of changes both spatial and temporal in nature, which subsequently leads to a more integrated view of the behavior of climatic conditions. It is this type of analysis that is the key to building the robust agricultural practice, scheduling of irrigation, and maximizing the water resource distribution under new climate conditions (Balogun et al., 2023). Through the exploration of the characteristics of rainfall during long durations, trends, cycles, and the short-term random variations and long-term climatic changes can be identified.

The purpose of this study is thus to determine the relationship between the rainfall variability and agricultural growing seasons in Nasarawa State quantitatively using the spatio-temporal methods of analysis. Some of the important parameters that are studied are the onset and cessation of rainfall, totals of cumulative rainfall, rain days, and the length of the growing season. These variables play the key role in comprehending the aspects of the cropping calendar, water availability, and adaptation mechanisms in rain-fed agricultural systems (Tyubee & Iwan, 2024).

The problem of monitoring the rainfall anomalies across geographic areas and long-term scales, however, is very methodological. Complete spatio-temporal evaluations can be limited by data constraints, discrete station placement, and meteorological gaps (Olayide et al., 2024). Nevertheless, in-depth climate studies are still obligatory, especially in such nations as Nigeria because agriculture plays a significant role in terms of job creation and economic resilience (Okunlola et al., 2021).

The research will fill a critical knowledge gap in localized climate variability research because it specifically examines the problem of Nasarawa State. Although bigger regional studies give more general information, state analysis gives more detailed information

needed to carry out specific adaptation planning and agricultural decision-making (Omay et al., 2023). Due to the predominantly rain-based farming in West Africa, the uncertainty in the rainfall variability shapes the crop performance and sustainability of water resources to a considerable degree (Wabi et al., 2021).

Also, the study of the monsoonal rainfall attributes such as the actual onset, discontinuation, and the correlation of cumulative rainfall with the growing season duration is important in climate adaptation planning in the Sudano-Saharan and Guinea Savannah zones of Nigeria (Umar et al., 2021). Determining rain patterns and cycles improves prediction power and contributes to positive climate-risk management. The results of these analyses are also used in developing mitigation measures that can stop the negative impacts of climate variability on agricultural systems (DT et al., 2025; Fuwape & Ogunjo, 2022).

In light of these considerations, this study provides a comprehensive spatio-temporal evaluation of rainfall variability and growing season dynamics in Nasarawa State over a multi-decadal period. The findings are expected to inform agricultural planning, strengthen climate adaptation policies, and support sustainable water resource management within the state and similar agro-ecological zones in Nigeria.

Considering these factors, this research study proposes an extensive spatio-temporal analysis of rainfall variability and growing season dynamics of Nasarawa State, during a multi-decadal timeframe. The results will be utilised in agricultural planning, reinforcement of climate adaptation policies and enhancement of sustainable water resource management in the state and other agro-ecological regions in Nigeria.

Methods

Study Area

The study was carried out in the Nasarawa State, Nigeria, which is the North Central part of the country (around 7.0 o -9.5 o N latitude and 7.5 o -9.5 o E longitude). The climate of the state is tropical savanna with clear wet (April- October) and dry (November- March) seasons. It has a diverse topography which comprises of plains, hills and river valleys which affect local rainfall distribution and agricultural yields. The research took the three ecological regions of the state (Northern, Central, and Southern) into consideration as a way of acknowledging the spatial differences in climate and growing conditions.

Data Preprocessing and Data Collection

The data of daily rainfall that was recorded by the Nigerian Meteorological Agency (NiMet) was used to find the historic data on daily rainfall in Nigeria in the 1980–2025 period, and it was cross-validated with Global Precipitation Measurement (GPM) satellite data to confirm their completeness and accuracy. In order to supplement rainfall analysis, it was also collected, and the daily minimum and maximum temperatures were also recorded, because these affect the growth of crops and the time the growing season occurs. The rainfall records were also summed up into monthly and dekadal sums to help in making phenological analyses. The multiple imputation and linear interpolation functioned to cover the missing values whereas the 3-sigma rule was used to identify the outliers and checked with the historical record. This preprocessing guaranteed the continuous and correct dataset that could be analysed both in time and space.

Analysis of the variability of rainfall

In a bid to determine interannual and seasonal variability, a number of statistical indicators were used. Calculation of the coefficient of variation (CV) to measure relative variability and Rainfall Anomaly Index (RAI) to determine abnormally wet or dry years was carried out. The MannKendall test was used to analyse the temporal variation of rainfall, such as the onset, cessation, and overall seasonal values, with slope estimator by Sen giving the strength of variation. Kriging interpolation analysis of the spatial variability was done using ArcGIS 10.8 to give continuous rainfall surfaces that capture geographic patterns throughout the state. Moreover, the time series decomposition methods were used to distinguish between the trend, seasonal, and residual values of the rainfall records to enable one to see long run changes better.

Growing Season Dynamics

The cumulative rainfall method was applied in order to evaluate the dynamics of the growing season. The onset of rainfall was considered to be the first dekad on a dry spell where cumulative rainfall had a value of more than 20mm in two consecutive dekads, and the termination was the final dekad prior to a dry spell marking the end of the productive rainy season. Length of Growing Season (LGS) was determined as days between the initiation and termination. GIS raster analysis was used to map spatial differences in LGS in Nasarawa State and identified regions with reduced or extended growing seasons which could have impacts on agricultural planning and crop production.

Software and Validation

R 4.3 was used in data processing, statistical analysis and trend detection and ArcGIS 10.8 in spatial interpolation and mapping. Preliminary data aggregation and plotting were performed in the Excel 2019. In order to have the reliability of the results the satellite-derived rainfall estimates of GPM had been compared to the station data with measures of root mean square error (RMSE) and Coefficient of Determination (R^2). This is a validation of the stability and soundness of the datasets utilised in the temporal as well as spatial analysis.

Source of Data

The data for this research were obtained from secondary source. Data of monthly rainfall amount and rain days (1997-2023) for thirteen (13) Local Government Areas were obtained from the Nigerian Meteorological Agency (NiMET), Abuja.

Trend Analysis

As recommended by WMO (1988) cited in Lawrence (2021), the simple method which measures climate variability by dividing the climatic time series into two periods of equal length was used to establish/determine climate variability. The two equal length time scales used are 1997-2010 and 2011-2023. The climate variability was computed by

$$Cv = \mu_1 - \mu_2 \quad \text{----------(4)}$$

$$Cv = \sigma_1 - \sigma_2 \quad \text{----------(5)}$$

Where $Cv =$ climate variability, $\mu_1 =$ mean of the first time scale, $\mu_2 =$ mean of the second time scale, $\sigma_1 =$ standard deviation of the first time scale and $\sigma_2 =$ standard deviation of the second time scale

The estimate of the magnitude of the trends in annual rainfall, annual maximum, minimum and mean temperatures for 27 years and their statistical significances were obtained. The method employed in detecting the trend of the climatic variables was the parametric student's t-test. This was performed by regressing climatic variables (y) on the time (x). This assumed a linear trend in the time series. The regression analysis was carried out considering time as independent variable, while annual rainfall, rain days, length of growing season, annual maximum, minimum and mean temperature as dependent variables.

$$Y_i = \beta_0 + \beta x_i - \varepsilon_1 \text{ ----------(6)}$$

Where $Y_i = i$ th observation of the dependent variable (response), $\beta_0 =$ the intercept (constant), $\beta =$ slope of the regression line (trend of the climatic variables), $x_i = i$ th value of the independent variable (years) and $\varepsilon_1 =$ random error

Ethical Considerations

All data utilized in this study were obtained from publicly available sources or through official requests to NiMet, ensuring proper acknowledgment and adherence to data usage policies.

RESULTS AND DISCUSSION

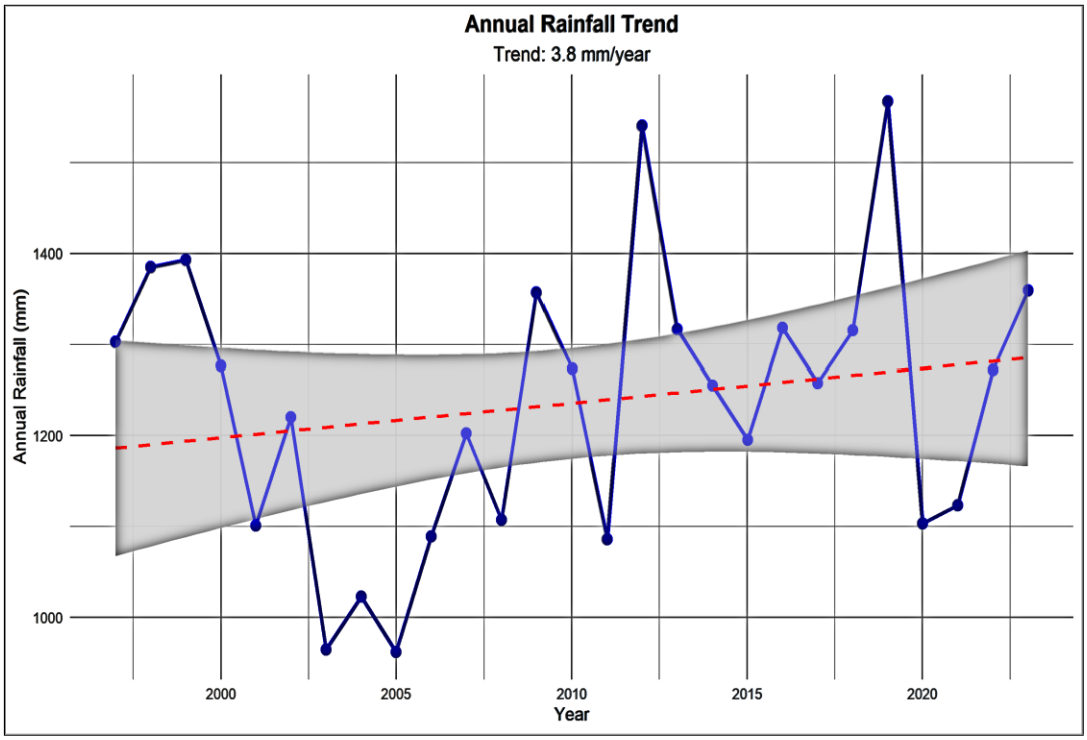


Figure 1: Nasarawa State Annual Rainfall

Source: NiMET (2024)

Figure 1 includes the totals of annual rainfall in Nasarawa State according to the data provided by Nigerian Meteorological Agency (NiMET, 2024). The findings show significant interannual changes together with a long-term positive growth trend during the research.

The time series illustrates that there are considerable changes in amount of rainfall on

annual basis with several years registering very high amounts, and others showing relatively low amounts. This trend is typical of rainfall processes in the Guinea Savannah ecosystem of the central Nigeria. Although these swings are observed, the regression analysis indicates a slight positive growth in yearly rainfall an indication that there is a progressive change towards wetter climates over the past few years.

The findings are especially important to the agriculture and water resources management of the Nasarawa State which is majorly a rain-fed farming operation. High growth in the total annual rainfall can boost agricultural productivity and can probably lengthen the growing period, whereas an increase of variability causes the risk of extreme conditions such as flooding, soil erosion, nutrient leaching, and abnormal plant development (Abdullahi et al., 2025). These hydrological disturbances not only weaken the crop yields but also jeopardize the sustainability of the agricultural systems in the long-term, thus contributing to the food insecurity in areas that are largely reliant on rain-fed agriculture (Olayide et al., 2024).

In addition, the noted rising pattern of the annual rainfall though gradually increasing is not as common as other regions of Nigeria where patterns of decreasing rainfalls have been recorded, which highlights the localised nature of the phenomenon of climate change in Nigeria (Ayanlade et al., 2023). The difference herein emphasizes the significance of geographically specific climate surveys and impact evaluations to support adaptation-intensive planning in agriculture and water resources planning (Ishaku et al., 2024).

It is even more complicated taking into account that as a total annual rainfall increases, there might be a parallel increase in a less predictable temporal distribution. This type of variability poses immense challenges to the water quantity and water quality management in terms of need of sophisticated and context-sensitive adaptive response (Fayose, 2025). To give an example, proper water management measures such as development of better storage facilities and sustainable water irrigation techniques are essential in alleviating the impacts of both the high and the low rainfalls (Salami et al., 2025).

Empirical data also indicate that the areas with slowly rising amounts of rainfall have also reported an increase in rates of urban flooding, proving that the greater the annual amounts, the more the occurrence of extreme hydrological events (O. et al., 2022,

Oyerinde, 2021). This highlights why there is a need to involve water resource management methods that involve the incorporation of better drainage facilities and effective early warning systems to mitigate the effects of floods and increase tolerance to climate hazards (Awode et al., 2025).

Adaptation strategies are urgently needed in order to deal with these new climate dangers. The efficiency of the water storage facilities like reservoirs and dams is also necessary to enhance the availability of water in dry seasons and the excess water in rainy seasons (Ekwueme & Agunwamba, 2021; Salami, 2024). These measures would be important in enhancing agricultural resilience and sustainable water resource management in Nasarawa State and Nigeria at large.

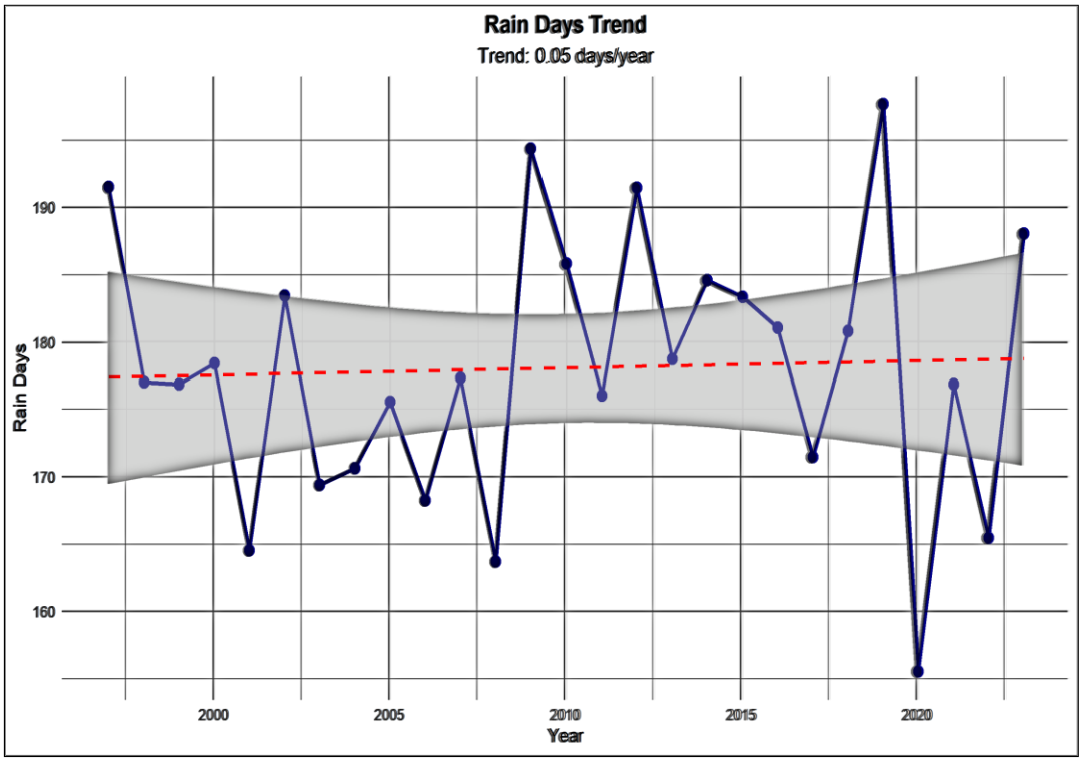


Figure 2: Rain days for Nasarawa State

Source: NiMET (2024)

In Figure 2, the annual distribution of rain days in Nasarawa State over the period of study is shown, using the meteorological observations of the Nigerian Meteorological Agency. Rain days, which are measured as the days with measurable precipitation, are a relevant parameter to explain the distribution of rainfall and supply of moisture, especially in places where agricultural productivity depends mostly on rainfall.

The findings show that there is significant interannual fluctuation in the count of rain days in the course of the study time. The variation in the figure reveals that the frequency of rainfall in Nasarawa State is very erratic, with certain years having a fairly high frequency of rainfall and others experiencing significant declines. This variability can be attributed to the increased impact of climatic variability and increased environmental changes on rainfall patterns in Nigeria. These trends have been associated with the prevalent climatic changes that are steadily changing rainfall regimes and hydrological cycles in the area (Olayide et al., 2024).

The trend model indicates a fairly constant average number of rainy days in the long term, but the expanding range of values around the average implies that the variability in the number of rainy days is growing. The given result is consistent with other studies that reported rising variability of rainfall and a decrease in the overall amount of yearly rainfall in the region of northern and central Nigeria (Abdullahi et al., 2025; Fuwape and Ogunjo, 2022). Specifically, studies related to Nasarawa State have established statistically significant negative changes in rainfall, which once again proves that the rainfall regime of the region is rather unstable (Ayanlade et al., 2023).

The increased unpredictability in the rainy days is also related to more unpredictable rainfall distribution, which includes changes in onset and cessation of rainfall and existence of dry periods despite the existence of relatively high annual rainfall amounts (Fayose, 2025). These anomalies are typical of the West African monsoon variations that control precipitation patterns in a large part of West Africa and have a great effect on the variability of precipitation in the Guinea savanna ecological zone.

Agronomically, the change in rain days is significant to the dynamics of the growing seasons in Nasarawa State. Agricultural systems that depend on rainfall are very sensitive to the timing and distribution of rainfall. Inconsistency in rain day counts can lead to the extension of the planting time, the reduction of the growing period, and the occurrence of dry intervals in the period of extreme crop development, thus weakening the crop yields and causing food insecurity (Tyubee & Iwan, 2024). Unpredictable rainfall patterns, including violent storms that lead to floods and extended dry seasons, are especially dangerous to developing economies that rely mostly on subsistence agriculture as a source of livelihood (Tegegn et al., 2024).

Moreover, increased uncertainty of rainfall patterns is a major concern to farmers and water resource managers in the northern part of Nigeria. The rise in variability of rainfall increases the vulnerabilities that already constitute the water availability, agricultural productivity, and rural livelihoods (Abubakar et al., 2024). These climatic changes point to the critical role of adaptive measures in agricultural planning and water management, such as better irrigation techniques, climate-sensitive agriculture, and better seasonal climate prediction (Audu et al., 2021; Magang and Lou, 2024).

The growing inconsistency of the rainfall patterns, which were marked by a series of severe rainfall events and long periods of dry seasons, also highlights the significance of enhancing the climate adaptation measures to maintain the level of agricultural productivity and economic stability in the area (Okafor et al., 2024). Other earlier studies within Nigeria have also reported high interannual rainfall variability, especially in the North, hence increasing drought risks, which underscores the importance of effective water management practices (Salami, 2024; Salami et al., 2025).

Also, unpredictable rainfall distributions are usually paired with extended heat waves and high temperatures that encourage the speed of soil moisture depletion and further limit crop yields (Alli, 2025). Therefore, the observed fluctuation in rainy days in Nasarawa State demonstrates the increased impact of climate variability on the hydrology of the region and the necessity of combined climate adaptation measures in order to protect the productivity of agriculture and food security.

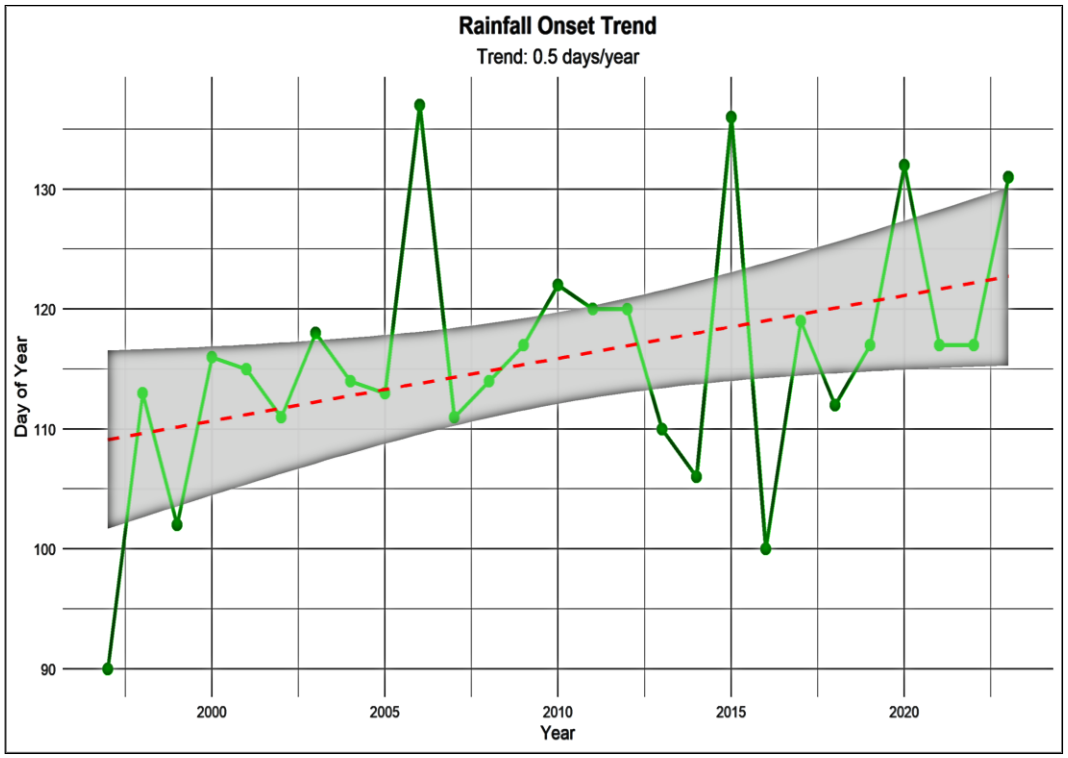


Figure 3: Rainfall Onset for Nasarawa State
Source: NiMET (2024)

The trend line in Figure 3 indicates a slow change in the onset dates, which shows that the onset dates of rainfall in the recent years are more conservative. Even though the differences between the years are still significant, this tendency indicates the possibility of the rainy season developing later than it used to be the case historically. The same trends have been observed in the other regions of Nigeria, where the late arrival of rainfall and changing patterns of the months are being aggravated by climate variability (Ideki & Weli, 2019).

In agricultural terms, inconsistency in the time of rainfall is a major challenge to the agricultural systems in Nasarawa State in which farming is highly reliant on rainfall. Late onset of rainfall may interfere with planting timelines and may subject crops to moisture stress during periods of critical germination and early developmental phases and, in some cases, may result in long-term droughts during vulnerable developmental periods (Umar et al., 2021). These deviations between predicted and observed rainfall patterns may have a drastic impact on crop production and jeopardize food security, especially among rural populations in which agriculture is a major income source (Ideki and Weli, 2019; Sufiyan et al., 2020).

Moreover, the growing uncertainty surrounding the occurrence of rainfall is also making farmers complex in making decisions in agriculture. The uncertainty in the timing

of rainfall causes the challenge of deciding on the right time to plant crops and preferable crop selection methods, which cause greater risk in production in rainy seasons (Magang and Lou, 2024). These problems are also exacerbated by the unpredictability of the rainfall patterns in Nigeria, which underscores the necessity to introduce better planning of agriculture and climate risk management practises (Olayide et al., 2024). The gradual change of the onset of rainfall can also lead to the withdrawal of the effective rainfall duration in North-Central Nigeria, and Nasarawa State is no exception hence exposing the area to droughts and shortening the effective growing season (Ideki & Weli, 2019). Therefore, to mitigate the negative effects of rainfall variability on agricultural productivity, farmers are trying to implement adaptive measures to curb the variability that include drought-resistant crop varieties, better irrigation methods, and climate resistant farming practises (Fayose, 2025). Moreover, to plan the agricultural activities and adjust to the climate, proper data about onset and termination of the rainfall and the duration of the rainy season are necessary. Predictable seasonal weather forecasts can help farmers to plan their planting time, choose the right kind of crops, and minimise possible losses related to crop yield because of rainfall unpredictability (Omay et al., 2022). Rain-fed farmers can find such information especially useful as it improves the effective organisation of the work related to agriculture and helps to improve the planning of food security and water resources (Awolala et al., 2022; Rwema et al., 2024). In general, the findings indicate the important variability between the periods and a propensity of the late rainfall onset in the Nasarawa State. The results highlight the increased impact of climate variability on rain-seasonality and the significance of the use of climate-informed agricultural practises to increase resilience and agricultural production in the area.

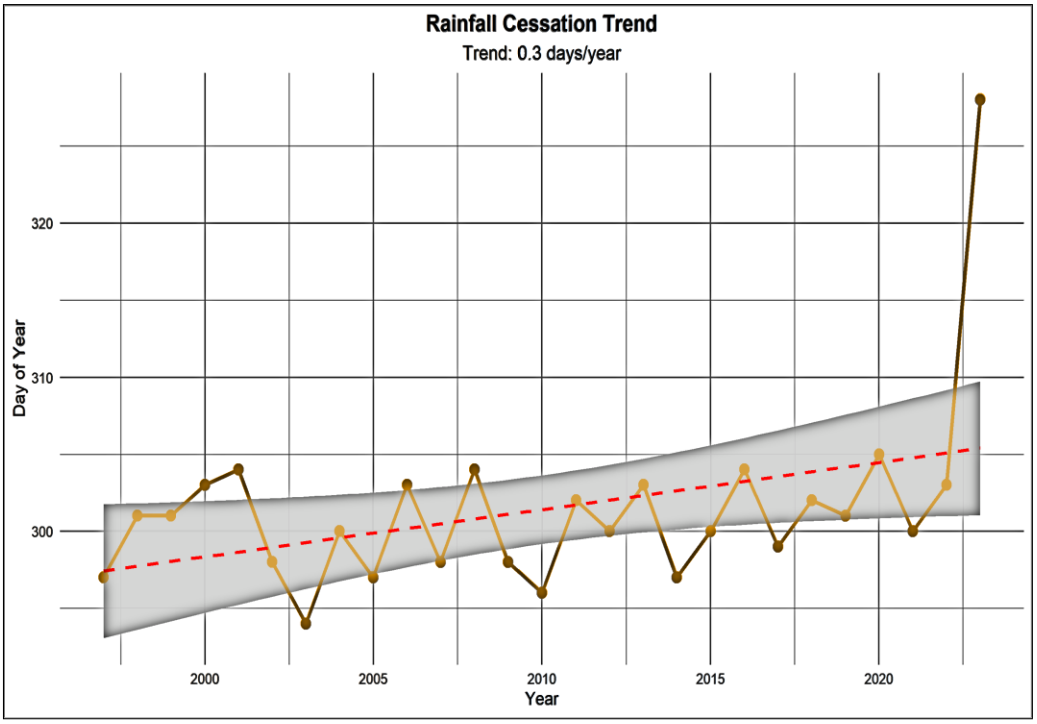


Figure 4: Cessation for Nasarawa State

Source: NiMET (2024)

The cessation of rainfall in Nasarawa State is shown in Figure 4 as a depiction of the time series of the event based on meteorological data that is provided by the Nigerian Meteorological Agency. The cessation of rainfall is an effective climatic boundary of rainy season and an important agro-climatic signal which is used to condition the end of the growing season of rain-fed agricultural systems. The findings indicate that there is a significant interannual variation in the dates of cessation of rainfall across the duration of study. Certain years registered relatively low rainfall termination whereas some years registered a significantly later termination of the rainy season. These changes emphasise the dynamism of rainfall regimes in Nasarawa State and the larger climatic variability implying the precipitation regimes in Nigeria. This variability in the seasonality of rainfall has been observed widely with emphasis on the increased impact of climate change and atmospheric processes in the region on the distribution and timing of rainfall (Olayide et al., 2024; Tyubee and Iwan, 2024). Figure 4 shows that there is an upward trend in the cessation date of rainfall, and over the recent years, there is a tendency whereby the rainy season is gradually ending later. Although this is the case, the large variations that have been experienced throughout the period of study suggest that the rainfall cessation is very unpredictable. This kind of irregularity has significant consequences in the planning of agriculture and water management especially in areas where crop yield is highly reliant on seasonal distribution of rainfall. The difference in the time of rainfall termination has a

direct influence on the duration and consistency of the agricultural growing season. The process of early cessation may reduce the effective growing period and exposing crops to terminal drought-prone conditions at critical growth phases such as flowering or grain filling to yield low yields and face high agricultural risk (Salami et al., 2025; Ademe et al., 2021). On the other hand, when stopped late, there is a possibility of extending the growing period and even favourable crop development, but, at the same time, extended moisture regimes can be accompanied by difficulties in harvesting, processing after harvesting, and the appearance of pests and diseases related to the increased availability of moisture (Fuwape & Ogunjo, 2022). In Nasarawa State, the variability in the climatic cessation of rainfall can make it tricky to decide and plan on agricultural activities. Rain-fed agricultural systems are based on the patterns of rainfall that is predictable to know the date of planting, type of crops to be planted, and the irrigation rate that is required. Farmers are at a higher risk of uncertainty when it comes to planning the agricultural activities and effective utilisation of water resources because the dates of cessation become more unpredictable (Rwema et al., 2024; Tegegn et al., 2024). Consequently, adaptation mechanisms, including better water management, climate-adaptive agricultural methods, and the choice of drought-resistant varieties of crops, would be needed to maintain agricultural productivity. Moreover, it is important to understand the processes that take place in the atmosphere to affect the termination of rainfall, which can enhance prediction of seasonal forecasting and management of climate risks. The rainfall cessation processes are usually associated with the larger atmospheric circulation patterns, i.e. the regional teleconnections and the variability of monsoons, affecting the timing and distribution of precipitation over West Africa. A better understanding of these mechanisms can be used to better predictive models and improve effective agricultural planning (Omay et al., 2023). The rising differences in the timing of rainfall termination also confirm the need to design early warning and weather-based agricultural policies. Exact data on when rainfall starts, stops, and the length of the season helps the farmers to determine the safe planting period, minimise risks of dry periods during the season, and maximise on crop yields due to the fluctuating climatic factors (Alli & Omofunmi, 2021; Fayose, 2025). The latter agro-climatological data is especially useful to rain-fed farmers, who can plan their process organisation and work more efficiently and increase their food security and control over water resources (Awolala et al., 2022; Umar et al., 2021). The recent researches also show that rain alterations in Nasarawa State have been increasing in the past decades, and

significant changes in the time when the rainfall starts and when it ends are also observed (Abdullahi et al., 2025). The changes are also accompanied by the fact that there are decreasing rainfall trends in state, which further exposes the agricultural sector to vulnerability and highlights the necessity to have strong climate adaptation measures (Ayanlade et al., 2023). In turn, agro-climatological evaluations of an adequate scale are required to guide the choice of crops, the timing of planting, and water management regimes helping to reduce the negative effect of climatic variability on the productivity of agriculture (Mahay et al., 2025). The variability in the cessation of rainfall observed reminds a very crucial aspect of rainfall processes in Nasarawa State. The timing and the length of the rainy season determine the agricultural output, food security and water management in the area. The persistent tracking of the rainfall patterns through the meteorological information of the Nigerian Meteorological Agency thus continues to play a critical role in enhancing climate resilience and facilitating the biodiversity of agricultural activities.

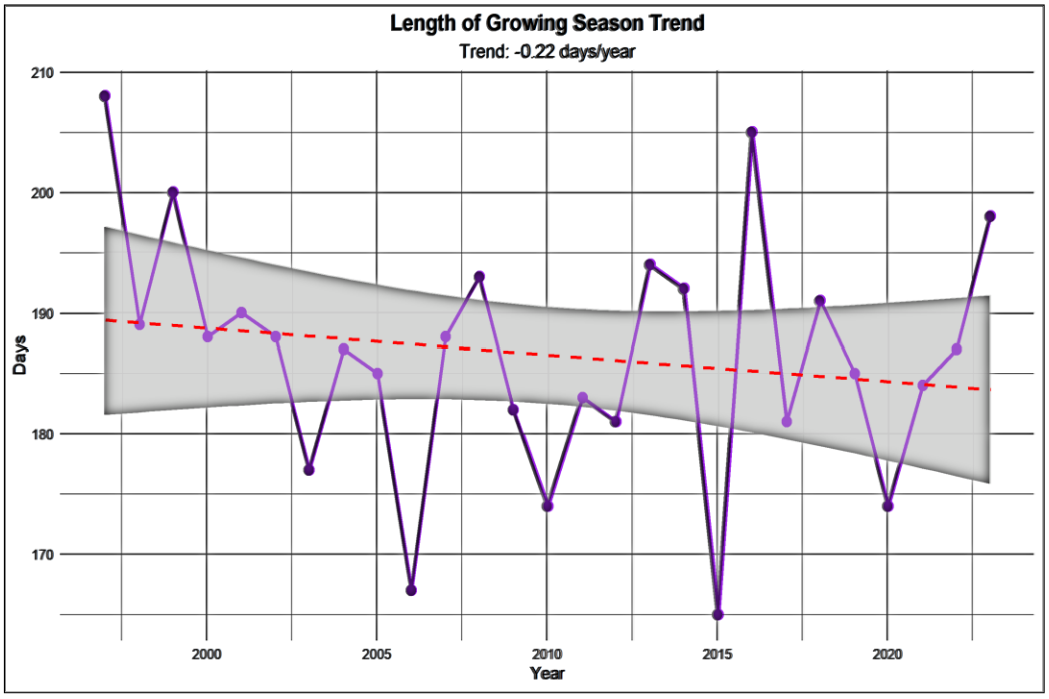


Figure 5: Length of growing season for Nasarawa State

Source: NiMET (2024)

Figure 5 below shows the time trend of the Length of the Growing Season (LGS) in Nasarawa State during the study period. Findings indicate that the interannual variability is high, with the growing season varying between around 165 days and more than 200 days in certain years. This change can be said to be the changing of the time of the beginning

and ending of rainfall, which, in combination, dictates the successful length of the agricultural growing season. This variability is in line with the unstable rainfall regimes witnessed over both Nigeria and other regions of West Africa where seasonal rainfall variability is highly affected by climate variability and atmospheric circulation patterns (Olayide et al., 2024; Tyubee and Iwan, 2024).

The time series also suggests that certain years were experienced with a longer growing season, mostly in the first half and the middle of the study period, where LGS was above 200 days. These extended growing periods are largely linked to the earlier onset of rainfall and late termination, which give good moisture conditions to the crop growth and enable the farmers to grow and raise crop varieties that take longer periods to grow. Other tropical areas have also reported similar agro-climatic reactions, whereby extended rainy spells can boost crop growth but also pose other difficulties such as late harvests and a higher prevalence of pests and diseases in extended periods of humidity (Fuwape & Ogunjo, 2022).

On the other hand, some years in the dataset have shorter growing seasons, especially between the mid-2000s and mid-2010s when LGS reduced to around 165-170 days. The length of time lost in the effective growing period in such ways is usually related to late onset of rainfall or early termination that limits the time the crop has to grow and creates the risk of moisture stress at vulnerable stages of development, like flowering and grain filling. It is common knowledge that early end of rainfall is one of the primary agro-climatic factors in rain-fed farming systems, which tend to lower yields and agro-risks (Salami et al., 2025; Ademe et al., 2021).

The trend line in Figure 5 reveals that there is a slight downward tendency in the length of the growing season with time, and this implies that the effective agricultural period in Nasarawa State is gradually getting shorter. Even though the downward trend is moderate, the wide confidence interval in the trend indicates that there is large variability in LGS year-to-year. This is characteristic of semi-humid tropical climates, whereby the distribution of rainfall is affected by changes in the West African monsoon system and atmospheric circulation that have significant effects on the changes that occur during the rainy season and when and how long they last (Omay et al., 2023).

The realized fluctuation in the duration of growing seasons has significant implications on the rain-fed agricultural systems that form the major farming activities in

Nasarawa State. Such systems rely on the predictable rainfall patterns to do agricultural planning, how to plant, and which types of crops to plant as well as how to manage water. The exaggerated uncertainty concerning the duration of the growing season may, hence, complicate the process of farm management and diminish the effectiveness of the water resource use (Rwema et al., 2024; Tegegn et al., 2024). As a result, it can be expected that farmers will experience more problems with matching crop growth with the conditions of available moisture.

From an adaptation perspective, the uncertainty and mild reduction in LGS highlights the significance of climate-resistant agricultural options. These can be the use of earlier harvesting varieties of crops, better moisture conservation methods on the soil, and better climate information services so that the planting can be guided. Agro-climatological information on the beginning and end of rains and the duration of the growing season can greatly decrease the production risks and enhance crop productivity in variable climatic conditions (Alli and Omofunmi, 2021; Fayose, 2025). The smallholder farmers are especially interested in such information since they are mostly reliant on rain-fed agriculture as a primary source of income (Awolala et al., 2022; Umar et al., 2021).

Recent research also noted a growing change in the characteristics of rainfalls in the Nasarawa State, such as the change in dates of the rainy season onset and termination (Abdullahi et al., 2025). The change is taking place together with increased regional variations in rainfall and, in other instances, decreasing rainfall patterns, exacerbating the sensitivity of the agricultural sector to climatic changes (Ayanlade et al., 2023). Consequently, permanent agroclimatological surveillance and enhanced seasonal prediction are fundamental in supporting adaptive agronomic planning, as well as minimization of the threat of climatic conditions (Mahay et al., 2025).

The trend in Figure 5 indicates that the duration of the growing season at Nasarawa State is very fluctuating and exhibits a slight downward trend, implying the effect of the fluctuating rainfall patterns. Seeing that the length of the rainy season is directly proportional to the possibilities of crop growth and food security as well as water resources management, a more consistent observation of the meteorological conditions remains the key to enhancing climate stability and the sustainable agricultural growth of the region.

Table 1: Variability of the Climatic Elements within Nasarawa State (1997-2023)

Parameter	Period	Annual Rainfall (mm)	Rain Days	LGS (Days)
Mean	1997-2010	1189.6	177	187
	2011-2023	1285	179	186
	Variability	-95.4	-2	1
	1997-2023	1235.5	178	187
Standard deviation	1997-2010	149.3	9.4	10.2
	2011-2023	147.5	11.0	10.3
	Variability	1.8	-1.6	-0.1
	1997-2023	153.5	10.0	10.1
Coefficient of variability	1997-2010	0.13	0.05	0.05
	2011-2023	0.12	0.06	0.06
	Variability	0.01	-0.01	-0.01
	1997-2023	0.12	0.06	0.05

Source: NiMET (2024)

Table 1 shows the statistical features of important climatic variables in terms of annual rainfall, rain days, and length of growing season (LGS) in Nasarawa State between 1997 and 2023, according to meteorological records at the Nigerian Meteorological Agency. These parameters are important parameters used to know how rain will vary and what the consequences of this variability are on agricultural productivity in rain-fed environments.

The average annual rainfall has changed to 1285 mm in 2011–2023 with an increase of 1189.6 mm in 1997–2010, which demonstrates that average rainfall in the later years, 2011–2023, is slightly higher than in the previous period. The mean of the 27-year period was 1235.5 mm, which implies that Nasarawa State is characterized by moderate rainfall that is characteristic of the Guinea savanna ecological zone (Olayide et al., 2024).

Rainy days also exhibited a slight variation between the two subperiods with a slight increment of 177 days (1997–2010) to 179 days (2011–2023) with a total mean of 178 days. This low change indicates a relative stability of rainfall frequency, but the intra-annual changes might still be present (Oderinde et al., 2022).

The LGS has not changed significantly, as in the period of 1997 2010, it was 187 days on average, and 2011 2023 was at 186 days on average. The insignificant variation between the years suggests that there has been a rather stable length of the growing season regardless of changes in the amount of rainfall (Madapala et al., 2022).

The values of standard deviation give understanding on the spread of the climatic parameters. The change of the annual rainfall variation was reduced to some extent as it dropped to 147.5 mm (20112023) compared to 149.3 mm (19972010) indicating a slight reduction in the rainfall variability. But the standard deviation 153.5 mm on the whole indicates the presence of significant changes every year (ABDULLAHI et al., 2025). The standard deviations of the two sub-periods of rain days were 9.4 and 11.0 days and this shows that the predictability of rain events has increased slightly. Likewise, the variability of LGS was also moderate and standard deviation was approximately 10 days. Coefficient of variability (CV) is a relative measure of the variability. The percentage of rainfall variability was 12.55 (19972010) and 11.48 (20112023) with a slight decrease in inter-annual rainfall variability over the years (Olayide et al., 2024). Rain days and LGS had comparatively low CVs (=0.05 -0.06), which implies the presence of constant seasonal structures despite changes in the total rainfall (Ayanlade et al., 2023). These results indicate that although the frequency of rainfall and the length of growing season have not changed significantly, the overall amount of rainfall has shown a significant fluctuation with time on an annual basis. When the entire growing season remains constant, such changes may affect the availability of soil moisture, crop growth and yield performance. Since agricultural activities in Nasarawa State rely on rainfall, unequal or unpredictable distribution or amount of precipitation during the growing season may cause a moisture stress or high rain which may impact on crop production. Rainfall variability, rain days and LGS continuous monitoring is therefore crucial to support the agricultural planning, climate adaptation, and water resource management in the region (ABDULLAHI et al., 2025; Olayide et al., 2024). The weather patterns in the Nasarawa State are characterised by fair variability through the relative stability of rain days and the duration of the growing season but significant variations in the rainfall amount each year which characterise the necessity of adaptive farming techniques.

Table 2: Decadal variability of climatic variables

Rainfall decadal variability (normal mean =1235.5mm)		
Period	**Mean (mm)**	**(Mean-normal mean)mm**
1997-2006	1171.5	-64
2007-2016	1264.8	29.8
2017-2023	1285.1	49.6
Rain days decadal variability (normal mean=178days)		

Period	Mean (days)	(Mean-normal mean)days
1997-2006	176	-2
2007-2016	182	4
2017-2023	177	-1
Length of growing season decadal variability (normal mean=187days)		
Period	**Mean (days)**	**(Mean-normal mean)days**
1997-2006	188	1
2007-2016	186	-1
2017-2023	189	-1

Source: NiMET (2024)

Decadal analysis of rainfall in the state of Nasarawa indicates that there are significant changes as compared to the long-term normal precipitation of 1235.5 mm. A decade from 1997 to 2006 had a mean of 1171.5 mm of rainfall, which is 64 mm less than the normal, showing a dry decade. This was then succeeded by the 2007–16 decade, in which the amount of rainfall rose to 1264.8 mm (29.3 mm above normal), which indicated wetness. This was carried on in the 2017–2023 period, as it had an average rainfall of 1285.1 mm, which was 49.6 mm higher than the long-term average. These trends are demonstrating a series of dry and wet decades, which follow the regional patterns of inter-decadal changes in rainfall in the Guinea savanna ecological zone (Ayanlade et al., 2023). These variations have significant effects on water supply, soil hydration, and food output, whereby dry seasons caused by below-average rainfalls might cause moisture stress, and wet seasons can cause the danger of flooding in low-lying regions. The study of the rainy days shows that there are comparatively slight changes in the decades. The overall rain days recorded between 1997 and 2006 were slightly below the average of 176 days, with a negative value of -2 days, and the 2007-2016 period had a slight increase of 182 days. The long-term mean of 177 days (-1 day) was almost equal to the 2017-2023 period of 177 days. These remarks indicate that the occurrence of rainfall events in Nasarawa State has not significantly differed, although the amounts of rain have fluctuated in decades (Oderinde et al., 2025). The stability of rain days is useful in agricultural scheduling as farmers can normally rely on the number of rainfalls to occur during a season. Decadal variation in the duration of the growing season (LGS) was insignificant. The 1997-2006 period was marginally above average at 188 days (-1 day), then marginally below average at 186 days (-1 day) in 2007-2016 and 2017-2023, respectively. These minor variations will mean that the

total coverage area under crops has not changed much, hence giving the farmers a predictable interval through which to grow their crops despite changes in the amount of rainfall received. The decadal analysis indicates that the amount of rainfall has larger variability than the number of rain days or LGS, indicating that the intensity and spread of precipitation events are more changeable than the rate or the length of the growing season. This directly impacts the rain-fed agriculture because even when there are inconsistencies in the distribution of rainfall during a given agricultural season, the distribution of the soil moisture, crop growth, and yield could still be affected. It is therefore necessary to continuously monitor all these climatic parameters to guide adaptive farming methods, e.g., drought-resistant crops, supplemental irrigation, and moisture-preservation techniques in the soil, to reduce the impact of decadal rainfall variations on agricultural yield in Nasarawa State (ABDULLAHI et al., 2025; OLAYIDE et al., 2024).

CONCLUSION

In the present study, the spatio-temporal variability of rainfall and growing season dynamics in the Niger State of Nasarawa in Nigeria was investigated based on the meteorological data of the years 1997 to 2023. The findings indicated that there was a significant year-to-year change in the annual rainfall, rain days, date of rainfall onset, date of rainfall cessation, and growing season duration. Even though the analysis revealed that there is a slight increase in annual rainfall with time, the distribution of rainfall is irregular. This variability shows the impact of varying climatic conditions that have impacts on rain patterns in the region.

When the number of rainy days is analyzed, it can be seen that the long-term average does not change much, but on the other hand, the frequency of events of rainfall has become more erratic. This kind of irregularity implies that there is more and more uncertainty of patterns in rainfall; this may derail farming routines and lead to a high probability of a dry spell or excessive rainfall during the crop season.

The analysis also found out that there were slow variations in the time of onset and cessation of rainfall, which have a direct impact on the length of the growing season. The duration of the growing period was about 165-200 days during the study period with minor variations over time. These changes present huge consequences to agricultural practices in the Nasarawa State, where farming activities are extensively reliant on rain. Constant

attention to the changes in rainfall and better agricultural planning based on climatic conditions are thus necessary to improve the productivity of agriculture and provide food security in the region.

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