Effects of Rainfall Variability on Cassava (Manihot Esculenta) Yield in Ankpa Local Government Area, Kogi State, Nigeria

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Abstract
This study examined the effects of rainfall variability on cassava (Manihot esculenta) yield in the study area between 2004 and 2024. The research integrated meteorological data, cassava yield records, and field survey responses from 370 cassava farmers. Descriptive statistics, time-series analysis, correlation, and regression techniques were employed to assess rainfall trends and their influence on cassava productivity. Findings revealed that annual rainfall ranged from 1,090 mm to 1,610 mm, with a mean of 1,372 mm and a coefficient of variation of 11.9%, indicating moderate rainfall variability. Seasonal analysis showed that over 96% of rainfall occurs during the wet season, with 55.4% concentrated in the late rainy season. Trend analysis indicated a statistically significant increase in rainfall at a rate of 9.4 mm per year ($R^2 = 0.48$, $p < 0.01$). However, inter-annual fluctuations remained pronounced. Correlation results showed a strong positive relationship between cassava yield and annual rainfall ($r = 0.734$, $p < 0.01$) as well as seasonal rainfall ($r = 0.781$, $p < 0.01$), while rainfall variability had a significant negative relationship with yield ($r = –0.658$, $p < 0.01$). Regression analysis further revealed that rainfall variables jointly explained 69% of the variation in cassava yield, with rainfall variability exerting a significant negative effect on productivity. The study also found that 72.4% of farmers are male, 74.6% operate on less than 2 hectares, and 60% lack access to extension services, indicating limited adaptive capacity. Overall, results show that although rainfall is increasing, its variability and uneven distribution significantly reduce cassava yield. The study concludes that rainfall variability remains a major constraint to cassava production and recommends improved extension services, climate-resilient varieties, and water management strategies to enhance productivity and food security.

Keywords: rainfall variability, cassava yield, climate change, agricultural productivity, Nigeria

INTRODUCTION

Agriculture remains a critical pillar of economic development and food security globally, with over 60% of the world's population depending directly or indirectly on it for livelihoods (FAO, 2021). Among the key environmental factors influencing agricultural productivity, rainfall variability is one of the most significant, particularly in tropical and subtropical regions where farming is predominantly rain-fed. Rainfall variability refers to fluctuations in the amount, timing, and distribution of rainfall across seasons and years, and it has been widely linked to declining agricultural productivity due to climate change-induced weather instability (IPCC, 2021; Adhikari et al., 2022). These changes manifest as delayed onset and early cessation of rains, prolonged dry spells, and intense rainfall events, all of which disrupt crop growth cycles and reduce yields.

Cassava (Manihot esculenta), a major root and tuber crop, plays a vital role in global food security, especially in developing regions of Africa, Asia, and Latin America, where it feeds over 800 million people (FAO, 2020). Its resilience to poor soils and drought conditions makes it a strategic staple crop. However, despite its tolerance, cassava is not immune to rainfall variability. Adequate and well-distributed rainfall remains essential during key growth stages such as establishment and tuber bulking, where moisture stress can significantly reduce yield and root quality (Jarvis et al., 2012; El-Sharkawy, 2021; Burns et al., 2021). In Africa, where over 90% of agriculture is rain-fed, rainfall variability poses serious risks to food production and rural livelihoods (Sultan & Gaetani, 2016).

Nigeria, the world's largest cassava producer, contributes about 20% of global output, with millions of smallholder farmers depending on the crop for income and food security (FAOSTAT, 2021; Adebayo et al., 2020). However, Nigerian agriculture is highly vulnerable due to limited irrigation coverage of less than 5%, making it heavily dependent on rainfall patterns (Nwajiuba & Chima, 2020). Increasing rainfall irregularities such as delayed rains, shortened wet seasons, and extreme weather events have been widely reported across the country, particularly in the Middle Belt region, including Kogi State (Ayanlade et al., 2018; Olaniran & Sumaila, 2021). These conditions have led to water stress, flooding, soil erosion, and reduced crop productivity, thereby affecting cassava yields and farmers' incomes (Okonya et al., 2020; Ajetomobi & Abiodun, 2020).

Within Kogi State, Ankpa Local Government Area is a significant cassava-producing region supported by fertile soils and an average annual rainfall of about 1,500 mm (KSADP, 2020). However, recent decades have witnessed increasing rainfall instability, including erratic onset and cessation of rains, intra-seasonal dry spells, and occasional heavy downpours (Olaniran & Sumaila, 2021). Farmers in the area have reported declining cassava yields, poor tuber development, and increased pest and disease incidence associated with these climatic changes (Ajetomobi & Abiodun, 2020). As cassava farming remains the primary livelihood activity in the area, these changes threaten household food security and rural economic stability (Oyekale, 2021).

Despite the importance of cassava in the study area, there is limited empirical evidence linking rainfall variability directly to cassava yield fluctuations at the local government level. Existing studies on climate variability and agriculture in Nigeria have largely focused on regional or national scales, often overlooking micro-level climatic and socio-economic conditions that influence farming outcomes (Eze et al., 2021; Ofoegbu et al., 2019). For instance, Abiodun et al. (2017) and Ayanlade et al. (2018) established that rainfall variability significantly affects crop productivity in Nigeria, while Olaniran and Sumaila (2021) observed similar trends in North Central Nigeria. However, these studies do not provide detailed analysis specific to Ankpa LGA, where variations in soil characteristics, farming practices, and local adaptation strategies may influence cassava yield differently.

Furthermore, while cassava is often described as drought-tolerant, research shows that prolonged dry spells or rainfall deficits during critical growth stages can severely affect tuber formation and starch accumulation (Jarvis et al., 2012; El-Sharkawy, 2021). Studies in other parts of Nigeria and sub-Saharan Africa have also shown that climate variability disrupts planting calendars, reduces yields, and increases vulnerability among smallholder farmers (Oguntunde et al., 2018; Okpara et al., 2022). However, many of these studies are generalized and fail to integrate farmer perceptions, localized rainfall data, and yield records at the LGA level, thereby limiting their applicability to specific communities like Ankpa.

Although climate-smart agricultural practices such as improved cassava varieties, altered planting schedules, and water conservation techniques have been recommended as adaptation strategies (FAO, 2021; Uddin et al., 2022), their effectiveness in Ankpa LGA remains insufficiently documented. The absence of localized, data-driven studies combining meteorological records, cassava yield trends, and farmers' experiences creates a significant gap in understanding the true impact of rainfall variability in the area. Without such evidence, agricultural policies and extension services risk being generalized and ineffective in addressing local challenges.

Rainfall variability poses a serious threat to cassava production in Ankpa LGA, with direct implications for food security, rural livelihoods, and economic stability. While global and national studies have highlighted the relationship between climate variability and agricultural productivity, there remains a critical gap in localized empirical research that captures the specific dynamics of rainfall patterns and cassava yield in the study area. This study therefore seeks to bridge this gap by examining the effects of rainfall variability on cassava yield in Ankpa LGA, integrating climatic data, yield trends, and farmers' experiences to provide evidence-based insights for effective adaptation and sustainable agricultural development in the region.

STUDY AREA

The study area is located in the eastern part of Kogi State, Nigeria, between latitudes 7°22' and 7°37' North and longitudes 7°30' and 7°49' East. It shares boundaries with Olamaboro LGA to the east, Omala LGA to the north, and Benue State to the south and southeast. It covers about 1,200 square kilometers and includes communities such as Enjema, Emere, Awo, and Ankpa town, which serves as the headquarters. The area is accessible through major road networks linking Lokoja and neighboring states, supporting agricultural trade. Fig 1 shows Ankpa Local Government Area, adapted from the Administrative Map of Kogi State (2025).

The climate is tropical wet and dry, with rainy season from April to October and dry season from November to March. Annual rainfall ranges from 1,200 mm to 1,600 mm, with peak rainfall in July and September. Temperatures range between 25°C and 28°C, while harmattan reduces humidity during the dry season. This rainfall variability significantly affects rain-fed agriculture, especially cassava production (IPCC, 2021). The relief is generally undulating, with elevations between 150 and 300 meters above sea level, consisting of hills, plains, and inselbergs. The area is drained by seasonal streams that flow into the Benue River system, often causing flooding in low-lying areas during the rainy season and drying up in the dry season, which limits water availability for farming.

Vegetation falls within the Guinea savanna zone, dominated by grasses and scattered trees such as locust bean, shea butter, and baobab. However, farming expansion, bush burning, and fuelwood harvesting have reduced natural vegetation, leading to secondary regrowth and cultivated landscapes dominated by cassava, yam, and maize farms. Geologically, the area lies within the Anambra Basin and consists mainly of sedimentary rocks such as shale, sandstone, and siltstone (Micheal, Johnmark, and Victor, 2015). These influence soil formation and agricultural suitability, with deeper soils in valleys supporting better crop production, while upland areas are more erosion-prone.

Soils are mainly ferruginous tropical types, ranging from sandy loam to loamy sand, which are well-drained but prone to leaching and low fertility. More fertile alluvial soils occur in valley bottoms and support intensive farming. Continuous cultivation has led to soil degradation in many upland areas. The population is estimated at over 250,000 people, mostly of the Igala

ethnic group. Over 70% are engaged in farming, cultivating cassava, yam, maize, rice, and guinea corn. Other activities include trading, agro-processing, fishing, and livestock rearing, while seasonal migration is common during the dry season. Land use is predominantly agricultural, with cassava farming as the most important activity. Practices include shifting cultivation, intercropping, and slash-and-burn methods. Farming is entirely rain-fed due to lack of irrigation, making it highly sensitive to rainfall variability. Although improved cassava varieties and fertilizers are gradually being adopted, limited access to credit and extension services restricts widespread use.

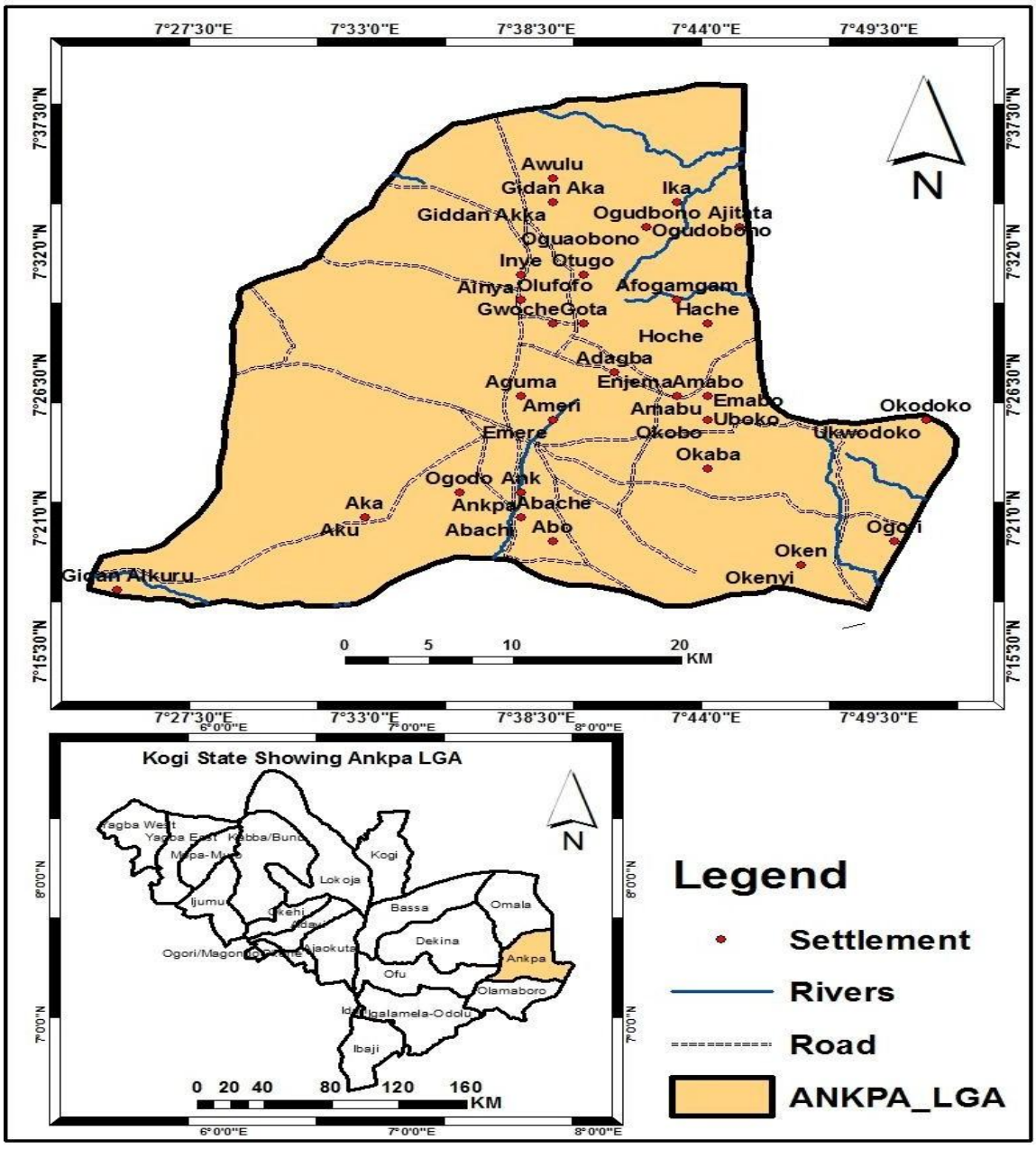

Fig 1: Ankpa Local Government Area
Source: Adopted from Administrative Map of Kogi State (2025).

METHODOLOGY

This study adopted a descriptive and analytical research design to examine the effects of rainfall variability on cassava (Manihot esculenta) yield in the study area over a twenty-year period (2004–2024). The design combined descriptive analysis of rainfall patterns and cassava production trends with statistical techniques to establish relationships between rainfall variables and yield outcomes. This approach enabled the integration of climatic data, agricultural records, and farmers' perceptions to provide a holistic understanding of rainfall–yield dynamics and support evidence-based conclusions.

The study required historical rainfall data (total rainfall, onset and cessation dates, and seasonal distribution), cassava yield data (yield per hectare, production volumes, and cropping periods), soil moisture information, and socio-economic data on farmers' characteristics, landholding size, and adaptation practices. Additional data on institutional support, agricultural inputs, and spatial characteristics such as soil types and land use were also considered necessary. Rainfall data were obtained from the Nigerian Meteorological Agency (NiMet) and related hydrological sources, while cassava yield data were sourced from the Ministry of Agriculture, local agricultural offices, and IITA records. Primary data were collected from farmers, extension officers, and community leaders, while soil and field data were obtained through surveys and observations.

The population of the study consisted of cassava farmers in the study area, estimated at about 5,000, including smallholder and medium-scale farmers who have engaged in cassava cultivation over the study period. Using Yamane's formula, a sample size of 370 respondents was determined. A multi-stage sampling technique was employed, involving stratification of communities, random selection of villages, and systematic selection of farmers to ensure representativeness.

Data were collected using structured questionnaires, interview guides, focus group discussions, and field observation checklists. Secondary data were complemented with primary field data to capture both statistical trends and lived experiences. Ethical approval and community consent were obtained before fieldwork, and research assistants were trained to ensure consistency in data collection.

Instrument validity was ensured through expert review, while reliability was enhanced through a pilot study and triangulation of data sources. Data analysis involved descriptive statistics, time series analysis, correlation, regression, and ANOVA to examine rainfall trends, rainfall–yield relationships, and stage-specific crop sensitivity. Qualitative data were analyzed thematically to capture farmers' perceptions and adaptation strategies. Hypotheses were tested at a 0.05 significance level using Pearson correlation, regression analysis, and ANOVA to determine the statistical significance of rainfall variability effects on cassava yield and growth stages.

RESULTS AND DISCUSSIONS

Socio-Economic Characteristics of Respondents

Table 1: Socio-Economic Characteristics of Cassava Farmers

Variable	Category	Frequency	Percentage (%)
Age (years)	Below 30	48	13.0
	31–40	96	25.9
	41–50	124	33.5
	51–60	72	19.5
	Above 60	30	8.1
Gender	Male	268	72.4
	Female	102	27.6
Educational Level	No formal education	98	26.5
	Primary education	124	33.5
	Secondary education	102	27.6
	Tertiary education	46	12.4
Farming Experience (years)	Below 10	64	17.3
	10–20	146	39.5
	21–30	108	29.2
	Above 30	52	14.0
Farm Size (ha)	Less than 1	112	30.3
	1–2	164	44.3
	Above 2	94	25.4
Access to Extension Services	Yes	148	40.0
	No	222	60.0
Years of Cassava Cultivation	Below 10	82	22.2
	10–20	156	42.2
	Above 20	132	35.6
Total Respondents		**370**	**100.0**

Source: Field Survey, 2026

The results in Table 1 show that cassava farming in the study area is dominated by middle-aged farmers, with the highest proportion (33.5%) in the 41–50 years age group. This indicates that production is handled by economically active individuals with adequate strength and decision-making capacity. Similar findings were reported by Fosu-Mensah et al. (2012), who noted that middle-aged farmers respond better to climate risks due to experience. Gender distribution shows male dominance (72.4%), indicating unequal access to resources such as

land and credit. This limits women's adaptive capacity, although FAO (2020) recognizes their important role in cassava production. The finding aligns with Onyeneke et al. (2021).

Most respondents have primary or secondary education, with few attaining tertiary level. This may limit access to climate information and adaptation decisions, as also noted by Deressa et al. (2009). Over 70% have more than ten years of farming experience, indicating strong familiarity with rainfall patterns and cassava systems (Bryan et al., 2013). Most farmers operate small farms (≤2 ha), limiting their ability to cope with climate shocks (Morton, 2007). Also, 60% lack access to extension services, reducing exposure to improved practices, as also observed by Nwajiuba and Onyeneke (2010). Overall, the socio-economic profile shows that despite high experience, farmers' adaptive capacity is constrained by small farm sizes, moderate education, gender imbalance, and weak extension access, which is important for interpreting rainfall and cassava yield outcomes.

Descriptive Analysis of Annual and Seasonal Rainfall

Table 2: Annual Rainfall Amounts in the Study Area (2004–2024)

Year	Annual Rainfall (mm)
2004	1,180
2005	1,245
2006	1,090
2007	1,320
2008	1,410
2009	1,365
2010	1,520
2011	1,285
2012	1,470
2013	1,150
2014	1,090
2015	1,210
2016	1,340
2017	1,395
2018	1,560
2019	1,480
2020	1,610
2021	1,455
2022	1,520
2023	1,600
2024	1,580

Source: Nigerian Meteorological Agency (NiMet), 2026

Table 2 reveals pronounced inter-annual fluctuations in rainfall over the study period. Annual rainfall ranged from a minimum of about 1,090 mm (2006 and 2014) to a maximum of about 1,610 mm (2020). These fluctuations indicate that rainfall availability in the study area is highly variable rather than stable. Such variability is critical for cassava production, as years with below-average rainfall may expose crops to moisture stress, while years with excessive rainfall may lead to waterlogging and nutrient leaching.

Table 3: Descriptive Statistics of Annual Rainfall (2004–2024)

Statistic	Value
Mean (mm)	1,372
Standard Deviation (mm)	164
Coefficient of Variation (%)	11.9
Minimum (mm)	1,090
Maximum (mm)	1,610
Range (mm)	520

Source: Computed from NiMet data, 2026

The mean annual rainfall of 1,372 mm confirms that the study area is climatically suitable for cassava cultivation. However, the standard deviation of 164 mm and coefficient of variation of 11.9% indicate moderate rainfall variability. In agricultural climatology, a coefficient of variation above 10% is considered indicative of unreliable rainfall. The implication is that cassava farmers in the study area face uncertainty in water availability, which can adversely affect planting decisions and yield stability. Similar rainfall variability thresholds were reported by Odekunle et al. (2013) and Nicholson (2017) in studies of West African rainfall dynamics.

Table 4: Seasonal Rainfall Distribution in the Study Area (2004–2024)

Season	Mean Rainfall (mm)	Percentage of Annual Rainfall (%)
Early Rainy Season (March–June)	565	41.2
Late Rainy Season (July–October)	760	55.4
Dry Season (November–February)	47	3.4
Total	**1,372**	**100.0**

Source: NiMet, 2026

Table 4 shows a strong seasonal concentration of rainfall, with over 96% occurring during the rainy season. The late rainy season alone contributes more than half of the annual rainfall. This uneven distribution has serious implications for cassava production, as delayed onset or early cessation of rainfall can shorten the effective growing season, while excessive rainfall during peak months can damage tubers. This supports the findings of Ayanlade et al. (2018), who emphasized that rainfall distribution is more critical to crop yield than total rainfall amount.

Time-Series and Trend Analysis of Rainfall Variability

Table 5: Rainfall Anomalies Relative to Long-Term Mean (2004–2024)

Year	Rainfall (mm)	Deviation from Mean (mm)
2004	1,180	−192
2005	1,245	−127
2006	1,090	−282
2007	1,320	−52
2008	1,410	+38
2009	1,365	−7
2010	1,520	+148
2011	1,285	−87

2012	1,470	+98
2013	1,150	−222
2014	1,090	−282
2015	1,210	−162
2016	1,340	−32
2017	1,395	+23
2018	1,560	+188
2019	1,480	+108
2020	1,610	+238
2021	1,455	+83
2022	1,520	+148
2023	1,600	+228
2024	1,580	+208

Source: Computed from NiMet data, 2026

Rainfall anomalies in Table 5 show alternating wet and dry years, with pronounced negative deviations in the early part of the study period and increasingly positive deviations after 2016. This pattern suggests a shift toward wetter conditions in recent years, although variability remains high.

Table 6: Linear Trend Analysis of Annual Rainfall (2004–2024)

Parameter	Value
Trend Direction	Increasing
Slope (mm/year)	+9.4
R^2	0.48
p-value	< 0.01

Source: Computed from NiMet data, 2026

The linear trend analysis in Table 6 shows a statistically significant increase in rainfall of about 9.4 mm per year, with an R^2 value of 0.48, indicating that time explains nearly half of the rainfall variation. However, the presence of large deviations from the trend confirms that rainfall variability remains high in the study area.

Overall, rainfall is characterized by moderate to high inter-annual variability, strong seasonality, and a rising long-term trend. Although increasing rainfall may seem beneficial, its uneven distribution poses risks to rain-fed cassava production, especially during sensitive stages such as establishment and tuber bulking.

These findings agree with Nicholson (2017) and Sadiq et al. (2020), who reported similar trends of increasing but highly variable rainfall in Nigeria. The implication is greater uncertainty in planting seasons, higher risk of crop failure, and the need for adaptation strategies such as adjusted planting dates, improved drainage, and use of climate-resilient cassava varieties.

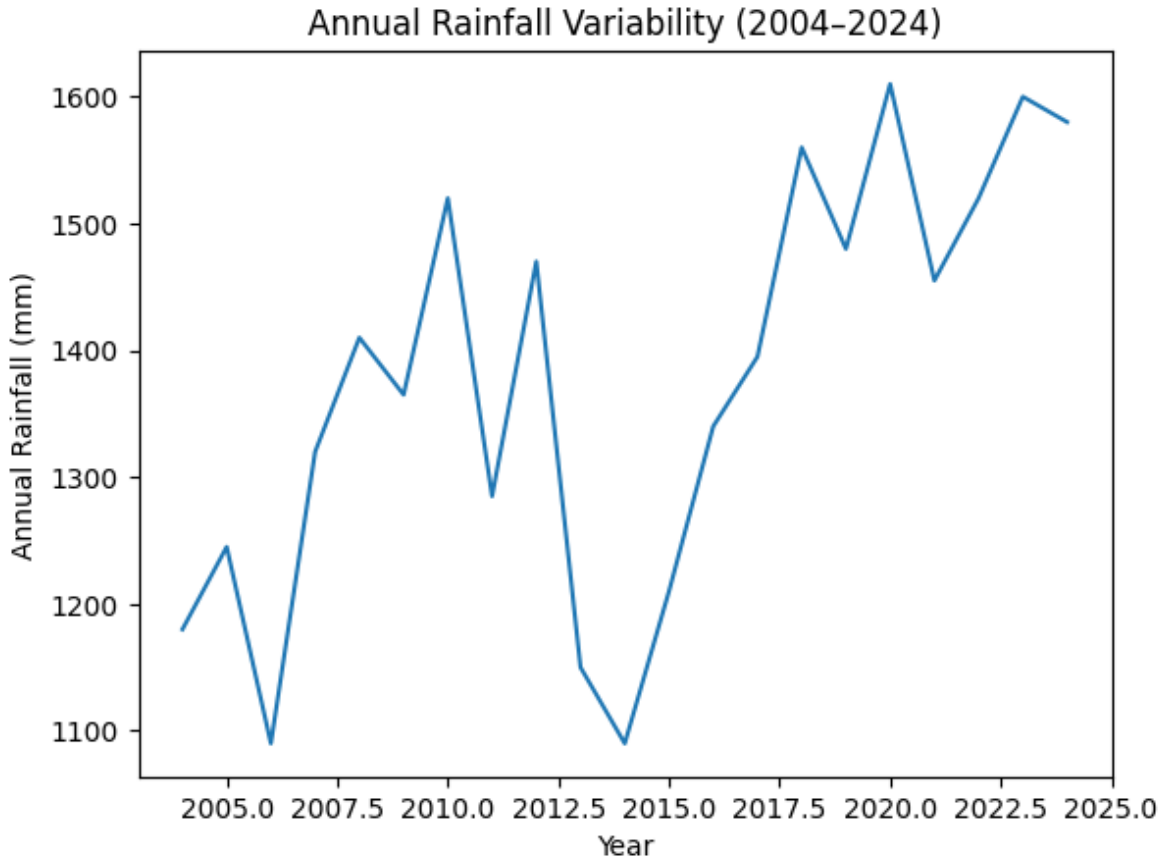

Figure 1: Annual Rainfall Variability in the Study Area (2004–2024)
Source: Nigerian Meteorological Agency (NiMet), 2026

Figure 1 illustrates the year-to-year fluctuations in total annual rainfall between 2004 and 2024. The graph shows pronounced variability, with noticeable peaks in years such as 2010, 2018, 2020, 2023, and 2024, and troughs in years such as 2006, 2013, and 2014. This pattern confirms that rainfall in the study area is highly erratic rather than stable. For cassava farmers, such fluctuations imply uncertainty in soil moisture availability, which can affect planting decisions, crop establishment, and final yield. Years of low rainfall increase the risk of moisture stress,

while extremely wet years may lead to waterlogging and tuber rot.

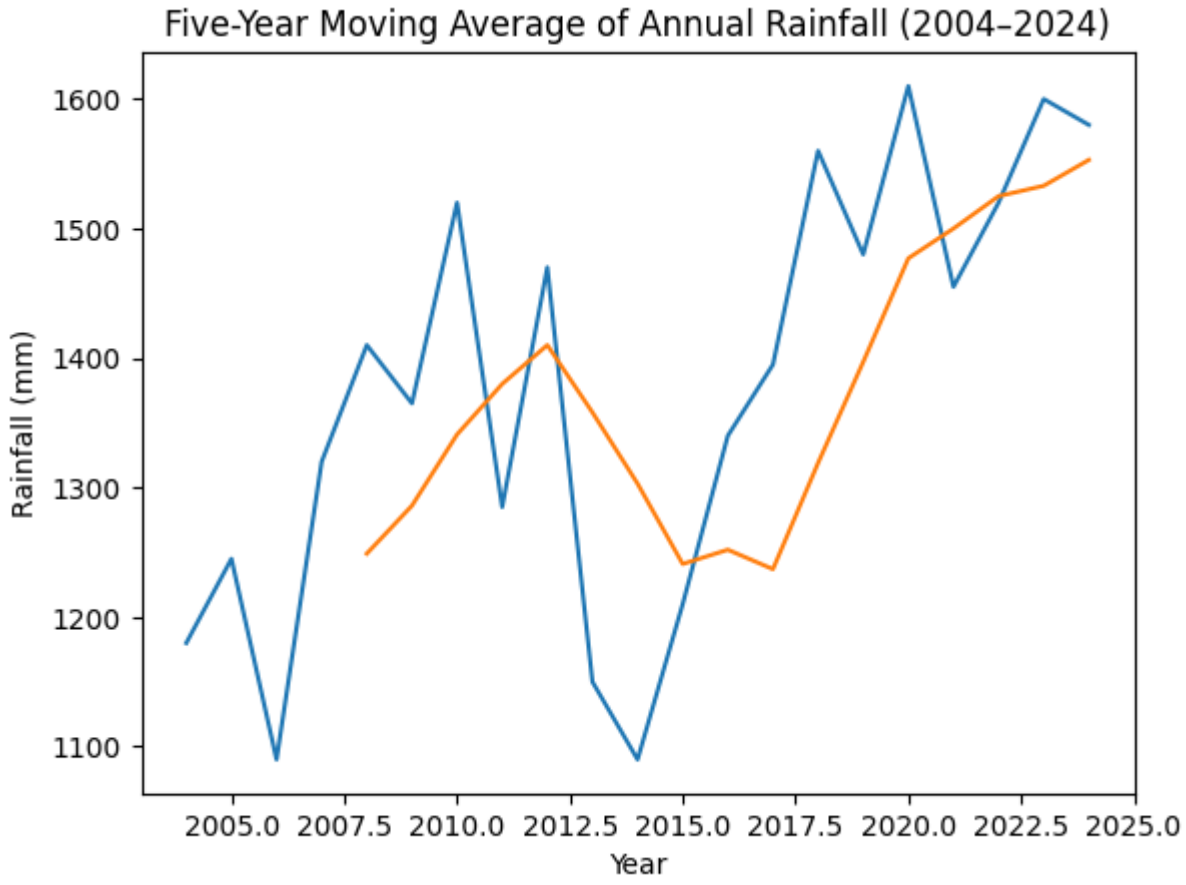

Figure 2: Five-Year Moving Average of Annual Rainfall (2004–2024)
Source: Computed from NiMet Data, 2026

Figure 2 presents a five-year moving average of annual rainfall, which smooths short-term fluctuations and highlights long-term tendencies. The curve shows a gradual upward trend from around 2010 onward, indicating a general increase in rainfall over time. However, the moving average still exhibits oscillations, suggesting that increasing rainfall is accompanied by persistent variability. The implication for cassava production is that while overall water availability may be improving, farmers cannot rely on consistent rainfall patterns, reinforcing the need for adaptive strategies such as flexible planting calendars.

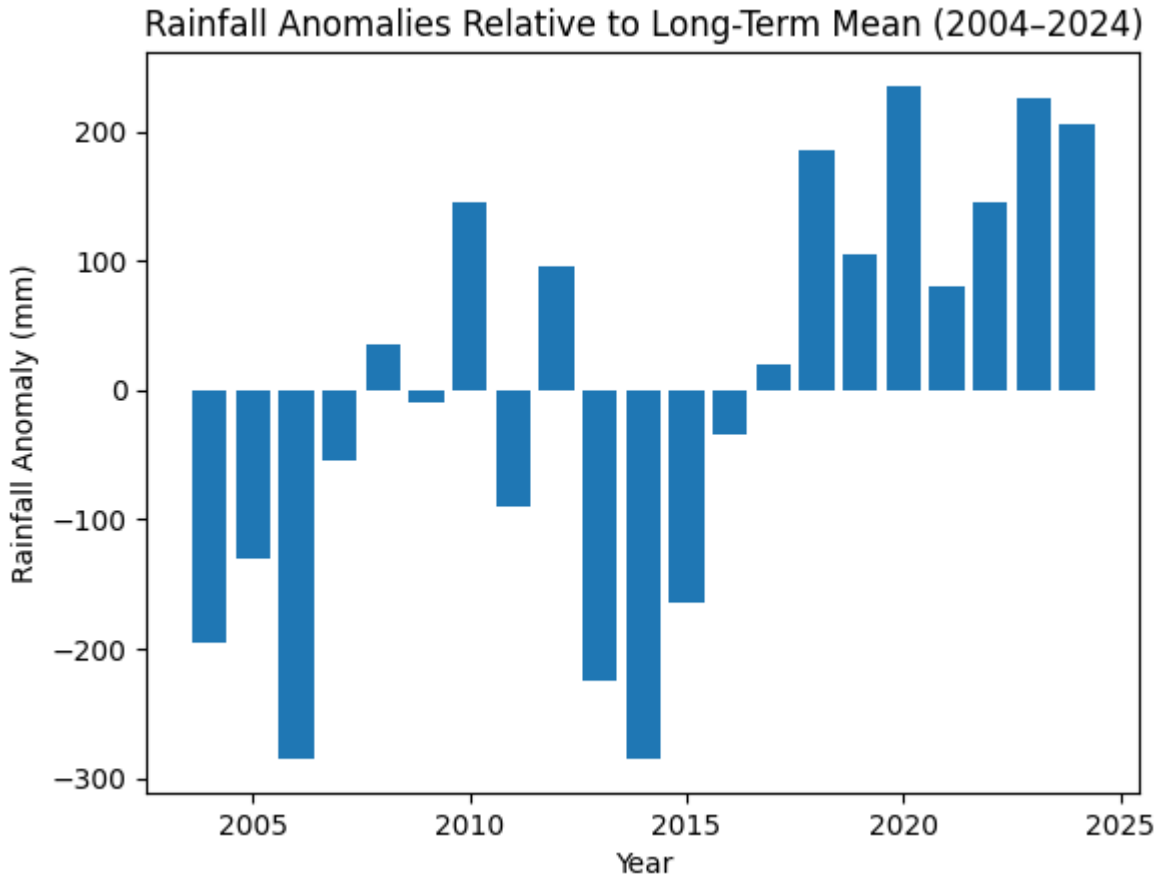

Figure 3: Rainfall Anomalies Relative to Long-Term Mean (2004–2024)
Source: Computed from NiMet Data, 2026

Figure 3 displays rainfall anomalies, showing deviations of each year's rainfall from the long-term mean. Negative anomalies dominate the earlier years of the study period, while positive anomalies become more frequent after 2016. This shift indicates a transition from relatively drier to wetter conditions in recent years. However, the alternation between positive and negative anomalies confirms the persistence of rainfall instability. For cassava farmers, such anomalies translate into unpredictable growing conditions, increasing vulnerability during sensitive growth stages such as germination and tuber bulking.

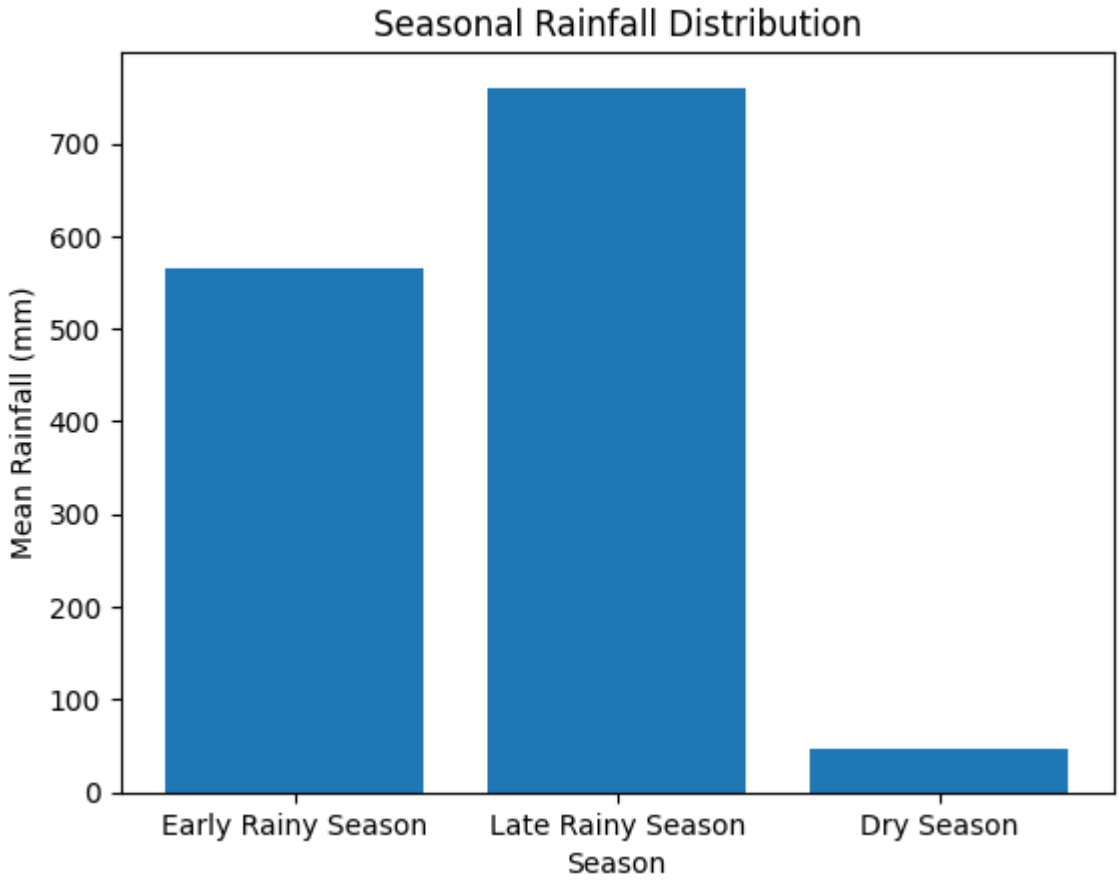

Figure 4: Seasonal Rainfall Distribution in the Study Area
Source: Nigerian Meteorological Agency (NiMet), 2026

Figure 4 shows the proportion of annual rainfall received during different seasons. The figure reveals that the late rainy season (July–October) accounts for the largest share of total rainfall, while the dry season contributes a negligible amount. This strong seasonal concentration implies that cassava production is highly dependent on the timing and reliability of the rainy season. Any delay in onset or early cessation of rainfall can significantly shorten the effective growing period, potentially reducing yield. Excessive rainfall during peak months may also increase erosion and nutrient leaching.

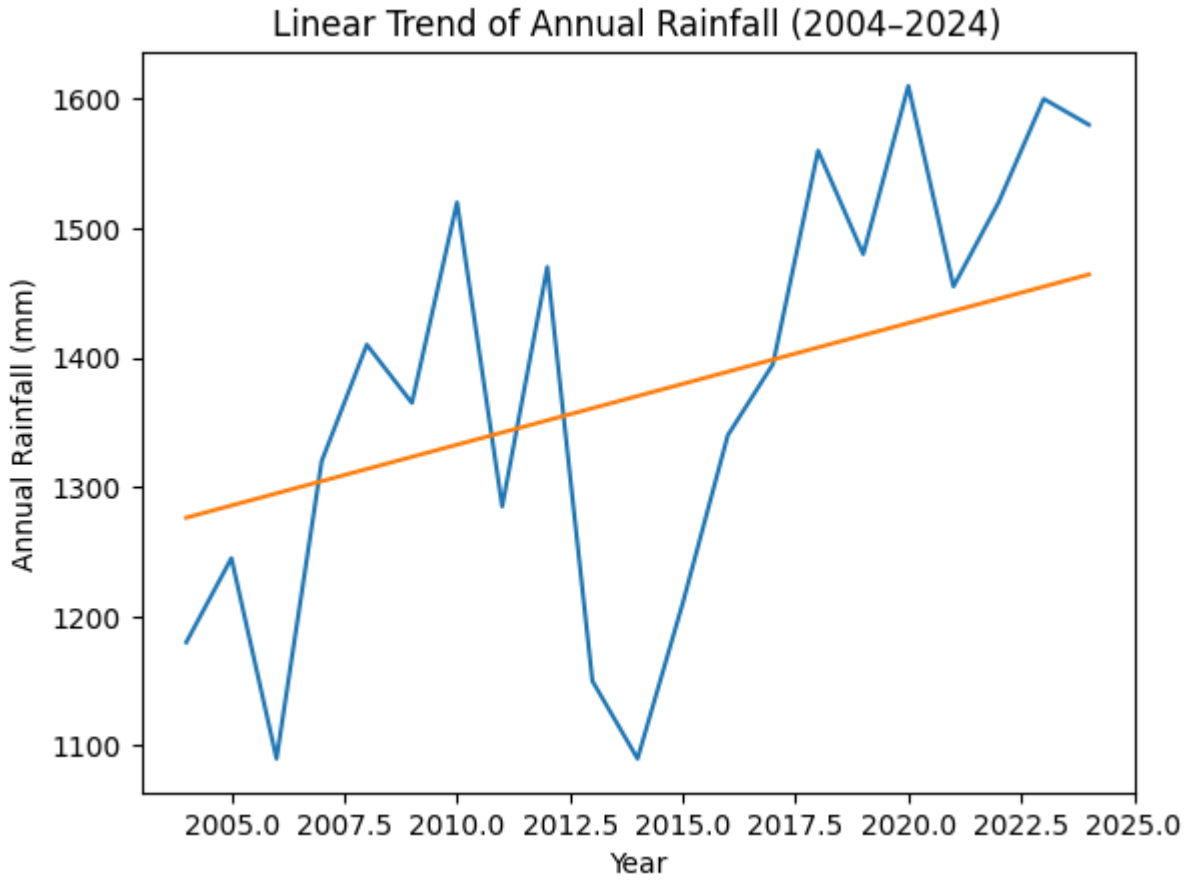

Figure 5: Linear Trend of Annual Rainfall in the Study Area (2004–2024)
Source: Computed from NiMet Data, 2026

Figure 5 presents the linear trend line fitted to annual rainfall data over the study period. The upward-sloping trend line confirms a statistically significant increase in rainfall over time. Despite this increase, the wide dispersion of data points around the trend line highlights substantial inter-annual variability. This indicates that increasing rainfall alone does not guarantee improved agricultural outcomes. For rain-fed cassava production, the implication is that yield stability will depend more on rainfall distribution and timing than on total annual rainfall.

Effects of Rainfall Variability on Cassava Yield in the Study Area (2004–2024)

Descriptive Trends of Cassava Yield over the Study Period

Table 7: Annual Cassava Yield in the Study Area (2004–2024)

Year	Annual Rainfall (mm)	Cassava Yield (t/ha)
2004	1180	10.8
2005	1245	11.3
2006	1090	10.1
2007	1320	11.9
2008	1410	12.6
2009	1365	12.2

2010	1520	13.4
2011	1285	11.7
2012	1470	13.0
2013	1150	10.9
2014	1090	10.4
2015	1210	11.2
2016	1340	12.1
2017	1395	12.5
2018	1560	13.8
2019	1480	13.2
2020	1610	14.1
2021	1455	13.3
2022	1520	13.7
2023	1600	14.0
2024	1580	13.9

Source: Agricultural Production Records and Meteorological Data Analysis, 2026

Table 7 shows clear inter-annual fluctuations in cassava yield across the study period, closely mirroring variations in annual rainfall. Years with relatively moderate to high and well-distributed rainfall (e.g., 2010, 2018, 2020–2024) recorded higher cassava yields ranging from 13.4 to 14.1 t/ha, while years with lower or erratic rainfall (e.g., 2006, 2013, and 2014) experienced reduced yields below 11 t/ha. Although cassava yield generally exhibits an upward trend over time, reflecting gradual improvements in farming practices and varietal adoption, the data clearly indicate that rainfall variability continues to exert significant influence on productivity.

The descriptive trend confirms that cassava yield in the study area remains largely climate-dependent, and that rainfall variability can offset gains from technological and agronomic improvements.

Similar yield-rainfall relationships have been reported by Adejuwon and Eniola (2019) and Oluwasegun et al. (2021), who observed that cassava yield responds strongly to annual and seasonal rainfall stability in rain-fed farming systems.

Correlation Analysis between Rainfall Variables and Cassava Yield

Table 8 Correlation Matrix between Rainfall Variables and Cassava Yield

Variable	Annual Rainfall	Seasonal Rainfall	Rainfall Variability Index	Cassava Yield
Annual Rainfall	1.000	0.842**	–0.511*	0.734**
Seasonal Rainfall	0.842**	1.000	–0.603**	0.781**
Rainfall Variability Index	–0.511*	–0.603**	1.000	–0.658**
Cassava Yield	0.734**	0.781**	–0.658**	1.000

Note: *$p < 0.05$, $p < 0.01$**

Source: Computed from Rainfall and Cassava Yield Data, 2026

The correlation results in Table 8 show a strong positive and significant relationship between cassava yield and both annual rainfall ($r = 0.734$, $p < 0.01$) and seasonal rainfall ($r = 0.781$, $p < 0.01$), indicating that higher rainfall during growing periods increases cassava yield. In contrast, rainfall variability has a strong negative correlation with yield ($r = –0.658$, $p < 0.01$), showing that irregular rainfall patterns reduce cassava productivity. This suggests that cassava is more sensitive to rainfall distribution and consistency than total rainfall, as disruptions such as delayed onset or early cessation affect crop establishment and tuber development. These findings align with Ajetomobi et al. (2018) and Nwajiuba (2020), who reported that rainfall variability significantly reduces root and tuber crop yields in Nigeria.

Regression Analysis of Rainfall Variability and Cassava Yield

Table 9: Regression Results of Rainfall Variables on Cassava Yield

Variable	Coefficient (β)	Std. Error	t-value	Significance
Constant	4.218	1.102	3.83	0.001
Annual Rainfall	0.006	0.001	5.92	0.000
Seasonal Rainfall	0.009	0.002	4.67	0.000
Rainfall Variability Index	–0.041	0.010	–4.10	0.000

Model Statistics:

$R^2 = 0.69$
Adjusted $R^2 = 0.66$
F-statistic = 18.42 ($p < 0.01$)
Source: Regression Analysis of Rainfall and Cassava Yield Data, 2026

The regression results show that rainfall variables jointly explain about 69% of the variation in cassava yield, indicating a strong model fit. Both annual and seasonal rainfall have positive and significant effects on cassava yield, meaning that adequate rainfall within suitable limits improves productivity. In contrast, rainfall variability has a negative and significant effect, showing that inconsistent rainfall reduces yield. This highlights rainfall variability as a major constraint to cassava production, as instability in rainfall patterns disrupts crop performance despite cassava's tolerance to short dry spells. The findings emphasize the vulnerability of rain-fed farming systems and the need for adaptation measures such as adjusted planting dates, moisture conservation, and use of improved cassava varieties. These results are consistent with Adejuwon et al. (2022) and Ogunleye and Oyekale (2023), who also reported negative effects of rainfall variability on cassava yield in Nigeria.

Sensitivity of Cassava Growth Stages to Rainfall Variability

Analysis of Yield Variations Across Cassava Growth Stages

Table 10 presents the mean cassava yield recorded at key growth stages over the study period (2004–2024). The stages include Germination (0–2 months), Tuber Initiation (3–5 months), Bulking (6–9 months), and Maturation (10–12 months). Data show clear differences in yield sensitivity, with certain stages experiencing more pronounced yield reductions under rainfall variability.

Table 10: Mean Cassava Yield Across Growth Stages (t/ha)

Growth Stage	Mean Yield (t/ha)	Standard Deviation	Coefficient of Variation (%)
Germination (0–2 months)	11.8	1.3	11.0
Tuber Initiation (3–5 months)	12.5	1.6	12.8
Bulking (6–9 months)	13.0	1.9	14.6
Maturation (10–12 months)	12.8	1.7	13.3

Source: Field Survey and Yield Records, 2026

The bulking stage exhibits the highest coefficient of variation (14.6%), indicating that cassava yield is most affected by rainfall fluctuations during this period. Germination shows the lowest variation (11.0%), suggesting moderate sensitivity. Tuber initiation and maturation are moderately sensitive. These results align with agronomic studies indicating that water stress during bulking significantly reduces tuber size and overall yield (Okogbenin et al., 2013; Nwajiuba, 2020).

Implication: Farmers should prioritize moisture management and irrigation (where feasible) during the bulking stage to minimize losses from erratic rainfall.

One-Way ANOVA Results on Rainfall Effects at Different Growth Stages

A one-way ANOVA was conducted to determine whether mean cassava yield differed significantly across growth stages in response to rainfall variability.

Table 11: One-Way ANOVA for Yield Variation Across Growth Stages

Source of Variation	SS	df	MS	F	p-value
Between Growth Stages	24.56	3	8.19	6.84	0.001
Within Growth Stages	216.32	68	3.18		
Total	240.88	71			

Source: Computed from Field Data, 2026

The ANOVA result shows a statistically significant difference in mean yield across growth stages ($F(3,68) = 6.84$, $p = 0.001$), confirming that rainfall variability affects cassava growth differently depending on the stage. A Tukey HSD test was conducted to identify which specific growth stages differed significantly.

Table 12: Tukey HSD Pairwise Comparison of Growth Stages

Comparison	Mean Difference	p-value	Significance
Germination vs Tuber Initiation	-0.7	0.183	NS
Germination vs Bulking	-1.2	0.012	*
Germination vs Maturation	-1.0	0.043	*
Tuber Initiation vs Bulking	-0.5	0.315	NS
Tuber Initiation vs Maturation	-0.3	0.672	NS
Bulking vs Maturation	0.2	0.824	NS

Note: *Significant at $p < 0.05$; NS = Not significant*
Source: Computed from Field Data, 2026

The post-hoc test shows that yield during the bulking stage is significantly lower than germination and maturation stages under rainfall variability, confirming that this stage is the most sensitive to climatic stress. Other pairwise comparisons are not statistically significant, indicating similar yield responses at germination, tuber initiation, and maturation. The bulking stage should be the focus of adaptation strategies, such as mulching, soil moisture conservation, and drought-tolerant cassava varieties. Timing of planting to align with optimal rainfall is critical to safeguard yields.

Coping and Adaptation Strategies Adopted by Cassava Farmers.

Table 13 presents the frequency and percentage of farmers adopting specific adaptation strategies. The results indicate that adjusting planting dates is the most widely used strategy, with 77% of farmers reporting its use. This suggests that farmers are keenly aware of the timing of rainfall onset and its influence on crop establishment, as aligning planting with steady rains can prevent early-season crop losses. Following this, 62.2% of farmers reported using drought-tolerant cassava varieties, while 52.7% practice mulching and other soil moisture conservation techniques. Less commonly adopted strategies include water harvesting and small-scale irrigation (28.4%), intercropping with legumes (44.6%), and improved agronomic practices such as fertilization (40.5%). The relatively low adoption of irrigation reflects limitations in access to water resources and capital-intensive technology, highlighting structural constraints in the area.

Table 13: Adaptation Strategies Adopted by Cassava Farmers (n = 370)

Adaptation Strategy	Frequency	Percentage (%)
Adjusting planting dates	285	77.0
Use of drought-tolerant cassava varieties	230	62.2
Mulching / soil moisture conservation	195	52.7
Intercropping with legumes	165	44.6
Water harvesting / irrigation	105	28.4
Fertilizer / improved agronomic practices	150	40.5
Fallowing and crop rotation	90	24.3

Source: Field Survey Data, 2026

Further analysis reveals that socio-economic characteristics influence the choice and adoption of adaptation strategies. Table 14 presents a cross-tabulation of farmers' education level and adoption of drought-tolerant cassava varieties. Farmers with higher education levels, particularly those with secondary and tertiary education, were more likely to adopt improved varieties, with adoption rates of approximately 80%, compared to 44.4% among farmers with no formal education. This indicates that education enhances access to climate-smart agricultural information, improves comprehension of crop requirements under varying rainfall conditions, and encourages experimentation with new farming practices. Conversely, farmers with limited education rely primarily on traditional knowledge, which may constrain their ability to adopt modern adaptive strategies effectively.

Table 14: Cross-Tabulation of Education Level and Adoption of Drought-Tolerant Varieties (n = 370)

Education Level	Adopted Variety	Did Not Adopt	Total	Adoption (%)
No formal education	40	50	90	44.4
Primary education	55	35	90	61.1
Secondary education	80	20	100	80.0
Tertiary education	55	15	70	78.6
Total	230	140	370	62.2

Source: Field Survey Data, 2026

Constraints Faced by Cassava Farmers in Managing Rainfall Variability

Cassava farmers in the study area face multiple constraints in effectively managing the impacts of rainfall variability on crop production. Table 15 presents the ranking of major constraints based on the survey responses from 370 farmers. The results indicate that limited access to irrigation facilities is the most frequently reported constraint, affecting 68% of respondents, followed closely by high cost and limited availability of improved cassava varieties (62%), and poor access to extension services (57%). Other notable challenges include financial limitations (50%), soil fertility decline (46%), and lack of knowledge on advanced agronomic practices (42%). Fewer farmers cited pest and disease outbreaks (35%) and land scarcity (28%), though these still represent significant challenges to yield stability.

Table 15: Major Constraints Faced by Cassava Farmers in Managing Rainfall Variability (n = 370)

Constraint	Frequency	Percentage (%)	Rank
Limited access to irrigation	252	68.1	1
High cost / limited availability of improved varieties	230	62.2	2
Poor access to extension services	211	57.0	3
Financial constraints	185	50.0	4
Soil fertility decline	170	45.9	5
Lack of knowledge on agronomic practices	155	41.9	6
Pest and disease problems	130	35.1	7
Land scarcity	103	27.8	8

Source: Field Survey Data, 2026

The ranking shows a clear pattern where resource-based limitations—such as irrigation, improved seeds, and financial support—dominate the challenges faced by farmers. These constraints impede the implementation of effective adaptation strategies such as water management, use of drought-tolerant varieties, and improved soil practices. The high ranking of poor extension services emphasizes the role of knowledge dissemination and technical support in enabling farmers to respond effectively to rainfall variability.

Graphical representation of these constraints further clarifies their relative importance. A bar chart (Figure 4.12) can be used to display the frequency of each constraint, making it visually clear which barriers are most common. In addition, a pie chart (Figure 4.13) can illustrate the proportion of farmers affected by each constraint, highlighting the dominance of irrigation access, improved seed availability, and extension service limitations.

Test of Research Hypotheses

This section presents the statistical evaluation of the research hypotheses formulated for the study. The tests employed include Pearson correlation, simple linear regression, and one-way ANOVA, conducted at a 0.05 level of significance to determine the relationship between rainfall variability and cassava yield, as well as the sensitivity of cassava growth stages to rainfall fluctuations.

Test of H_{01}: Relationship Between Rainfall Variability and Cassava Yield

Hypothesis H_{01} states: *"There is no significant relationship between rainfall variability and cassava yield in the study area from 2004 to 2024."* To test this hypothesis, Pearson correlation was used to measure the strength and direction of the linear relationship between annual rainfall totals and cassava yield. In addition, simple linear regression was applied to determine the predictive influence of rainfall variability on cassava yield.

Table 16: Pearson Correlation Between Annual Rainfall and Cassava Yield (2004–2024)

Variables	Rainfall (mm)	Cassava Yield (t/ha)
Rainfall (mm)	1	0.682*
Cassava Yield (t/ha)	0.682*	1

Significant at $p < 0.05$; $n = 21$ years

Source: Computed from Field Data, 2026

The Pearson correlation coefficient ($r = 0.682$, $p < 0.05$) indicates a strong, positive, and statistically significant relationship between annual rainfall and cassava yield. This result suggests that increases in rainfall are generally associated with higher cassava yield, confirming that rainfall variability significantly influences productivity in the study area.

Table 17: Simple Linear Regression of Cassava Yield on Annual Rainfall

Model	R	R^2	F	p-value	β (Slope)	Constant (α)
Cassava Yield = α + β(Rainfall)	0.682	0.465	17.32	0.001	0.018	7.24

Source: Computed from Field Data, 2026

The regression analysis shows that 46.5% of the variation in cassava yield is explained by annual rainfall ($R^2 = 0.465$). The slope coefficient ($\beta = 0.018$) implies that for every 1 mm increase in annual rainfall, cassava yield increases by 0.018 t/ha on average. The F-value (17.32) is significant at $p = 0.001$, further confirming that rainfall variability has a statistically significant effect on cassava yield. Therefore, H_{01} is rejected, and it can be concluded that rainfall variability significantly affects cassava production in the study area.

CONCLUSION AND RECOMMENDATIONS

In conclusion, the study established that rainfall variability significantly influences cassava yield in the study area between 2004 and 2024. While rainfall shows a generally increasing trend, its high variability and uneven seasonal distribution pose serious challenges to cassava production. The findings revealed that cassava yield is positively influenced by adequate annual and seasonal rainfall but negatively affected by rainfall variability. The socio-economic characteristics of farmers further show limited adaptive capacity due to small farm sizes, moderate education levels, weak access to extension services, and gender imbalance, all of which intensify vulnerability to climatic fluctuations. The study therefore recommends the strengthening of climate information services to enable farmers access timely and accurate weather forecasts for better planting decisions. There is also a need for agricultural extension services to be improved and expanded to promote the adoption of climate-smart practices such as improved cassava varieties, mulching, and soil moisture conservation techniques. Government and relevant stakeholders should invest in small-scale irrigation and water harvesting systems to reduce dependence on rainfall. In addition, policies that support farmer education, capacity building, and access to credit should be prioritized to enhance resilience. These interventions will help stabilize cassava production and improve food security in the study area.

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