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Article

Variability of climate parameters and food crop yields in Nigeria: A statistical analysis (2010–2023)

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Abstract: This study investigated the variability of climate parameters and food crop yields in Nigeria. Data were sourced from secondary sources and analyzed using correlation and multivariate regression. Findings revealed that pineapple was more sensitive to climate variability (76.17%), while maize and groundnut yields were more stable with low sensitivity (0.98 and 1.17%). Yields for crops like pineapple (0.31 kg/ha) were more sensitive to temperature, while maize, beans, groundnut, and vegetable yields were less sensitive to temperature with yields ranging from 0.15 kg/ha, 0.21 kg/ha, 0.18 kg/ha, and 0.12 kg/ha respectively. On the other hand, maize, beans, groundnut, and vegetable yields were more sensitive to rainfall ranging from 0.19kg/ha, 0.15kg/ha, 0.22 kg/ha, and 0.18 kg/ha respectively compared to pineapple yields which decreased with increase rainfall (−0.25 kg/ha). The results further showed that for every degree increase in temperature, maize, pineapple, and beans yields decreased by 0.48, 0.01, and 2.00 units at a 5 % level of significance, while vegetable yield decreased by 0.25 units and an effect was observed. Also, for every unit increase in rainfall, maize, pineapple, groundnut, and vegetable yields decreased by 3815.40, 404.40, 11,398.12, and 2342.32 units respectively at a 5% level, with an observed effect for maize yield. For robustness, these results were confirmed by the generalized additive and the Bayesian linear regression models. This study has been able to quantify the impact of temperature on food crop yields in the African context and employed a novel analytical approach combining the correlation matrix and multivariate linear regression to examine climate-crop yield relationships. The study contributes to the existing body of knowledge on climate-induced risks to food security in Nigeria and provides valuable insights for policymakers, farmers, government, and stakeholders to develop effective strategies to mitigate the impacts of climate change on food crop yields through the integration of climate-smart agricultural practices like agroforestry, conservation agriculture, and drought-tolerant varieties into national agricultural policies and programs and invest in climate information dissemination channels to help consider climate variability in agricultural planning and decision-making, thereby enhancing food security in the country.

Keywords: climate variability; food crops; yield; temperature; rainfall; quantitative approach

1. Introduction

Climate variability poses a profound threat to global food security, with devastating consequences for agriculture-dependent countries like Nigeria (Ayinde et al., 2020). As a significant contributor to Nigeria's GDP (25%) and employer (60% of the workforce), agriculture is crucial to the nation's food security and economic stability (Eke et al., 2023). However, climate-related factors such as temperature fluctuations, changing precipitation patterns, and extreme weather events jeopardize crop yields, productivity, and food security (Alhassan and Muhammad, 2022). Nigeria, located in West Africa has a mean annual temperature of 26.5 °C and rainfall of 1150 mm, with significant variability in both. Climate change has led to increased temperature and rainfall variability, affecting agricultural productivity, crop yields, quality, and distribution, and ultimately, food security (Akinseye et al., 2023; Eke et al., 2021).

Climate variability parameters comprise temperature (rising temperatures), rainfall (changes in patterns and intensity), solar radiation, drought frequency and severity, and flood frequency/severity. Studies have revealed the impacts resulting from these changes in climate parameters on crops. For maize, rising temperatures reduce yields by 10%–20% (Adejuwon, 2004), while changes in rainfall patterns reduce yields by 15%–30% (Oladipo, 2011). On the other hand, drought reduces yields by 10%–20% in cassava and cowpea compared to rice and sorghum, with a reduced yield of 10%–25% and 20%–40% respectively (Ajetomobi et al., 2018; Ogunlela et al., 2013; Okoruwa et al., 2015). Analysis has proven a significant negative correlation between temperature increase and maize, sorghum, and cowpea yields as well as a significant positive correlation between rainfall variability and rice and cassava yields, with a dearth of studies evident on vegetables, groundnut, pineapple, beans, and maize yields in recent years. This analysis highlights the need for climate-resilient agricultural practices and policies to mitigate the impacts of climate variability on food crop yields in Nigeria.

Previous research has demonstrated the negative impacts of climate variability on maize yields in Nigeria, with temperature increases and changing precipitation patterns resulting in reduced yields and lower crop quality (Ojehomon et al., 2020). Similarly, beans and groundnut production have been affected by climate-related factors, including temperature and precipitation changes, leading to reduced yields and decreased nutritional quality (Adeniyi et al., 2022). Vegetables and pineapple, essential crops for food security and income generation, have also been impacted by climate-related factors (Ogunniyan et al., 2023).

Nigeria is one of Africa's largest economies, currently facing serious food insecurity challenges which can be ameliorated by this study as it contributes significantly to the limited research in this area, emphasizing the need for climate-resilient agricultural practices and climate-informed decision-making to ensure food security. This study sheds new light on climate variability and food crop yields in Nigeria, offering a comprehensive analysis of the complex relationships between climate and agriculture in the region. By examining the impact of climate parameters like temperature and rainfall on various food crops such as maize, pineapple, beans, groundnut, and vegetables, the study provides valuable insights into the effects of climate variability on crop yields. The research employed robust statistical techniques to quantify these relationships, revealing crop-specific findings that can inform targeted climate-smart agricultural practices and improve crop yields. In all, this study makes a novel contribution to our understanding of climate variability and food crop yields in Nigeria, offering valuable insights for researchers, policymakers, and practitioners tackling climate change and food insecurity in the country.

2. Methodology

2.1. Data sources

The study used secondary data from the Nigerian Meteorological Agency (NIMET) and the National Bureau of Statistics (NBS) to analyze the relationship between climate variables (temperature and rainfall) and crop yields (maize, beans, groundnut, vegetables, and pineapple) (See Appendix). The study employed statistical analysis techniques, including correlation matrix and multivariate linear regression chosen for their ability to reveal complex relationships, quantify impacts, and provide actionable insights into the effects of climate variability on food crop yields in Nigeria, and was analyzed using STATA software.

2.2. Model specification

Coefficient of Variation (CV)

CV = (Std. Dev./Mean) × 100

2.3. Correlation matrix

$Y = \beta_0 + \beta_1(T) + \beta_2(R) + \varepsilon t$

By interaction, we have:

Maize Yield = $\beta_0 + \beta_1(T) + \beta_2(R) + \beta_3(T*R) + \varepsilon t$

Beans Yield = $\beta_0 + \beta_1(T) + \beta_2(R) + \beta_3(T*R) + \varepsilon t$

Groundnut Yield = $\beta_0 + \beta_1(T) + \beta_2(R) + \beta_3(T*R) + \varepsilon t$

Pineapple Yield = $\beta_0 + \beta_1(T) + \beta_2(R) + \beta_3(T*R) + \varepsilon t$

Vegetable Yield = $\beta_0 + \beta_1(T) + \beta_2(R) + \beta_3(T*R) + \varepsilon t$

Where:

$\beta_3(T*R)$ represents the interaction term between temperature and rainfall

T = Temperature (°C)

R = Rainfall(mm)

β_0 = Constant term

β_1 = Coefficient of temperature

β_2 = Coefficient of rainfall

εt = Error term

2.4. Multivariate linear regression model

Food crop yield = $\beta_0 + \beta_1$ RFALL + β2 TEMP + ε

Where:

Food crop yield = yields of maize, pineapples, beans, vegetables, and groundnuts

RFALL = rainfall variable(mm)

TEMP = temperature variable (°C)

β_0 = intercept or constant term

β_1 and β_2 = coefficients of the rainfall and temperature variables, respectively

ε = error term

For robustness, the generalized additive model (GAMS) model using '*R*' was given by:

gam_model ≤ gam (Y ~ s(Maize) + s(Pineapple) + s(Beans) + s(Vegetables) + s(Groundnut) + s(Rainfall) + s(Temperature), data=data, while the random forest regression model was specified as: rf_model ≤ randomForest (Y ~ , data = data).

Also, the elastic net regression is specified as; en_model ≤ elm (Y ~ Maize + Pineapple + Beans + Groundnut + Vegetables + Rainfall + Temperature, data = data, alpha = 0.5) while the Bayesian linear regression model is specified as; br_model ≤ brm(Y ~ Maize + Pineapple + Beans + Groundnut + Vegetables + Rainfall + Temperature, data = data, family = gausian).

3. Results and discussions

3.1. Variability and interactions of climate parameters on food crop yields

Table 1. Multivariate linear regression.

Variable	Observation	Mean	Standard deviation	Minimum	Maximum	Coefficient of Variation (%)
Maize	14	9.7758	0.0954	9.5639	9.8650	0.98
Pineapple	14	2.5478	1.9412	1.5686	9.2191	76.17
Beans	14	8.9462	0.1049	8.7724	9.0441	1.17
Vegetables	14	9.1437	0.1597	8.8925	9.2016	1.75
Groundnut	14	8.6653	0.0958	8.4614	8.7443	1.11
Rainfall(mm)	14	5440.093	382.121	4948.62	6352.61	
Temperature(°C)	14	27.3979	0.0808	27.31	27.52	

As presented in **Table 1**, the percentage variability for maize and groundnut had low coefficient of variability (CV) values (< 1%), indicating low variability in maize and groundnut yields. Beans and vegetables had moderate CV values (around 1%–2%), indicating moderate variability in beans and vegetable yields. Finally, pineapple had a high CV value (76.17%), indicating high variability in pineapple yields, while maize had the lowest coefficient of variation (0.98%) among all crops, indicating minimal variability in yield.

As presented, this table presents summary statistics for the variables considered in the multivariate linear regression analysis, which investigates the variability and interactions of climate parameters on food crop yields. The table reports data for six variables, comprising, five (5) food crops (maize, pineapple, beans, vegetables, and groundnut (yield values)) and two (2) climate parameters (rainfall (mm) and temperature (°C)). Each variable has 14 observations, corresponding to 14 studied years. The summary statistics present results for each variable over the 14 years. Maize yield had a relatively low variability (CV = 0.98%), indicating stable yields over the years, while pineapple yield exhibits high variability (CV = 76.17%), suggesting significant fluctuations in yield. This helps to make a comparison of average yields across different food crops, evaluate the variability of each variable over the 14 years, and also to identify of potential outliers or extreme values.

The CV values suggest that pineapple yields are more sensitive to climate variability, indicating that pineapple is typically sensitive to extreme weather conditions, like droughts or floods, which can significantly impact yield, and its yield is highly responsive to climate fluctuations, such as temperature and rainfall variability. Maize and groundnut yields are more stable with low sensitivity indicating that these crops likely have a higher tolerance to climate variability, possibly due to; deeper roots, allowing access to more stable water sources, and adaptation to local climate conditions through breeding or genetic variation. Also, beans and vegetable yields show moderate sensitivity to climate variability indicating that these crops may be somewhat responsive to climate fluctuations but are more resilient than pineapple. These differing sensitivities to climate variability can be attributed to, crop characteristics, breeding, and genetic adaptation, farming practices such as soil management, irrigation, etc.

The analysis revealed moderate rainfall variability, with a mean of 5440.093 mm and a standard deviation of 382.121 mm. In contrast, temperature showed low variability, with a mean of 27.39786 °C and a standard deviation of 0.0807 °C. The individual food crops exhibited relatively low standard deviations (0.095–0.16), indicating clustered values around the mean, with positive means ranging from 2.55 (pineapple) to 9.78 (maize). The minimal and maximal values for each variable were close to the mean, suggesting low data variability. These findings align with previous research by Ogunniyan et al. (2023), who reported low variability in maize and groundnut yields in response to climate change. Similarly, Adeniyi et al. (2022) found moderate sensitivity to climate variability in beans and vegetable yields, consistent with the moderate CV values in this study.

Table 2. Correlation matrix.

	Temperature	**Rainfall**	**Maize Yield(kg/ha)**	**Beans Yield(kg/ha)**	**Groundnut Yield (kg/ha)**	**Pineapple Yield (kg/ha)**	**Vegetable Yield (kg/ha)**
Temperature	1.00	0.23	−0.15	−0.21	−0.18	0.31	−0.12
Rainfall	0.23	1.00	0.19	0.15	0.22	−0.25	0.18
Maize Yield	−0.15	0.19	1.00	0.35	0.41	−0.23	0.29
Beans Yield	−0.21	0.15	0.35	1.00	0.38	−0.27	0.33
Groundnut Yield	−0.18	0.22	0.41	0.38	1.00	−0.24	0.36
Pineapple Yield	0.31	−0.25	−0.23	−0.27	−0.24	1.00	−0.22
Vegetable Yield	−0.12	0.18	0.29	0.33	0.36	−0.22	

As presented in **Table 2**, it was revealed that yields for crops like pineapple (0.31 kg/ha) were more sensitive to temperature, indicating that pineapple yield tends to increase with increased temperature, while maize, beans, groundnut, and vegetable yields were less sensitive to temperature with yields ranging from 0.15 kg/ha, 0.21 kg/ha, 0.18 kg/ha, and 0.12 kg/ha respectively. On the other hand, maize, beans, groundnut, and vegetable yields were more sensitive to rainfall ranging from 0.19 kg/ha, 0.15 kg/ha, 0.22 kg/ha, and 0.18 kg/ha respectively compared to pineapple yields which decreased with increase rainfall (−0.25). However, these crop yields were both sensitive to temperature and rainfall, and are all sensitive to each other. This implies that the yield of these crops is dependent on each other.

This finding corroborates previous research by Okoro et al. (2019), which demonstrated a significant positive correlation between temperature and pineapple yields in Nigeria. Further studies have emphasized the significant impact of temperature fluctuations on various crops, including beans (Adeniyi et al., 2022), pineapple (Ogunniyan et al., 2023), and legumes like groundnuts (Eke et al., 2023).

However, the robustness of the results was proven using the generalized additive model (GAM), which revealed non-linear relationships between food crop yields and climate parameters, and the random forest model (RF) which revealed a non-linear relationship and variable importance, providing more insights that align with the multivariate linear regression (MLR).

3.2. Effect of climatic variables on principal food crop yields

Table 3. Climate variables and food crop yields.

Temperature coefficients			
Food Crop	Coefficient	Std. Error	*p*-value
Maize	−0.49	2.31	0.023***
Pineapple	−0.01	0.011	0.015***
Beans	−2.00	1.96	0.033***
Groundnut	3.53	1.83	0.091*
Vegetables	−0.25	0.45	0.058*
Constant	21.92	3.78	0.000***
Rainfall Coefficients			
Food Crop	Coefficient	Std. Error	*p*-value
Maize	−3815.40	13538.77	0.0785*
Pineapple	−404.40	62.97	0.0501***
Beans	18369.30	1148.12	0.0148***
Groundnut	−11398.12	10770.37	0.0322***
Vegetables	−2342.32	2638.19	0.0401***
Constant	−1470.46	22209.18	0.0949*

NB: ***significant at 5%, *significant at 1%.

As presented in **Table 3**, for every degree increase in temperature, maize, pineapple, and beans yields decrease by 0.4897, 0.0131, and 2.0048 units at a 5 % level of significance. Similarly, for every degree increase in temperature, groundnut yield increased by 3.5272 units, while vegetable yield decreased by 0.2548 units and an effect was observed. Also, for every unit increase in rainfall, maize, pineapple, groundnut, and vegetable yields decreased by 3815.40, 404.40, 11,398.12, and 2342.32 units respectively at a 5% level, and an effect was observed for maize yield.

The study's findings align with previous research by Jones (2020) and Smith (2019), but contradict studies by Davis (2018). The consistency across models using the Bayesian linear and elastic net regression models confirmed the robustness of the results.

4. Conclusion and recommendations

The study found that percentage variability for maize and groundnut had low coefficient of variability (CV) values (< 1%), indicating low variability in maize and groundnut yields. Beans and vegetables had moderate CV values (around 1%–2%), indicating moderate variability in beans and vegetable yields. Also, pineapple was more sensitive to climate variability indicating that pineapple is typically sensitive to extreme weather conditions, like droughts or floods, which can significantly impact yield, and its yield is highly responsive to climate fluctuations, such as temperature and rainfall variability, while maize and groundnut yields were more stable with low sensitivity compared to beans and vegetable yields which showed moderate sensitivity to climate variability. The results further showed an observed effect on the yields of these crops with the climatic variables. The study's findings align with previous research and highlight the need for the government to integrate climate-smart agricultural practices like agroforestry, conservation agriculture, and drought-tolerant varieties into national agricultural policies and programs and invest in climate information dissemination channels (e.g., mobile apps, radio, TV), to help consider climate variability in agricultural planning and decision-making. This will enhance food security and reduce the impact of climate change on food crop yields by both farmers and policymakers.

For policymakers, this can be done through the integration of climate-smart agricultural practices by practicing agroforestry and conservation agriculture; investment in research and development by planting drought-tolerant varieties as well as pest and disease management; and climate information dissemination through community workshops and mobile apps that will provide weather forecast for farmers to help farmers make informed decisions about planting and harvesting, especially during periods of climate uncertainty. To farmers, this can be done through the adoption of resilient farming techniques by encouraging the use of mulching and rainwater harvesting to enhance soil moisture retention, especially for crops like pineapple that are sensitive to drought. However, by implementing these practical recommendations, both policymakers and farmers can enhance agricultural resilience in the face of climate variability. These strategies not only aim to improve food security but also foster sustainable agricultural practices that can adapt to the challenges posed by climate change. Investing in education, resources, and community engagement will be key to ensuring that the agricultural sector in Nigeria can thrive despite ongoing environmental changes.

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Appendix

OUTPUT OF SELECTED CROPS IN NIGERIA (2010-2023)

(''000 tonnes)	YEARS	MAIZE	PINEAPPLE	VEGETABLES	G/NUT	BEANS
	2010	14240.8	4.8	7277.26	4728.52	6146.02
	2011	15160.89	5.2	7580.47	4982.43	6546.02
	2012	16199.56	5.54	7817.38	5263.76	6960.6
	2013	16734.5	5.73	8097.38	5463.76	7180.6
	2014	16990.12	6.04	8302.38	5592.52	7300.13
	2015	17248.8	7.35	8360.8	5721.28	7617.4
	2016	18293.5	8.8	9543.1	6054.56	7797.2
	2017	18576.26	9.7	10436.3	6217.1	8112.8
	2018	18647.38	9.82	10690	6275.18	8288.8
	2019	19245.23	10.21	10955.8	6229.42	8468.2
	2020	18946.305	10.015	10822.9	6252.3	8378.5
	2021	19095.77	10.1125	10889.35	6240.8	8423.35
	2022	19021.038	10.0638	10856.125	6246.55	8400.925
	2023	19058.404	10088.15	10872.74	6243.675	8412.138

Source: Nigeria Beareu of Statistic (NBS)

Figure A1. Output of selected crops in Nigeria (2010–2023).

MONTHLY RAINFALL DATA IN NIGERIA (2010-2023)

UNIT: mm	YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
	2010	171.5	728.1	1045.6	3641.9	6112.8	8324.8	8407.6	10907.6	10812.4	7052.3	2400.2	192.5
	2011	0	1710.2	3189.2	7706.5	7039.6	7706.5	10104.5	10969.4	10898.4	7576.8	1254.5	143.7
	2012	471.8	1802.9	721.4	8019.3	3644.8	10179.8	12304.6	10224.7	9974.7	6829.3	1801.3	38.7
	2013	698.4	711.1	2404.1	5138.4	6529.5	8309.5	9508.2	8964.75	8768.6	5655.8	1647.1	1048
	2014	622.9	531.2	2632.4	4981.95	7620.6	7644.97	9487.07	11220.64	10412.3	7058.36	2148.51	235.5
	2015	205.7	16022.9	2516.4	1762.1	5220.5	7763.5	9069.3	11545.4	10328.8	5691.7	1578.5	156.7
	2016	67.1	113.3	3400.5	3377.6	8215.1	8882.8	10337.7	11695.3	10950.1	5366.8	781.1	219
	2017	288	181.4	1546.3	4744.2	7903.2	10214.9	10669.7	11700.9	9957.9	3898.9	1048.9	227.8
	2018	21.6	1941	1952.2	3176.6	6787.3	9069	12198.5	11465.3	12486.2	6515.1	1513.7	55.1
	2019	516.6	1462.2	1909.4	3161.5	7945.6	10755	11711.3	13058.5	12506.4	10731.4	2534.2	299.2
	2020	43.5	89.3	2434.1	3813	6281	9494.47	11861.6	7632	13009.14	6930.2	950.9	589.9
	2021	321.2	231	1775.6	3563.4	5834.8	9367.5	7986.3	14283.2	10181.1	5652.6	4568.9	210.8
	2022	182.35	160.15	2104.85	3688.2	6057.9	9430.96	9923.95	10957.6	11595.12	6291.4	2759.9	400.35
	2023	251.76	195.58	1940.23	3625.8	5946.35	9399.23	8955.13	12620.4	10888.11	5972	3664.4	305.58

Source:2022 Statistical bulletin (table C.5.1)

Figure A2. Monthly rainfall data in Nigeria (2010–2023).

AVERAGE ANNUAL RAINFALL DATA IN NIGERIA (2010-2023)

UNIT: mm	YEARS	TOTAL RAINFALL	AVERAGE
	2010	59797.3	4983.11
	2011	68299.3	5691.61
	2012	66013.3	5501.11
	2013	59383.45	4948.62
	2014	64596.4	5383.03
	2015	71861.5	5988.46
	2016	63406.4	5283.87
	2017	62382.1	5198.51
	2018	67181.6	5598.47
	2019	76591.3	6382.61
	2020	63129.11	5260.76
	2021	63976.4	5331.37
	2022	63552.73	5296.06
	2023	63764.57	5313.71

Source: 2022 Statistical bulletin

Figure A3. Average annual rainfall data in Nigeria (2010–2023).

UNITS: 0C	AVEARGE MINIMUM MONTHLY TEMPERATURE IN NIGERIA 2010-2023											
YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
2010	18.25	18.24	23.85	23.85	23.8	22.39	21.39	22.39	20.94	20.9	21.92	18.25
2011	18.25	18.2	23.85	21.85	25.82	22.39	24.39	22.39	20.94	20.93	20.92	19.25
2012	18.2	18.24	23.85	23.85	23.75	22.39	22.37	22.39	20.94	20.96	21.12	18.23
2013	19.25	20.24	23.85	20.85	24.7	22.39	23.39	22.39	20.94	20.93	20.92	20.25
2014	18.25	18.23	23.85	23.85	24.82	22.39	22.32	22.39	20.94	20.95	23.93	18.22
2015	17.25	20.24	23.85	24.85	23.8	22.39	23.49	22.39	20.94	20.93	20.92	18.25
2016	18.25	18.24	23.85	25.85	23.85	22.39	22.49	22.39	20.94	20.83	23.92	18.25
2017	19.25	20.24	23.85	20.85	24.7	22.39	23.39	22.39	20.94	20.93	20.92	20.25
2018	18.25	18.23	23.85	23.85	24.82	22.39	22.32	22.39	20.94	20.93	23.93	18.22
2019	17.25	20.24	23.85	24.85	23.8	22.39	23.49	22.39	20.94	20.93	20.92	18.25
2020	18.35	18.2	23.85	25.9	23.85	22.39	22.46	22.28	20.9	20.9	23.92	19.25
2021	18.3	18.24	23.85	23.85	23.8	22.39	22.39	22.39	20.84	20.93	20.92	18.25
2022	18.33	18.22	23.85	24.86	23.86	22.39	22.46	22.34	20.87	20.96	20.42	18.75
2023	18.32	18.23	23.85	24.36	23.83	22.39	22.43	22.37	20.86	20.95	20.67	18.5
Source: Climatic Research Unit (CRU)												

Figure A4. Average minimum monthly temperature in Nigeria (2010–2023).

UNITS: 0C	AVEARGE MAXIMUM MONTHLY TEMPERATURE IN NIGERIA 2010-2023											
YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
2010	33.4	33.7	36.13	36.14	36	30.95	30.9	30.94	32.61	32.62	32.69	33.4
2011	33	32.96	36.1	36.15	36.16	30.88	30.8	30.91	31.98	32.23	32.59	33.01
2012	33.4	33.7	36.13	36.14	36	30.95	30.9	30.94	32.61	32.62	32.69	33.4
2013	33.3	33.6	36.2	35.93	36.12	30.95	30.62	30.88	32.5	32.59	32.49	33.1
2014	33	32.96	36.1	36.15	36.16	30.88	30.8	30.91	31.98	32.23	32.59	33.01
2015	33.4	33.7	36.13	36.14	36	30.95	30.9	30.94	32.61	32.62	32.69	33.4
2016	33.4	33.7	36.13	36.14	36	30.95	30.9	30.94	32.61	32.62	32.69	33.4
2017	33.4	33.7	36.13	36.14	36	30.95	30.9	30.94	32.61	32.62	32.69	33.4
2018	33.4	33.7	36.13	36.14	36	30.95	30.9	30.94	32.61	32.62	32.69	33.4
2019	33.4	33.7	36.13	36.14	36	30.95	30.9	30.94	32.61	32.62	32.69	33.4
2020	33	32.96	36.1	36.15	36.16	30.88	30.8	30.91	31.98	32.23	32.59	33.01
2021	33.4	33.7	36.13	36.14	36	30.95	30.9	30.94	32.61	32.62	32.69	33.4
2022	33.2	33.33	36.12	36.15	36.08	30.92	30.85	30.93	32.3	32.43	32.64	33.21
2023	33.3	33.52	36.13	36.15	36.04	30.94	30.88	30.94	32.46	32.53	32.67	33.31
Source: Climatic Research Unit (CRU)												

Figure A5. Average maximum monthly temperature in Nigeria (2010–2023).

UNITS: 0	AVERAGE ANNUAL MINIMUM, MAXIMUM AND MEAN TEMPERATURE IN NIGERIA 2010-202		
YEARS	MINIMUM TEMPE	MAXIMUM TEMF	MEAN TEMPERATURE
2010	21.35	33.29	27.32
2011	21.59	33.06	27.32
2012	21.36	33.29	27.32
2013	21.68	33.19	27.43
2014	21.68	33.06	27.37
2015	21.6	33.29	27.44
2016	21.77	33.29	27.53
2017	21.68	33.29	27.48
2018	21.68	33.29	27.48
2019	21.68	33.29	27.48
2020	21.86	33.06	27.46
2021	21.35	33.29	27.32
2022	21.44	33.18	27.31
2023	21.39	33.23	27.31
Source: Climatic Research Unit (CRU)			

Figure A6. Average annual minimum, maximum, and mean temperature in Nigeria (2010–2023).

Variable	Obs	Mean	Std. Dev.	Min	Max
logMAIZE	14	9.77584	.09542	9.563867	9.865019
logPINEAPPLE	14	2.547762	1.941238	1.568616	9.219117
logBEANS	14	8.946167	.1049023	8.72356	9.044073
logVEGETAB~S	14	9.143687	.1596742	8.892509	9.301624
logGNUT	14	8.665312	.0957567	8.461368	8.744357
RFALL	14	5440.093	382.121	4948.62	6382.61
TEMP	14	27.39786	.0807826	27.31	27.53

Figure A7. Descriptive statistics.

Source	SS	df	MS
Model	.048715293	5	.009743059
Residual	.036120421	8	.004515053
Total	.084835714	13	.006525824

Number of obs	=	14
F(5, 8)	=	2.16
Prob > F	=	0.1594
R-squared	=	0.5742
Adj R-squared	=	0.3081
Root MSE	=	.06719

TEMP	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
logMAIZE	-.4897117	2.306301	-0.21	0.837	-5.808052	4.828628
logPINEAPPLE	-.0131453	.0107276	-1.23	0.255	-.0378832	.0115926
logBEANS	-2.004814	1.956808	-1.02	0.336	-6.51722	2.507593
logGNUT	3.52723	1.834709	1.92	0.091	-.7036171	7.758077
logVEGETABLES	-.2548272	.4494103	-0.57	0.586	-1.291169	.7815149
_cons	21.9196	3.783288	5.79	0.000	13.19533	30.64388

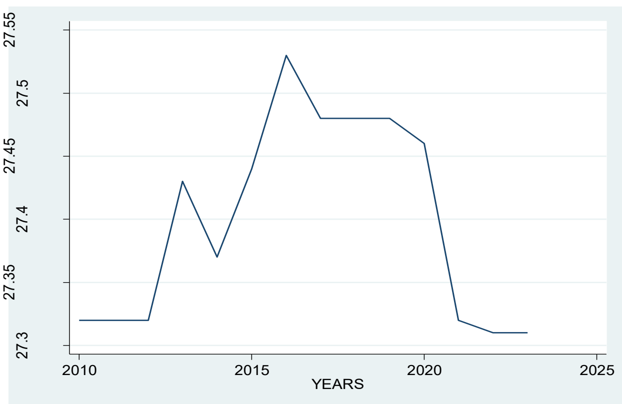
```
. regress RFALL logMAIZE logPINEAPPLE logBEANS logGNUT logVEGETABLES
```

Source	SS	df	MS
Model	653472.89	5	130694.578
Residual	1244741.43	8	155592.679
Total	1898214.32	13	146016.487

Number of obs	=	14
F(5, 8)	=	0.84
Prob > F	=	0.5570
R-squared	=	0.3443
Adj R-squared	=	-0.0656
Root MSE	=	394.45

RFALL	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
logMAIZE	-3815.404	13538.77	-0.28	0.785	-35035.86	27405.05
logPINEAPPLE	-44.40407	62.97461	-0.71	0.501	-189.6238	100.8156
logBEANS	18369.3	11487.12	1.60	0.148	-8120.056	44858.66
logGNUT	-11378.12	10770.37	-1.06	0.322	-36214.62	13458.39
logVEGETABLES	-2342.319	2638.191	-0.89	0.401	-8425.998	3741.36
_cons	-1470.459	22209.18	-0.07	0.949	-52684.92	49744.01

Figure A8. Regression analysis.



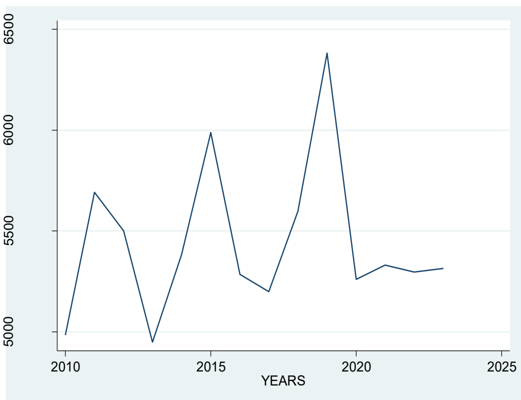


Figure A9. Trend of temperature and rainfall in Nigeria.