

INTEGRATED ASSESSMENT OF CLIMATE VARIABILITY, SOIL QUALITY, AGRICULTURAL PRODUCTIVITY AND ADAPTIVE CAPACITY FOR FOOD CRISIS MANAGEMENT IN BENUE STATE, NIGERIA

Authors: Adekunle Joseph Ajayi¹ and Christopher Onosemuode¹

¹Department of Environmental Management and Toxicology, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria

Corresponding Author: Adekunle Joseph Ajayi

Email: Adekunle.Ajayi@shorelinenaturalresources.com

Author's contributions

This study was a collaborative effort of the authors. The author reviewed and approved the final version of the manuscript for publication.

Article Information

DOI: <https://doi.org/10.60787/fpj.vol3no9.140>

EISSN 1596-0501E



This work is licensed under a Creative Commons Attribution-Non Commercial-ShareAlike 4.0 International License

CITATION: Adekunle Joseph Ajayi and Christopher Onosemuode (2026). Integrated assessment of climate variability, soil quality, agricultural productivity and adaptive capacity for food crisis management in Benue State, Nigeria. *Frontline Professionals Journal* 3(9), 242-256

ABSTRACT

Food security in Benue State, Nigeria, has become a problem due to climate variability, rapid land degradation, and declining agricultural productivity. The study evaluated climatic trends and deterioration, soil quality, productivity, and farmers' adaptive capacity in each of the six Local Government Areas (Katsina-Ala, Ukum, Makurdi, Guma, Otukpo and Apa). Descriptive statistics, Mann-Kendall trend analysis, Sen's slope estimation, ANOVA, multiple regression, and hierarchical cluster analysis were employed to examine climatic data for the period 2005–2024, soil properties, crop yields, and farm environmental and socio-economic information from 600 respondents. Temperature and rainfall increased by 0.041°C/year and 0.052°C/year, respectively, and rainfall decreased by 4.12mm/year, a significant decline. The number of rainy days decreased by 0.63 days/year, and the frequency of flood and drought events increased by 0.21 and 0.16 events/year, respectively. The properties of soil showed great differences among the LGAs; the highest bulk density was 1.49 g/cm³ in Makurdi Local Government Area, while the lowest moisture content was 13.7% in Makurdi LGA, with Otukpo LGA having comparatively good soil. Crop yields also varied widely; Otukpo produced the highest yields in most crops. Between 2005–2009 and 2020–2024, yam, cassava, maize, soybean, and sorghum yields declined by 20.4%, 19.5%, 30.3%, 29.4%, and 28.4%, respectively, while rice yields increased by 23.1%. Multiple regression analysis showed that soil organic matter had the greatest positive influence on yield, and exposure to flooding and temperature had the greatest negative influences.

Keywords: Climate change; Soil quality; Agricultural productivity; Food security; Climate variability; Soil fertility; Farmers' adaptation; Benue State.

INTRODUCTION

Nigeria's climate-driven economic activities, especially the agricultural sector, on which the food security and livelihoods of the country's rural populace depend, are facing a new, compounding challenge posed by climate

change and environmental degradation. High temperatures coupled with the uncertainty of precipitation, flood, drought, soil erosion, amongst other environmental factors, affect the productivity of crops and the non-dependability of the farming system, making the household vulnerable to food insecurity (Ani et al., 2022; Aroyehun, 2023; Fagbemi et al., 2025; Ihugba, 2025). Besides this, it is observed in Nigeria that the impacts of climate change, combined with the effects of environmental degradation, synergise with socioeconomic pressures, worsening food security (Alehile et al., 2025; Escalante et al., 2025; Gabriel et al., 2025). The impact is compounded by the agriculture and broader economic effects of climate change-related disasters. In a purely farming population, such issues are particularly relevant – land fertility, rainfall patterns, and environmental stability directly contribute to farm productivity. However, when rainfall is exacerbated by soil erosion, it results in the deterioration of these soils that can have implications on reduced productive capacity of agricultural lands and reduced capacity of farmers to handle climate shocks, as reported in Folorunso & Folorunso, 2022; Iwuchukwu et al, 2023 and Gambo et al, 2025. Moreover, the cumbersome logistical challenges of insecurity, farmer–herder conflict, and access to farmland also impede the entire process of farming and agricultural development in Benue State, where farming is carried out daily (Ioryue, 2024; Ioryue et al., 2024; GBEREVBIE & AFORIJIKU, 2025). The growing urbanisation, with its attendant pressure, is also on the agricultural blocks, especially in a growing centre like Makurdi (Ode, 2024). Climate change impact on the household level environment can lead to decreased income, lack of or reduced food availability and diversity in food consumption, but if some adaptation strategies are implemented at the household level, such as climate-smart agriculture can contribute to resilience and food security outcomes (Zakari et al., 2022; Omotoso & Omotayo, 2025). Other livelihood practices, such as migration in response to climate shocks, can also contribute to the socioeconomic dimensions of food insecurity (Odebunmi & Adesida, 2025). Furthermore, food losses and food waste are major cross-cutting concerns, as not all the food produced in a more complex climate will contribute to higher food availability and food security (Haruna et al., 2023). In addition, recent studies applying machine learning methods have proven the utility of climatic data and environmental information for analysing food insecurity in Nigeria (Alehile et al., 2025), and new studies conducted among rural farming communities found linking the ever-felt climatic phenomena and food crop production (Ezeh et al., 2026), respectively. However, within these new insights, there is a need for a multi-dimensional approach and awareness of the different vulnerabilities to food crises at the subnational level, including perspectives on the changing climate, soil factors, production, and climate and environmental adaptation, as well as recognising farmers' adaptive capacities. Based on the above, the overall objective of this study is to assess the climate variability and soil quality and agricultural productivity of selected LGAs of Benue State with emphasis on climatic variability, soil fertility, environmental degradation/adaptation and how these influence the agricultural productivity, with an aim of providing evidence to solve the food crisis by improving food system management.

METHODOLOGY

Study Design, Study Area and Research Framework

To achieve this, the study used an analytical research protocol that integrated retrospective assessments of climatic and agricultural trends, followed by field assessments of soil quality, farm environmental characteristics, agricultural productivity, and farmers' socioeconomic characteristics. The timeframe of the retrospective was from 2005 to 2024, and the field work was conducted in six (6) Local Government Areas (LGAs), namely, Katsina-Ala, Ukum, Makurdi, Guma, Otukpo, and Apa, all in Benue State. The chosen LGAs spanned the state's variations in climate, soil, and agricultural settings. The climatic assessment included annual rainfall, minimum and maximum temperatures, relative humidity, rainy days, and flood and drought incidents. Annual rainfall mean was 1,326.0 mm, minimum temperature mean was 23.2°C, maximum temperature mean was 33.0°C, relative humidity was 69.6 %, and 103.8 rainy days were observed throughout the study period. In addition, flood and drought frequencies were observed. The study design involved reviewing the relationships among climatic variability, soil properties, the environment, and agricultural performance; other explanatory variables included socioeconomic conditions and farmers' adaptive capacities.

Climate and Secondary Data Collection

Climatic data of the last 20 years (2005–2024) were collated for the six LGAs and featured data on annual rainfall (mm), maximum minimum temperature (°C), maximum maximum temperature (°C), relative humidity (%), rainy day occurrences, flood events and drought episodes. Spatial climatic variability was characterised using descriptive statistics such as mean, standard deviation, and coefficient of variation (CV), calculated as $CV = \text{std}/\text{mean} * 100$. Temporal variation was evaluated across four five-year periods (2005–2009, 2010–2014, 2015–2019, and 2020–2024), and rainfall and temperature anomalies were calculated relative to the mean over the study period. The Mann–Kendall trend test was performed to identify climatic trends, and the magnitude and direction of temporal change were quantified using Sen's slope estimator. Observed trends were tested for statistical significance using Kendall's tau, Z-values, and p-values.

Soil Sampling and Laboratory Assessment

Within the 6 selected LGAs, soil assessments were carried out at agricultural sites, including physical, chemical, and fertility characteristics. The physical properties measured were sand (%), silt (%), clay (%), bulk density (g/cm^3), porosity (%) and moisture content (%). The chemical and fertility properties were soil pH in H_2O , electrical conductivity ($\mu\text{S}/\text{cm}$), and organic carbon (%). Organic matter (%), total nitrogen (%), C: N ratio, available phosphorus (mg/kg), exchangeable calcium, magnesium, potassium and sodium (cmol/kg), cation exchange capacity (CEC; cmol/kg) and base saturation (%). Where necessary, the conversion/calculation formulas for organic matter and the C:N ratio, and the base saturation formula, were used to obtain the corresponding soil indicators from the measured values. Means and standard deviations were calculated and used to summarise the soil results, which were compared between the six LGAs. The provided study document lists measured parameters and results, but does not specify the laboratory measurement standards used (such as ISO, ASTM, AOAC, or others); thus, no specific standard is assumed.

Soil Fertility Classification

The fertility status of the soil has been assessed through soil pH, organic carbon, total N, available P, exchangeable K, CEC and soil organic matter as the major fertility parameters. The values of each parameter were categorised as low, moderate or high. Soil pH below 5.5 was classified as low, 5.5–6.5 as moderate and above 6.5 as high; organic carbon below 1.0%, 1.0–2.0% and above 2.0%; total nitrogen below 0.10%, 0.10–0.20% and above 0.20%; available phosphorus below 8, 8–15 and above 15 mg/kg ; exchangeable potassium below 0.15, 0.15–0.30 and above 0.30 cmol/kg ; CEC below 6, 6–12 and above 12 cmol/kg ; and organic matter below 2.0%, 2.0–3.5% and above 3.5%, respectively. The proportion of sampling locations in each fertility category was determined using the percentage-frequency formula, allowing comparison of soil fertility conditions across the different locations under study.

Farm Environmental Assessment

Field observations for topography, soil drainage, visual soil erosion, surface runoff, soil cracking, waterlogging and evidence of flooding enabled an assessment of the farm-level environmental conditions. Topography was divided into flat, gently sloping, undulating/steep, and drainage into well-drained, moderately drained, and poorly drained. Erosion and surface runoff were assigned in class based on the observations, while soil cracks, waterlogging, and evidence of flooding were recorded as per the observations. These variables were used to provide background information for interpreting the effects of climatic variability and environmental degradation on agricultural productivity. It was noted during the field assessment that there are differences among the farms in drainage and erosion conditions: 63 well-drained, 39 moderately drained, and 18 poorly drained. To summarise the distribution of environmental conditions, frequencies and percentages were calculated using the appropriate formulas.

Agricultural Productivity Assessment

The yields of yams, cassava, maize, rice, soybeans, and sorghum were used to determine agricultural productivity, with crop production reported in tonnes per hectare (t/ha). Crop yields were obtained as mean values for each crop and compared across Katsina-Ala, Ukum, Makurdi, Guma, Otukpo, and Apa. For the temporal productivity changes, the four 5-year periods of 2005 to 2009, 2010 to 2014, 2015 to 2019 and 2020 to 2024 were considered,

and the percentage change in yield for each pair of time periods was calculated using the percentage-change formula. One-way ANOVA was performed to test whether crop yields differed significantly among the six LGAs, using the F-value and p-value to assess statistical significance.

Socioeconomic and Adaptation Assessment

Primary socioeconomic data were obtained from 600 respondents engaged in agricultural activities in the study area. The variables measured were sex, age, level of education, household size, farming experience, farm size, and primary livelihood activity. Experience in farming was judged as less than 10 years, 10–20 years and more than 20 years, and the size of farm was categorised as less than 1 hectare, 1 to 3 hectares and more than 3 hectares and livelihood included crop production, livestock production, agricultural trading, wage employment and others. To describe the socioeconomic characteristics of the respondents, frequencies and percentages were calculated using the formulas for frequency (f) and percentage. To reflect farmers' adaptive capacity, an adaptation index was developed to serve as an explanatory variable in the regression analyses, alongside climatic, soil, and flood-related factors.

Statistical Analysis

Descriptive and inferential statistical methods were used to analyse the data. Data were summarised using descriptive statistical methods, including frequencies and percentages, mean, standard deviation, and coefficient of variation; the relevant formulas were applied appropriately. Data were analysed using analysis of variance (ANOVA) to determine differences among the six LGAs in soil physical and chemical properties and crop yield, with significance at $P < 0.05$. The soil analysis included sand, silt, clay, bulk density, porosity, moisture content, pH, EC, organic carbon, organic matter, total nitrogen, C:N ratio, available phosphorus, exchangeable Ca, Mg, K, and Na, CEC, and base saturation. If significant differences were present, the groups shown in the results are used to differentiate locations that differ statistically.

Multiple Regression Analysis

In a multiple linear regression approach, the authors aimed to identify the combined effects of climatic, soil, flood-exposure, and adaptation variables on agricultural productivity. The dependent variable was the grain yield, and the predictor variables were annual rainfall, mean temperature, soil organic matter, soil moisture, available phosphorus, flood exposure index, and flood adaptation index. The multiple linear regression formula was used to model the relationship between crop yield and the predictor variables. For the regression results, the unstandardized coefficients, standard errors, standardised beta coefficients, t-values, and p-values were used to evaluate the results and assess multicollinearity among the explanatory variables in the study, which was calculated using the VIF formula. A model that included the seven predictors and their corresponding statistical diagnostics was created.

Hierarchical Cluster Analysis

The results of hierarchical cluster analysis of the six LGAs, based on a combination of climatic, soil, environmental, and agricultural features, revealed similarities among the LGAs. This analysis resulted in three main associations: (1) Otukpo–Katsina-Ala, (2) Ukum–Apa and (3) Makurdi–Guma, which showed clusters of areas of similar environmental and agricultural characteristics. The analysis was conducted using similarity/distance measures between the LGA-level observations and the clusters, as defined by the analysis, which were assumed to be "groups" of areas that were both environmentally and agriculturally integrated and not unique climate or soil groups.

Data Quality Assurance and Ethical Considerations

Data quality assurance packages included reviews to ensure that climatic, soil, agricultural, environmental, and socio-economic data were complete, consistent, correctly coded, and contained the appropriate metric for statistical analysis. Field and laboratory observations were structured by their respective observation parameters, and survey responses were coded into one of several predetermined socioeconomic categories. The statistical

results were verified for consistency before inference, and the significance level was used to evaluate all inferential analyses. The socioeconomic component was participatory, and the use of the questionnaires was explained to the participants; no one was forced to participate, and information provided in the questionnaires was treated confidentially and used solely for research purposes. Notion of specific ethical approval numbers, laboratory quality control procedures, duplicates, blank, certified reference materials and instrument calibration record (if available in original laboratory study records) is not included in the supplied source.

RESULTS

Table 1: Annual Climatic Characteristics of Selected LGAs in Benue State

LGA	Mean annual rainfall (mm)	Mean minimum temperature (°C)	Mean maximum temperature (°C)	Mean relative humidity (%)	Mean rainy days	Flood events, 2005–2024	Drought episodes, 2005–2024
Katsina-Ala	1,421.6	22.4	32.1	72.8	112	6	4
Ukum	1,386.3	22.7	32.5	71.4	108	5	5
Makurdi	1,247.8	23.8	33.8	67.2	98	11	6
Guma	1,291.5	23.4	33.4	68.1	101	13	5
Otukpo	1,334.7	23.1	32.9	69.6	104	7	5
Apa	1,273.9	23.5	33.3	68.4	100	9	6
Overall mean	1,326.0	23.2	33.0	69.6	103.8	8.5	5.2
Standard deviation	65.5	0.5	0.6	2.1	5.3	3.1	0.8
Coefficient of variation (%)	4.9	2.3	1.9	3.0	5.1	36.6	15.5

Table 2: Five-Year Climatic Trend in Benue State, 2005–2024

Period	Mean rainfall (mm)	Rainfall anomaly (%)	Mean temperature (°C)	Temperature anomaly (°C)	Flood frequency	Drought frequency
2005–2009	1,359.4	+2.5	27.3	–0.5	7	4
2010–2014	1,341.8	+1.2	27.7	–0.1	9	5
2015–2019	1,317.2	–0.6	28.1	+0.3	14	8
2020–2024	1,285.6	–3.0	28.6	+0.8	21	14
Overall	1,326.0	0.0	27.9	0.0	51	31

Table 3: Mann–Kendall Trend and Sen’s Slope Results for Climatic Variables

Variable	Kendall’s tau	Z-value	p-value	Sen’s slope
Annual rainfall	–0.368	–2.27	0.023	–4.12 mm/year
Minimum temperature	0.611	3.74	<0.001	+0.041°C/year
Maximum temperature	0.674	4.13	<0.001	+0.052°C/year
Relative humidity	–0.295	–1.89	0.059	–0.18%/year
Number of rainy days	–0.442	–2.76	0.006	–0.63 day/year
Flood frequency	0.516	3.19	0.001	+0.21 event/year
Drought frequency	0.484	2.98	0.003	+0.16 episode/year

Table 4: Soil Physical Properties by LGA

LGA	Sand (%)	Silt (%)	Clay (%)	Bulk density (g/cm ³)	Porosity (%)	Moisture content (%)
Katsina-Ala	59.8 ± 5.6	18.7 ± 2.8	21.5 ± 3.4	1.34 ± 0.08 ^c	49.4 ± 3.1 ^a	18.9 ± 2.7 ^a
Ukum	62.4 ± 6.1	17.9 ± 2.5	19.7 ± 3.2	1.37 ± 0.09 ^{bc}	48.3 ± 3.4 ^{ab}	17.8 ± 2.5 ^{ab}
Makurdi	68.6 ± 5.9	15.4 ± 2.3	16.0 ± 2.9	1.49 ± 0.11 ^a	43.8 ± 4.1 ^c	13.7 ± 2.2 ^c
Guma	64.7 ± 6.3	16.8 ± 2.7	18.5 ± 3.1	1.44 ± 0.10 ^{ab}	45.7 ± 3.8 ^{bc}	15.2 ± 2.4 ^{bc}
Otukpo	57.9 ± 5.2	19.5 ± 2.9	22.6 ± 3.5	1.32 ± 0.08 ^c	50.2 ± 3.0 ^a	19.6 ± 2.8 ^a
Apa	61.5 ± 5.7	18.2 ± 2.6	20.3 ± 3.3	1.40 ± 0.09 ^b	47.2 ± 3.5 ^{ab}	16.7 ± 2.5 ^b
Mean	62.5 ± 6.4	17.8 ± 2.9	19.8 ± 3.8	1.39 ± 0.11	47.4 ± 4.1	17.0 ± 3.2
F-value	8.64	5.37	7.15	10.83	9.41	12.26
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 5: Soil Acidity, Salinity and Organic Matter Characteristics

LGA	pH in H ₂ O	EC (μS/cm)	Organic carbon (%)	Organic matter (%)	Total nitrogen (%)	C:N ratio
Katsina-Ala	5.82 ± 0.39 ^b	126.4 ± 25.7 ^b	1.54 ± 0.31 ^{ab}	2.66 ± 0.54 ^{ab}	0.142 ± 0.031 ^a	10.85
Ukum	5.64 ± 0.42 ^{bc}	118.7 ± 23.8 ^b	1.42 ± 0.29 ^b	2.45 ± 0.50 ^b	0.129 ± 0.028 ^{ab}	11.01
Makurdi	5.21 ± 0.36 ^d	159.2 ± 31.4 ^a	0.91 ± 0.24 ^d	1.57 ± 0.42 ^d	0.081 ± 0.021 ^d	11.23
Guma	5.37 ± 0.40 ^{cd}	147.5 ± 29.8 ^a	1.08 ± 0.26 ^{cd}	1.86 ± 0.45 ^{cd}	0.096 ± 0.024 ^{cd}	11.25
Otukpo	6.02 ± 0.37 ^a	112.8 ± 21.6 ^b	1.69 ± 0.34 ^a	2.91 ± 0.59 ^a	0.151 ± 0.033 ^a	11.19
Apa	5.71 ± 0.41 ^b	121.6 ± 24.9 ^b	1.31 ± 0.28 ^{bc}	2.26 ± 0.48 ^{bc}	0.116 ± 0.026 ^{bc}	11.29
Overall mean	5.63 ± 0.49	131.0 ± 31.6	1.33 ± 0.40	2.29 ± 0.69	0.119 ± 0.038	11.14
F-value	11.72	8.46	18.15	18.12	16.84	—
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	—

Table 6: Available Phosphorus, Exchangeable Bases and Cation Exchange Capacity

LGA	Available P (mg/kg)	Ca (cmol/kg)	Mg (cmol/kg)	K (cmol/kg)	Na (cmol/kg)	CEC (cmol/kg)	Base saturation (%)
Katsina-Ala	11.84 ± 3.15 ^{ab}	4.92 ± 1.04 ^{ab}	1.87 ± 0.42 ^{ab}	0.24 ± 0.06 ^a	0.13 ± 0.04	9.84 ± 1.65 ^{ab}	72.8 ± 8.4 ^a
Ukum	10.27 ± 2.86 ^{bc}	4.36 ± 0.96 ^b	1.65 ± 0.39 ^b	0.21 ± 0.05 ^{ab}	0.12 ± 0.03	9.11 ± 1.52 ^b	69.6 ± 8.1 ^{ab}
Makurdi	6.48 ± 2.17 ^d	2.89 ± 0.72 ^d	1.08 ± 0.31 ^d	0.13 ± 0.04 ^d	0.15 ± 0.04	6.82 ± 1.28 ^d	62.4 ± 7.7 ^c
Guma	7.72 ± 2.38 ^{cd}	3.34 ± 0.81 ^{cd}	1.24 ± 0.34 ^{cd}	0.16 ± 0.04 ^{cd}	0.14 ± 0.04	7.43 ± 1.36 ^{cd}	65.7 ± 7.9 ^{bc}
Otukpo	13.16 ± 3.42 ^a	5.38 ± 1.12 ^a	2.04 ± 0.46 ^a	0.26 ± 0.07 ^a	0.12 ± 0.03	10.37 ± 1.74 ^a	75.1 ± 8.6 ^a
Apa	9.36 ± 2.64 ^c	4.01 ± 0.89 ^{bc}	1.51 ± 0.37 ^{bc}	0.19 ± 0.05 ^{bc}	0.13 ± 0.03	8.57 ± 1.47 ^{bc}	68.1 ± 8.0 ^b
Overall mean	9.81 ± 3.67	4.15 ± 1.24	1.57 ± 0.53	0.20 ± 0.07	0.13 ± 0.04	8.69 ± 1.91	68.9 ± 9.0

F-value	15.62	14.75	13.46	12.84	1.38	13.91	6.74
p-value	<0.001	<0.001	<0.001	<0.001	0.237	<0.001	<0.001

Table 7: Soil Fertility Classification by Sampling Location

Fertility indicator	Low category criterion	Moderate category criterion	High category criterion	Low, n (%)	Moderate, n (%)	High, n (%)
Soil Ph	<5.5	5.5–6.5	>6.5	46 (38.3)	69 (57.5)	5 (4.2)
Organic carbon	<1.0%	1.0–2.0%	>2.0%	35 (29.2)	76 (63.3)	9 (7.5)
Total nitrogen	<0.10%	0.10–0.20%	>0.20%	42 (35.0)	74 (61.7)	4 (3.3)
Available phosphorus	<8 mg/kg	8–15 mg/kg	>15 mg/kg	39 (32.5)	68 (56.7)	13 (10.8)
Exchangeable potassium	<0.15 cmol/kg	0.15–0.30 cmol/kg	>0.30 cmol/kg	33 (27.5)	79 (65.8)	8 (6.7)
CEC	<6 cmol/kg	6–12 cmol/kg	>12 cmol/kg	12 (10.0)	99 (82.5)	9 (7.5)
Organic matter	<2.0%	2.0–3.5%	>3.5%	44 (36.7)	68 (56.7)	8 (6.7)

Table 8: Average Crop Yield by LGA

LGA	Yam (t/ha)	Cassava (t/ha)	Maize (t/ha)	Rice (t/ha)	Soybean (t/ha)	Sorghum (t/ha)
Katsina-Ala	13.8 ± 2.4 ^a	17.6 ± 3.1 ^a	2.31 ± 0.46 ^a	2.74 ± 0.52 ^b	1.42 ± 0.29 ^a	1.68 ± 0.33 ^a
Ukum	13.1 ± 2.2 ^{ab}	16.9 ± 2.9 ^{ab}	2.18 ± 0.42 ^{ab}	2.61 ± 0.49 ^b	1.35 ± 0.27 ^{ab}	1.61 ± 0.31 ^{ab}
Makurdi	9.6 ± 1.8 ^d	12.7 ± 2.5 ^d	1.61 ± 0.35 ^d	2.21 ± 0.45 ^c	0.98 ± 0.22 ^d	1.22 ± 0.27 ^d
Guma	10.4 ± 1.9 ^{cd}	13.8 ± 2.6 ^{cd}	1.74 ± 0.37 ^{cd}	3.18 ± 0.57 ^a	1.07 ± 0.23 ^{cd}	1.31 ± 0.28 ^{cd}
Otukpo	14.2 ± 2.5 ^a	18.4 ± 3.3 ^a	2.42 ± 0.48 ^a	2.69 ± 0.51 ^b	1.48 ± 0.30 ^a	1.72 ± 0.34 ^a
Apa	11.7 ± 2.1 ^{bc}	15.2 ± 2.8 ^{bc}	1.96 ± 0.40 ^{bc}	3.04 ± 0.55 ^a	1.21 ± 0.25 ^{bc}	1.47 ± 0.30 ^{bc}
Overall mean	12.1 ± 2.7	15.8 ± 3.5	2.04 ± 0.50	2.75 ± 0.59	1.25 ± 0.32	1.50 ± 0.36
F-value	14.83	13.92	15.17	8.64	14.28	12.76
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 9: Percentage Change in Major Crop Yield, 2005–2024

Crop	Mean yield, 2005–2009 (t/ha)	Mean yield, 2010–2014 (t/ha)	Mean yield, 2015–2019 (t/ha)	Mean yield, 2020–2024 (t/ha)	Overall change (%)	Trend
Yam	13.7	13.1	12.2	10.9	-20.4	Declining
Cassava	17.4	16.9	15.8	14.0	-19.5	
Maize	2.34	2.19	2.01	1.63	-30.3	
Rice	2.51	2.63	2.77	3.09	+23.1	
Soybean	1.43	1.35	1.21	1.01	-29.4	
Sorghum	1.69	1.61	1.48	1.21	-28.4	

Table 10: Socioeconomic Characteristics of Respondents

Characteristic	Category	Frequency	Percentage (%)
Sex	Male	347	57.8
	Female	253	42.2
Age	18–30 years	96	16.0
	31–40 years	178	29.7
	41–50 years	181	30.2
	51–60 years	103	17.2
	Above 60 years	42	7.0
Education	No formal education	81	13.5
	Primary education	157	26.2
	Secondary education	231	38.5
	Tertiary education	131	21.8
Household size	1–4 persons	142	23.7
	5–8 persons	309	51.5
	Above 8 persons	149	24.8
Farming experience	Below 10 years	132	22.0
	10–20 years	247	41.2
	Above 20 years	221	36.8
Farm size	Below 1 hectare	136	22.7
	1–3 hectares	324	54.0
	Above 3 hectares	140	23.3
Main livelihood	Crop farming	384	64.0
	Livestock farming	61	10.2
	Agricultural trading	83	13.8
	Wage employment	42	7.0
	Other activities	30	5.0

Table 11: Multiple Regression Predicting Crop Yield

Predictor	Unstandardised coefficient, β	Standard error	Standardised β	t-value	p-value	VIF
Constant	4.286	1.173	—	3.654	<0.001	—
Annual rainfall	0.0031	0.0008	0.224	3.875	<0.001	1.64
Mean temperature	-0.118	0.039	-0.186	-3.026	0.003	1.71

Soil organic matter	0.746	0.124	0.371	6.016	<0.001	1.83
Soil moisture	0.091	0.026	0.216	3.500	0.001	1.92
Available phosphorus	0.064	0.018	0.203	3.556	<0.001	1.48
Flood exposure index	-0.284	0.077	-0.211	-3.688	<0.001	1.39
Adaptation index	0.193	0.058	0.178	3.328	0.001	1.31

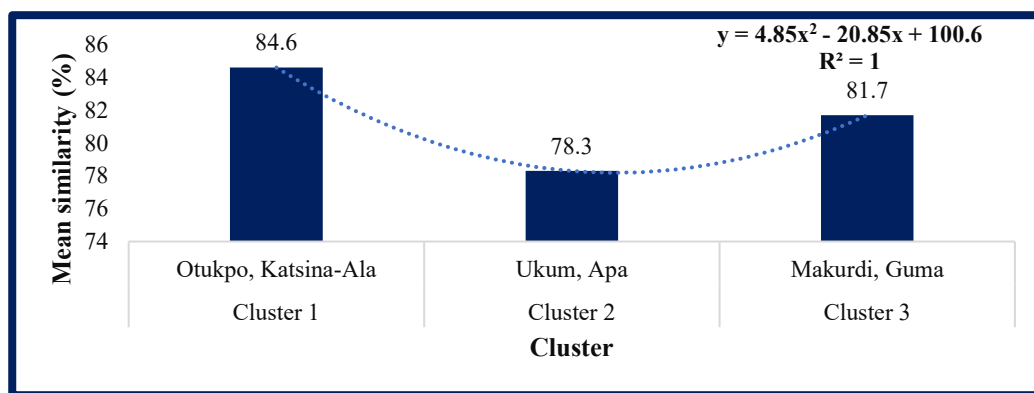


Figure 1: Consolidated Hierarchical Cluster Analysis and LGA Risk Grouping

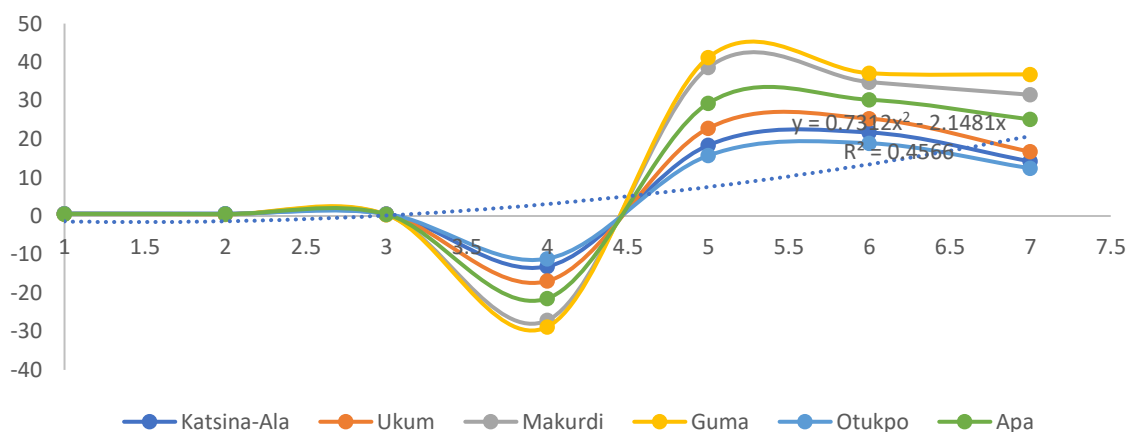


Figure 2: NDVI, Vegetation Condition and Land-Degradation Indicators by LGA

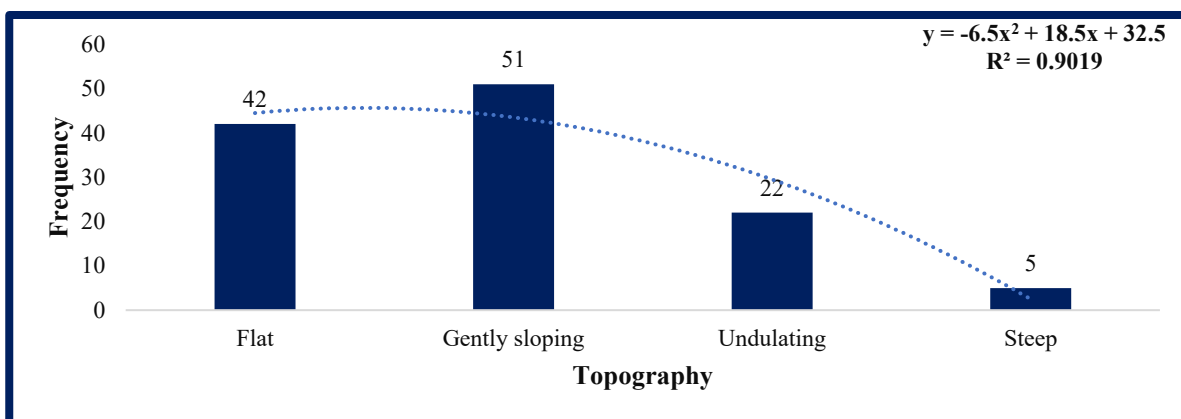


Figure 3: Topographic Characteristics of the Observed Farms

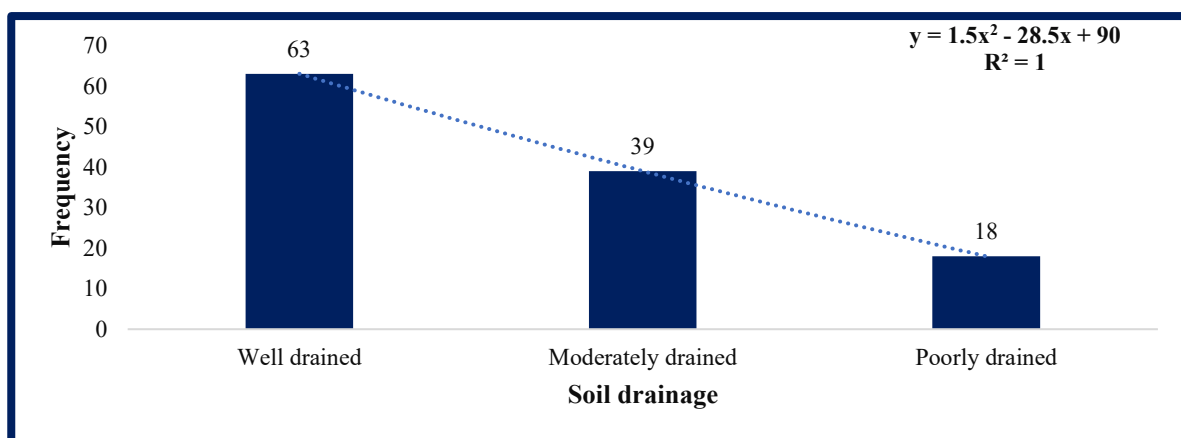


Figure 4: Soil Drainage Characteristics of the Observed Farms

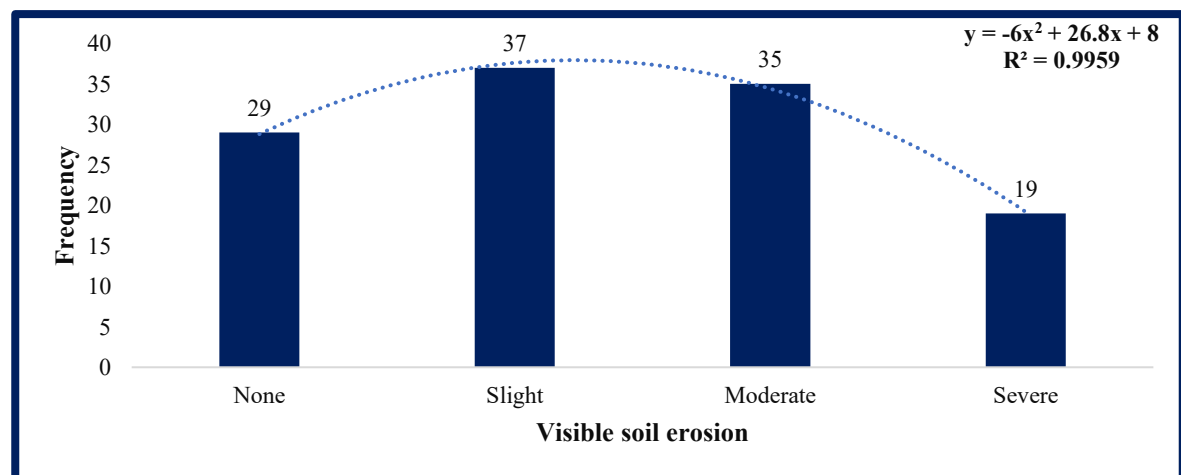


Figure 5: Visible soil erosion Characteristics of the Observed Farms

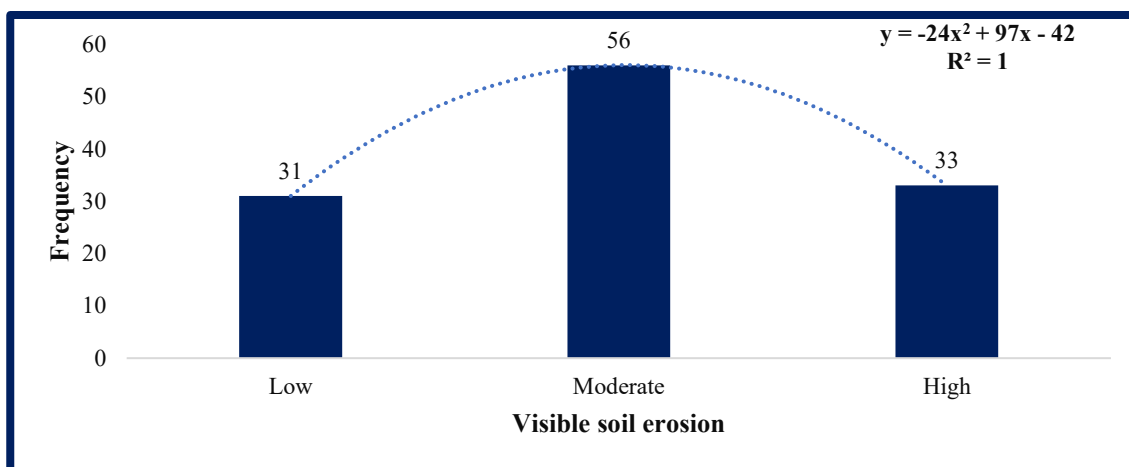


Figure 6: Surface Runoff Characteristics of the Observed Farms

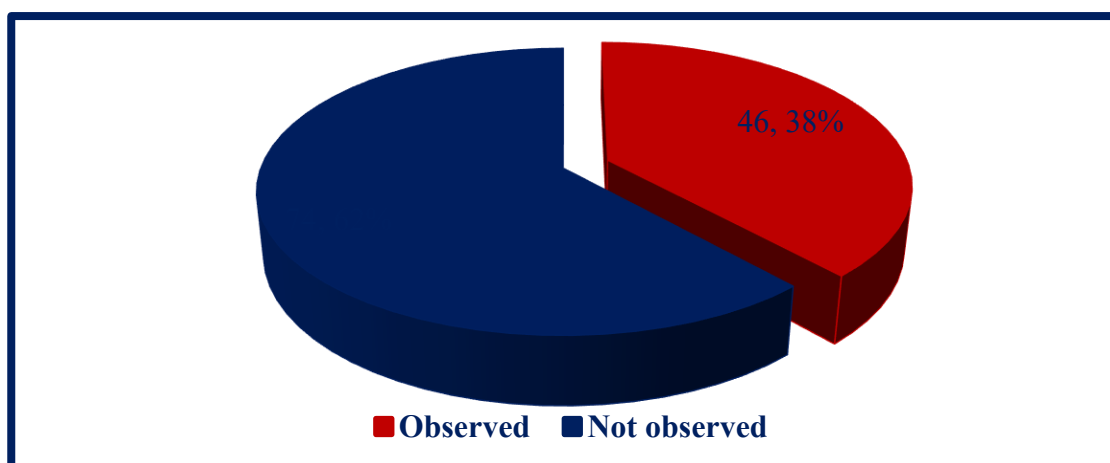


Figure 7: Soil cracking characteristics of the Observed Farms

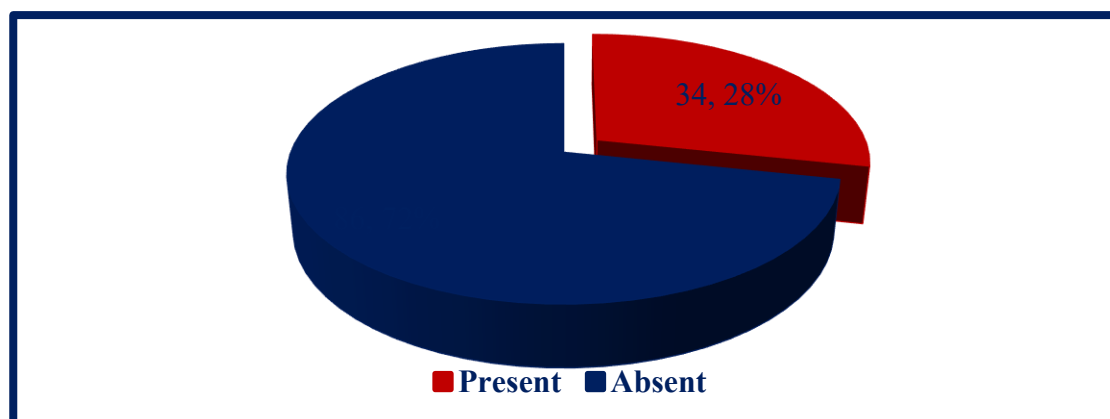


Figure 8: Waterlogging Characteristics of the Observed Farms

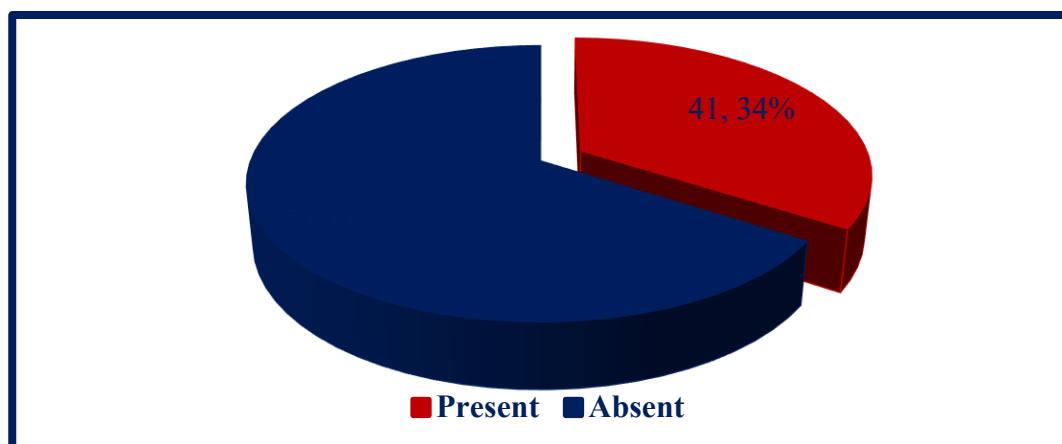


Figure 12: Flood evidence of the Observed Farms

DISCUSSION

The different adaptation evaluation results presented as a triangle indicate that there is a clear relationship among the selected LGAs, soil conditions, and agricultural productivity, and that this relationship remains consistent across all analyses as the level of Climate variability increases. In terms of spatial differences in climatic parameters, remarkable differences are observed in Table 1, with Katsina-Ala having the highest mean annual rainfall of 1,421.6 mm and the highest number of rainy days (112), compared to Makurdi, which recorded the lowest mean annual rainfall of 1,247.8 mm. In contrast, both recorded six drought episodes in between, but Guma recorded the highest number of flood events (13). What is most important, however, is that there is a step-wise change in climate as can be observed from Table 2, where the reduction in rainfall decreases from 1359.4 to 1285.6 mm, while the mean temperature increases from 27.3 to 28.6°C, the number of flood times increases from 7 to 21 events and the drought times increase from 4 to 14 episodes. These trends are statistically proven in Table 3, where annual rainfall, minimum and maximum temperatures show significant decreases (+0.041 mm/year, $p < 0.001$; +0.052 mm/year, $p < 0.001$, respectively), and the number of rainy days shows a significant decrease. In contrast, the number of flood days and drought days showed significant increases (-0.368 , $p = 0.023$ and $+0.216$, $p < 0.001$, respectively). The finding is consistent with the conclusions of Ani et al. (2022), Aroyehun (2023), Fagbemi et al. (2025), and Ezech et al. (2026), which attributed the increase in climate change stressors (Temperature and rainfall) to increased food production pressure in Nigeria. Another indicator will be the soil result, to consider any soil-driven agriculture applications. As shown in table 4, the sand content was highest (68.6%) and Bulk density the highest (1.49 g/cm^3) with the lowest porosities (43.8%) and lowest moisture content (13.7%) in Makurdi while the lowest sand content (44.2%) and lowest bulk density (1.32 g/cm^3) and highest porosity (50.2%) and moisture content (19.6%) in Otukpo. Furthermore, the chemical conditions in Makurdi and Guma were very poor, as evidenced by the lowest values for pH, organic carbon, organic matter, and total nitrogen. At the same time, Otukpo has the lowest value of the major parameter, the C: N ratio, among the LGAs with the highest chemical parameter values. The other quantities in the equation—available phosphorus, exchangeable bases, CEC and base saturation values, as shown in Table 6—also definitely differ highly significantly between areas. The above is also substantiated by soil sampling locations results indicated in Table 7, which showed that 38.3%, 29.2%, 32.5%, 35.0% and 36.7% of the soils were rated as low in soil pH, soil organic carbon, soil total nitrogen, soil available phosphorus and soil organic matter, respectively. The adjustment of the two data sets (climate and soil) is therefore largely uniform, and climatic stress can be coupled with the well-known large spatial variation in soil fertility, providing a satisfactory environmental basis for the differences in crop productivity. This aligns with Iwuchukwu et al. (2023) and Gambo et al. (2025), who identified soil erosion/soil degradation and soil infertility as factors contributing to Nigeria's agricultural vulnerability.

As described in the previous pages, all these environment gradients are combined with a third one, mean values of yield were found to be significantly different (all p -values < 0.001) for all the six crops in the LGAs except for rice

for which Guma had the best yield of 3.18t/ha whilst the lowest yield for the crop was obtained at Makurdi, the highest yield for yam was registered at Otukpo at 14.2t/ha, for cassava at Guma at 18.4t/ha, for maize at Otukpo at 2.42t/ha, for soybean at Otukpo and for sorghum at Otukpo at 1.48t/ha and 1.72t/ha respectively (Table 8). Table 9 strengthens this evidence over time: between 2005–2009 and 2020–2024, yams declined by 20.4%, cassava by 19.5%, maize by 30.3%, soybean by 29.4%, and sorghum by 28.4%, whereas rice increased by 23.1%. The regression analysis in Table 11 provides further statistical triangulation, showing that crop yield was positively associated with annual rainfall (standardized $\beta = 0.224$, $p < 0.001$), soil organic matter ($\beta = 0.371$, $p < 0.001$), soil moisture ($\beta = 0.216$, $p = 0.001$), available phosphorus ($\beta = 0.203$, $p < 0.001$) and adaptation index ($\beta = 0.178$, $p = 0.001$), but negatively associated with mean temperature ($\beta = -0.186$, $p = 0.003$) and flood exposure ($\beta = -0.211$, $p < 0.001$). Of particular interest was the standardised coefficient (which actually reflects the relative importance of each soil condition to the model, but not as a cause, as discussed above), which is the highest for SOIL ORGANIC MATTER. The VIF should not exceed 10; our VIF values range from 1.31 to 1.92, indicating that no serious multicollinearity was observed. These are corroborated by the socioeconomic result presented (Table 10), which shows that the majority of the respondents (64.0%) are mainly involved in crop farming, and 41.2% of them responded to agricultural experience of 10-20 years, making them very sensitive to fluctuation in agricultural and environment while 54.0% out of that 41.2% owns farm with 1-3 ha in size. The three integrated environmental/agricultural clusters (Otukpo/Katsina-Ala, Ukum/Apa, and Makurdi/Guma) and trends in NDVI, Vegetation Condition, and Land-degradation indicators are presented in Figures 1 and 2, respectively. In contrast, the distribution of farm topography is presented in Figure 3. All of these, together with what Escalante et al. (2025) found (among others) regarding environmental exposures to climate change, agriculture, and adaptive capacities, determine the food security outcome, creating a picture of cumulative exposures. The synergy between the especially strong declines in yields of several staple crops and the added pressure of an increase in the severity of floods and dryness, as well as spatial variation in soil fertility, is evident, highlighting the need for a combined response to the food crisis in Benue State rather than just to floods and dryness and to soil fertility.

CONCLUSION

The study also shows a positive correlation between climate variation and soil attributes/productivity in the selected LGAs of Benue State. It shows a tremendous reduction in rainfall and rainy days, an increasing likelihood of floods and droughts, and rising temperatures, indicating that climatic pressures are mounting on agriculture. A marked spatial variability in soil physical and chemical properties further highlights unequal fertility status, while a dramatic decrease in yam, cassava, maize, soybean, and sorghum production reflects declining productivity. Based on the regression results, rainfall, soil organic matter, soil moisture, available phosphorus, and adaptation are positive factors influencing productivity, whereas temperature and flood exposure are negative factors. Therefore, the integration of climate adaptation and soil management is key to sustainable food production.

RECOMMENDATIONS

The study suggests more robust climate-smart agriculture through drought- and flood-tolerant varieties, improved water management practices, and timely climate information for farmers. Improve soil fertility through integrated nutrient management, organic amendments, erosion control, and site-specific soil management, especially in areas with low organic matter and nutrient availability. The government and other agricultural institutions need to expand early-warning mechanisms for flood and drought risk management and train farmers to adopt adaptation strategies. Increasing investment in climate-resilient infrastructure, extension services, and agricultural finance should be prioritised to strengthen farmers' adaptive capacity. Finally, ongoing surveillance of climatic patterns, soil health, vegetation health, and productivity management should be utilised to address the food crisis in Benue State based on evidence.

REFERENCES

- Akpan, E. (2025, November). A MULTIDISCIPLINARY APPROACH TO CONFRONTING SECURITY AND FOOD CRISES IN NIGERIA: A COMMUNICATION FRAMEWORK FOR LEVERAGING ENVIRONMENTAL EDUCATION IN THE NORTH-EAST. In *AUN INTERNATIONAL CONFERENCE* (Vol. 3, No. 1).
- Alehile, K. S., Salami, H., & Otohinoyi, K. D. (2025). Climate change, environmental degradation, and food security in Nigeria: A machine learning analysis. *Intelligent Agriculture*, 1(1), 26–39.
- Ani, K. J., Anyika, V. O., & Mutambara, E. (2022). The impact of climate change on food and human security in Nigeria. *International Journal of Climate Change Strategies and Management*, 14(2), 148–167.
- Aroyehun, A. (2023). Impacts of climate change and population growth on food security in Nigeria. *Black Sea Journal of Agriculture*, 6(3), 232–240.
- Aroyehun, A. R., Onoja, A. O., & Ugwuja, V. C. (2025). Addressing Climate Change Vulnerability Issues Through Financial Risk Management in Cassava Farming: Evidence from the Niger Delta Region, Nigeria. In *Energy Transition, Climate Action and Sustainable Agriculture: Perspectives and Strategies for Africa* (pp. 463–491). Cham: Springer Nature Switzerland.
- Ayanlowo, Y., & Davis, S. O. (2025). THE IMPACT OF CLIMATE CHANGE-INDUCED Enobakhare, E. O., Oleabhie, E. J., Erhahon, O., & Evans, K. (2025). Environmental Security: The Conceptual Issues in Climate Change, Global Warming and the Nigerian Environment. *International Journal*, 13(3), 56–62.
- Escalante, L., Mamboundou, P., Meyimdjui, C., & Omoju, O. E. (2025). Economic and food security impacts of climate disasters and mitigation policies: insights from Nigeria. *Environmental and Resource Economics*, 88(6), 1657–1677.
- Ezeh, J. O., Madukwe, E. U., & Ukaegbu, E. C. (2026). Observed climate change factors and food crop production in a typical rural farming community in Nigeria: implications for food security. *Discover Agriculture*, 4(1), 40.
- Fagbemi, F., Oke, D. F., Akinyele, O. D., & Bello, K. M. (2025). Carbon emissions and food production: why climate change is a threat to Nigeria's food security. *Journal of Environmental Studies and Sciences*, 15(1), 101–112.
- Folorunso, M. A., & Folorunso, S. A. (2022). Environmental degradation in Nigeria: the challenges of peaceful co-existence. In *Peace Studies for Sustainable Development in Africa: Conflicts and Peace Oriented Conflict Resolution* (pp. 207–218). Cham: Springer International Publishing.
- Gabriel, P. O., Aina, D. A., & Ilufoye, O. (2025). Impact of Environmental Challenges on Smallholder Farming and Household Food Security in Kwara State, Nigeria. *NIPES JSTR SPECIAL ISSUE*, 7(1), 1683–1694.
- Gambo, A., Fullen, M. A., & Baldwin, T. C. (2025). Indigenous farmers' knowledge and perception of desertification and soil erosion in Jigawa State, Nigeria. *Discover Soil*, 2(1), 22.
- Garba, A., & Abdullahi, M. G. (2026). Evaluation of climatic trends in Dass LGA, Bauchi State, Nigeria. *International Journal of Technology, Health and Sustainability*, 2(1), 52–56.
- GBEREVBIE, D. E., & AFORIJIKU, O. E. (2025). Climate Change-Induced Herder-Farmer Conflicts: Implications for Food Security, in Ondo State, Nigeria. *Nnamdi Azikiwe Journal of Political Science*, 10(4), 32-45.
- Haruna, U. A., Luther, M. L., Zubairu, M., Abonyi, E. E., Dibal, S. M., Gegele, T. A., ... & Lucero-Prisno III, D. E. (2023). Food loss and waste in Nigeria: Implications for food security and environmental sustainability. In *Advances in food security and sustainability* (Vol. 8, pp. 217–233). Elsevier.
- Haruna, U. A., Luther, M. L., Zubairu, M., Abonyi, E. E., Dibal, S. M., Gegele, T. A., ... & Lucero-Prisno III, D. E. (2023). Food loss and waste in Nigeria: Implications for food security and environmental sustainability. In *Advances in food security and sustainability* (Vol. 8, pp. 217–233). Elsevier.

- Idigo, B. C. The Effects of Climate Change on Food Security in Nigeria: A Review.
- Ihugba, U. E. (2025). The economic impact of climate change on Nigeria's agriculture and food security. *African Development Finance Journal*, 8(3), 138–168.
- Ioryue, D. A. (2024). Farmer-herder conflict and national security in Nigeria: The Benue State in perspective. *Kashere Journal of Politics and International Relations*, 2(2), 245–259.
- Ioryue, D. A., Jimoh, O. I., & LOVETH, E. (2024). The Impact of Insecurity on Agricultural Development in Nigeria: A Study of Benue State (2011-2023). *Zamfara Journal of Politics and Development*, 5(3), 169–194.
- Iwuchukwu, F. U., Ewuzie, U., Ajala, O. J., Ojukwu, V. E., Nnorom, I. C., Egbueri, J. C., ... & Ighalo, J. O. (2023). A consideration of the climatic drivers, focal points and challenges of soil erosion, land degradation, landslides and landscapes in Nigeria. *Climate Change Impacts on Nigeria: Environment and Sustainable Development*, 449–477.
- Ode, J. I. (2024). The Effects of Urban Expansion on Agricultural Land in Makurdi LGA. Benue State. *ScienceOpen Preprints*.
- Odebunmi, R. O., & Adesida, B. (2025). Climate-Induced Migration and the Challenges of Food Insecurity in Nigeria. *African Journal of Stability and Development (AJSD)*, 17(2), 1008–1035.
- Omotoso, A. B., & Omotayo, A. O. (2025). Enhancing dietary diversity and food security through the adoption of climate-smart agricultural practices in Nigeria: micro-level evidence. *Environment, Development and Sustainability*, 27(7), 17077–17094.
- Omotoso, A. B., & Omotayo, A. O. (2025). Enhancing dietary diversity and food security through the adoption of climate-smart agricultural practices in Nigeria: micro-level evidence. *Environment, Development and Sustainability*, 27(7), 17077–17094.
- Utaji, M. E., & Nyityo, D. S. (2024). The Impact of Religion on Environmental Sustainability: The Case of Benue State, Nigeria. *Nsukka Journal of Religion and Cultural Studies*, 12(3), 39–44.
- Zakari, S., Ibro, G., Moussa, B., & Abdoulaye, T. (2022). Adaptation strategies to climate change and impacts on household income and food security: Evidence from the Sahelian region of Niger: *Sustainability*, 14(5), 2847.