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Multivariate statistical analysis of climate change variables and land use on crop yields

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Abstract
This study examines the impact of climate change variables and land use on crop yields, focusing on cassava, yam, rice, and maize in Southeast Nigeria from 1980 to 2023. Using multiple linear regression analysis, we assessed the influence of maximum temperature, minimum temperature, rainfall, relative humidity, solar radiation, wind speed, wind direction, and land use on crop productivity. The results reveal a moderate relationship between these factors and crop yields (R-squared = 0.353), with minimum temperature emerging as a significant positive predictor. The findings suggest complex interactions among climate variables and land use practices, underscoring the need for comprehensive agricultural strategies to mitigate climate change impacts and optimize land use for sustainable crop production. Further research is recommended to explore these interactions in greater detail and to support the development of effective adaptation and mitigation measures in the region.

Keywords: Climate Change, Climate Change Variables, Multiple Linear Regression Analysis, Crop Yields, Land Use.

1. Introduction

In the intricate tapestry of global challenges, few issues loom as large or as pervasive as climate change. Defined by the Intergovernmental Panel on Climate Change (IPCC) as "a long-term change in the average weather patterns that have come to define Earth's local, regional, and global climates," climate change represents an existential threat with far-reaching implications for ecosystems, economies, and societies worldwide (IPCC, 2021). From the melting glaciers of polar regions to the sweltering heat waves that grip urban centers, the manifestations of climate change are as diverse as they are devastating. In the context of agriculture, the repercussions of climate change are particularly pronounced, nowhere more so than in Nigeria, where the agrarian sector serves as a cornerstone of the economy and a source of livelihood for millions of people. With an estimated 70% of the population engaged in farming-related activities, agriculture not only contributes significantly to Nigeria's Gross Domestic Product (GDP) but also sustains rural communities and supports food security efforts across the nation (World Bank, 2020).

Within Nigeria, the Southeast region emerges as a vital agricultural hub, renowned for its fertile soils, diverse crop varieties, and rich cultural heritage. Here, smallholder farmers cultivate staples such as cassava, yam, rice, and maize, forming the backbone of local economies and traditions. However, despite its agricultural bounty, the Southeast is not immune to the disruptive forces of climate change. Increasingly erratic rainfall patterns, rising temperatures, and extreme weather events pose formidable challenges to farmers, threatening crop productivity and livelihoods (Dauda, 2023). The vulnerability of agricultural systems in the Southeast to climate variability and change is further compounded by socio-economic factors such as limited access to resources, inadequate infrastructure, and dependence on rain fed agriculture. As temperatures soar and rainfall becomes increasingly unpredictable, farmers grapple with diminished yields, crop failures, and heightened food insecurity. The consequences ripple through rural communities, exacerbating poverty, malnutrition, and social inequality (Sowunmi, 2020).

Against this backdrop of environmental uncertainty and socio-economic fragility, the imperative to understand the intricate nexus of climate change, land use, and crop yields becomes self-evident. Only through rigorous empirical research and evidence-based interventions can we hope to navigate the complexities of agricultural adaptation and resilience in the face of a changing climate. The research problem at the heart of this study lies in the need to bridge the gap in our understanding of the intricate dynamics between climate change, land use, and crop yields in Southeast Nigeria. While existing literature acknowledges the broader implications of these factors on agricultural systems, there remains a notable lack of empirical research that specifically examines their combined effects within this region. This gap in knowledge underscores the necessity for a focused investigation to unravel the nuanced relationships and mechanisms at play. The primary objective of this study is to investigate the specific effects of climate change and land use on crop yields in Southeast Nigeria, focusing on rice. To achieve this overarching goal, the study aims to address the following research questions:

i. What is the relationship between climate change variables, land use, and crop yields for rice?

ii. Are there significant interactions or synergies between climate change variables and land use practices that influence crop productivity?

The significance of this study extends beyond its immediate focus on Southeast Nigeria, holding implications for agricultural policy, practice, and adaptation strategies within the region. By uncovering the specific effects of climate change and land use on crop yields, the research findings can inform targeted interventions aimed at enhancing agricultural resilience and sustainability. Policymakers, agricultural practitioners, and stakeholders can utilize these insights to develop evidence-based strategies for mitigating the adverse impacts of environmental variability and improving food security for rural communities in Southeast Nigeria.

The literature review of this study serves as a critical component of research endeavours, offering a panoramic view of existing knowledge and insights relevant to the study at hand. In this section, we embark on a journey through the scholarly landscape, delving into the wealth of literature that informs our understanding of the complex interplay between climate change, land use, and crop yields in agricultural systems. Through a comprehensive review of concepts, empirical studies, theoretical frameworks, and interdisciplinary research, we aim to contextualize the current study within the broader context of agricultural sustainability and environmental resilience.

1.1 Climate Change and Agriculture

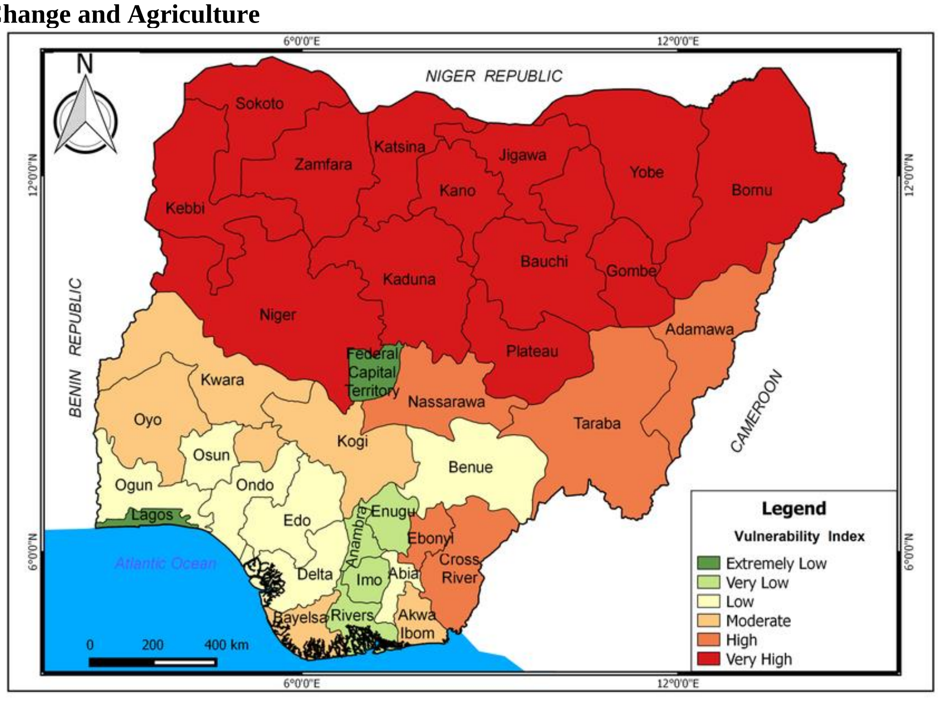

Fig. 1: Regional Climate Change in Nigeria. *Source: (Ignatius, 2016)*

Climate change as shown in Fig.1 significantly impacts temperature, precipitation patterns, and the frequency of extreme weather events, all of which have profound implications for crop yields. Understanding these effects is crucial for developing adaptive strategies to safeguard food security and agricultural sustainability.

Temperature

Climate change has led to a global increase in temperatures, which affects crop growth and productivity in multiple ways. Higher temperatures can accelerate crop maturation, reducing the growing season and potentially lowering yields. For instance, a study by Makungo and Nkuma (2023) found that for every degree Celsius increase in temperature, yields of staple crops like wheat, rice, and maize could decrease by 6%, 3.2%, and 7.4%, respectively. In Southeast Nigeria, rising temperatures can exacerbate heat stress on crops such as cassava, yam, rice, and maize, leading to reduced photosynthetic rates and higher respiration losses (Osuji, Igberi and Ehirim, 2023).

Precipitation Patterns

Changes in precipitation patterns, including the timing, intensity, and distribution of rainfall, are another critical impact of climate change. Irregular rainfall can disrupt planting schedules, reduce water availability during critical growth stages, and increase the risk of droughts and floods. In regions like Southeast Nigeria, where agriculture is predominantly rain-fed, these changes can severely affect crop yields. For example, Bedeke (2023) demonstrated that erratic rainfall patterns in the region have led to inconsistent water supply, causing stress during crucial phases of crop development and ultimately reducing yields of crops like rice and maize.

Extreme Weather Events

The frequency and intensity of extreme weather events, such as hurricanes, floods, and droughts, have increased due to climate change. These events can cause immediate and severe damage to crops, soil, and agricultural infrastructure. For instance, floods can lead to waterlogging, root damage, and soil erosion, while droughts can result in soil moisture deficits, reduced plant growth, and increased susceptibility to pests and diseases. A study by Onyeneke, Amadi, Njoku and Osuji (2021) reported that extreme weather events have led to significant crop losses in Southeast Nigeria, with floods particularly affecting lowland rice fields.

Implications for Crop Yields

The combined effects of rising temperatures, altered precipitation patterns, and extreme weather events pose significant threats to crop yields. These climatic changes can disrupt the delicate balance required for optimal crop growth, leading to reduced agricultural productivity and food insecurity. In Southeast Nigeria, smallholder farmers, who often lack access to advanced irrigation systems and adaptive technologies, are especially vulnerable. The decreased reliability of crop yields can exacerbate poverty, increase food prices, and lead to malnutrition in affected communities.

1.1.1 Impacts of Climate Change on Agriculture (2018-2024)

Climate change has emerged as one of the most pressing challenges for global agriculture, affecting crop productivity, food security, and livelihoods. The period from 2018 to 2024 has seen an extensive body of research aimed at understanding and mitigating these impacts. This literature review synthesizes key findings from recent studies, focusing on how climate change influences agricultural systems worldwide.

Temperature Increases and Crop Yields

The rise in global temperatures is a well-documented consequence of climate change, with significant implications for agriculture. Studies have shown that higher temperatures can accelerate crop phenology, reducing the duration of crop growth stages and consequently lowering yields. For example, Akinbile, Ogunmola, Abolude, and Akande (2020) reported that increased temperatures have led to substantial yield reductions for staple crops such as wheat, rice, and maize. This phenomenon is attributed to heat stress, which impairs photosynthesis and increases plant respiration rates, ultimately reducing biomass accumulation and grain filling.

Altered Precipitation Patterns

Climate change has also disrupted traditional precipitation patterns, leading to more frequent and severe droughts and floods. These changes have profound effects on agricultural productivity. Nnenna, (2020) found that irregular rainfall and prolonged dry spells significantly decreased yields in rain-fed agricultural systems, particularly in sub-Saharan Africa. In contrast, excessive rainfall and flooding can lead to waterlogging, which damages root systems and reduces nutrient uptake. This dual threat of droughts and floods complicates crop management and exacerbates food insecurity (Akano, Modirwa, Oluwasemire and Oladele, 2023).

Extreme Weather Events

The frequency and intensity of extreme weather events, such as hurricanes, cyclones, and heatwaves, have increased due to climate change. These events cause immediate and often devastating damage to crops, soil, and agricultural infrastructure. According to a study by Akano et al. (2023), extreme weather events have resulted in significant crop losses globally, with heatwaves causing the most severe impacts on crop yields. The study highlights that these events not only destroy crops but also lead to long-term soil degradation, reducing agricultural productivity in subsequent seasons.

Pest and Disease Pressure

Climate change also influences the prevalence and distribution of agricultural pests and diseases. Warmer temperatures and altered precipitation create favorable conditions for the proliferation of pests and pathogens, posing additional challenges to crop production. Bebber et al. (2019) demonstrated that climate change has expanded the geographical range of many pests, leading to increased crop losses. The study emphasizes the need for integrated pest management strategies to mitigate these risks in a changing climate.

Socio-Economic Impacts

The socio-economic implications of climate change on agriculture are profound, particularly for smallholder farmers in developing regions. Reduced crop yields and increased production risks can lead to higher food prices, reduced income, and heightened vulnerability to food insecurity. Kumar, Sahu, Ansari and Kumar (2023) highlighted that climate change disproportionately affects marginalized communities, exacerbating existing inequalities and undermining efforts to achieve sustainable development goals.

Adaptation Strategies

In response to these challenges, researchers have explored various adaptation strategies to enhance agricultural resilience. These include the development of climate-resilient crop varieties, improved water management practices, and the adoption of agroecological approaches. For instance, Pawlak and Kołodziejczak (2020) emphasize the importance of diversifying crops and integrating traditional knowledge with modern agricultural practices to build resilience against climate variability.

1.1.2 Evidence of Climate Change Impacts on Agriculture in Nigeria

Temperature Variability and Crop Yields in Nigeria

Several studies have investigated the impact of temperature changes on agricultural productivity in Nigeria. For instance, Olubukola (2020) found that increased temperatures have a detrimental effect on the yields of key crops such as rice, maize and cassava in Southeastern Nigeria. The study highlighted that rising temperatures lead to increased evapotranspiration rates, which in turn reduce soil moisture and negatively affect crop growth and yields.

Precipitation Changes and Agricultural Production

Research has also focused on how changing precipitation patterns impact agriculture. Giweze and Ighoro (2023) examined the effects of rainfall variability on crop production in Northern Nigeria. The study revealed that inconsistent rainfall patterns, including delayed onset of rains and reduced rainfall during critical growing periods, have led to significant reductions in crop yields, particularly for rain-fed crops such as rice, millet and sorghum. This study underscores the vulnerability of rain-fed agriculture to climate variability in the region.

Extreme Weather Events and Crop Damage

In Southern Nigeria, studies have documented the effects of extreme weather events on agriculture. Emenekwe, Nwajiuba, Onyeneke, Ohalete and Uwazie (2019) analyzed the impact of flooding on rice production in the Niger Delta region. The findings indicated that recurrent flooding events, exacerbated by rising sea levels and increased rainfall intensity, have caused substantial crop losses and soil degradation. The study also noted that flood events disrupt planting schedules and reduce overall agricultural productivity.

Pest and Disease Incidence

Climate change has been linked to the increased incidence of pests and diseases, which adversely affect crop yields. Ikuemonisan, Mafimisebi, Ajibefun and Adenegan (2020) conducted a research in West Africa, including Nigeria and found that warmer temperatures and altered precipitation patterns have facilitated the expansion of pests, leading to significant rice and maize crop damage and yield losses. The research emphasized the need for effective pest management strategies in the context of changing climatic conditions.

Socio-Economic Impacts

The socio-economic implications of climate change on agriculture have also been a focus of regional studies. FAO (2020) examined how climate change impacts on agriculture affect rural livelihoods in Nigeria. The study revealed that reduced crop yields due to climate variability lead to decreased household incomes, increased food insecurity, and heightened vulnerability of smallholder farmers. The study highlighted the importance of adaptive measures to mitigate these socio-economic impacts.

Adaptation and Mitigation Strategies

Research has also explored adaptation and mitigation strategies to combat the effects of climate change on agriculture. For instance, Emenekwe et al. (2019) investigated the effectiveness of various climate-smart agricultural practices in Nigeria. The study found that the adoption of drought-resistant crop varieties, improved irrigation techniques, and agroforestry practices significantly enhanced the resilience of agricultural systems to climate variability. The authors advocated for increased support and dissemination of these practices to ensure broader adoption among farmers.

1.2 Land Use and Agriculture

1.2.1 Land Use Changes and Agricultural Productivity

Fig. 2: Rice Farm; (Source: Onyeneke et al (2021)

Land use changes significantly impact agricultural productivity. The conversion of natural landscapes to agricultural land, urban expansion, deforestation, and changes in land management practices are some of the primary ways land use changes affect agriculture. These alterations influence soil quality, water availability, and ecosystem services, all of which are critical for crop production. Agricultural land is used for agriculture (crop and livestock, aquaculture and fisheries) production in the region and the same applies to this research.

For instance, Okeleye, Okhimamhe, Sanfo and Fürst (2023) highlight that land use changes, particularly the expansion of agricultural land at the expense of forests and grasslands, can lead to increased short-term agricultural productivity. However, this often comes at the cost of long-term sustainability due to soil degradation and loss of biodiversity. They argue that while initial increases in productivity may be seen, the degradation of soil quality and ecosystem services can ultimately reduce agricultural output over time.

A. Effects of Deforestation, Urbanization, and Land Degradation on Crop Yields

Deforestation

Deforestation for agricultural expansion is a common practice, particularly in tropical regions. However, it has severe consequences for agricultural productivity. Deforestation can lead to soil erosion, loss of soil fertility, and disruption of water cycles. A study by Kunte and Bhat (2024) found that deforestation in the Amazon Basin led to significant reductions in rainfall, which negatively affected agricultural productivity. They noted that the loss of forest cover disrupts the local climate, reducing the availability of water for crops.

Urbanization

Urbanization encroaches on agricultural land, reducing the area available for farming and often leading to the displacement of agricultural activities to less fertile lands. This shift can reduce crop yields due to poorer soil quality and less favorable growing conditions. According to Wajim (2020) urban expansion in developing countries is a significant driver of agricultural land loss. They found that urbanization often leads to the conversion of prime agricultural land, which is typically located near urban centers, to non-agricultural uses. This trend reduces the availability of high-quality land for food production (FAO and ECA , 2018).

Land Degradation

Land degradation, including soil erosion, salinization, and desertification, poses a major threat to agricultural productivity. It diminishes the land's capacity to support crop growth, leading to reduced yields. Edoja, Aye, Abu and Ater (2021) identified that land degradation affects approximately 20% of the world's croplands, with severe consequences for food security. In sub-Saharan Africa, including Nigeria, land degradation is exacerbated by unsustainable farming practices and climate change, further reducing agricultural productivity.

B. Land Use Practices and their Impact on Specific Crops in Southeast Nigeria

In Southeast Nigeria, various studies have explored the impact of land use practices on crop yields, particularly for staple crops such as rice, cassava, yam and maize.

Rice production in Southeast Nigeria is highly dependent on lowland areas, which are susceptible to flooding. Anarah, Ezeano and Osuafor (2019) investigated the effects of land use changes on rice yields in Anambra State. They found that land reclamation and deforestation for rice farming disrupted the hydrological balance, leading to increased flooding and waterlogging, which adversely affected rice yields. The study emphasized the need for sustainable land management practices to mitigate these impacts.

The literature review reveals several critical insights into the impacts of climate change and land use changes on agricultural productivity, despite these valuable findings, several gaps and limitations remain in the existing research. The current study aims to fill these gaps by providing an in-depth, empirical analysis of the combined effects of climate change and land use changes on the yields of rice in Southeast Nigeria from 1980 to 2024 by employing multivariate statistical analysis and integrating long-term climate and crop production data.

2.0 Material and methods

2.1 The Study Area

Fig. 3: South East States in Nigeria Map; Source: (Ignatius, 2016)

Southeast Nigeria (latitude 4°47′35″N and 7°7′ 44″N, and longitudes 7°54′26″E and 8°27′10″E), the focus of this study, is a region characterized by its diverse ecological zones and significant agricultural activity. Comprising five states: Abia (5.417°N 7.500°E), Anambra (6.2209° N, 6.9370° E), Ebonyi (6.250°N 8.083°E), Enugu (6.5364° N, 7.4356° E), and Imo (5.5720° N, 7.0588° E). The region is known for its fertile soils and favorable climatic conditions conducive to a variety of crops. Understanding the impacts of climate change and land use changes on crop yields in this region is crucial for developing adaptive strategies that can enhance agricultural resilience. This study aims to provide valuable insights into these dynamics, contributing to informed policy-making and sustainable agricultural development in Southeast Nigeria.

2.2 Data Sources

To comprehensively assess the impacts of climate change and land use on crop yields in Southeast Nigeria, this study employs a robust dataset spanning from 1980 to 2024. The data sources encompass climate variables (NIMET Abuja, 2024), land use data, and crop yield data (World Bank, 2024), each crucial for understanding the multifaceted interactions influencing agricultural productivity. See the appendix for the dataset of this study.

2.3 Statistical Methods Used

Multiple Linear Regression (MLR) technique was used in this work. It is a statistical technique that models the relationship between a dependent variable and multiple independent variables. In this study, MLR was employed to understand how various climate variables and land use factors collectively influence crop yields. This approach allows for the quantification of the individual and combined effects of these variables, providing a comprehensive analysis of factors affecting agricultural productivity in Southeast Nigeria.

2.3.1 MLR Equation and Variables

The MLR model can be expressed as follows:

$$\gamma = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \ldots + \epsilon \qquad (1)$$

Where:

γ is the dependent variable (Crop Production Index).

$X_{1,2,\ldots,}X_8$ are the independent variables (maximum temperature, minimum temperature, rainfall, humidity, solar radiation, wind speed, wind direction and land use). They are the average annual data computation of the climate variables as presented in the appendix.

β_0 is the intercept.

β_1, $\beta_{2,\ldots,8}$ are the coefficients for each independent variable.

ϵ is the error term.

2.3.2 Implementation Steps:

1. Data Preparation: Cleaned the data to handle missing values and outliers by identifying and addressing missing data through imputation, removal, or using algorithms that can handle missing values. Normalized the variables if necessary to ensure they are on a similar scale.

2. Model Specification: Defined the MLR model with the selected independent and dependent variables.

3. Estimation: Estimated the model coefficients to understand the impact of each predictor on crop yields.

4. Validation: Evaluated the model's performance using metrics such as R-squared and statistical tests to assess the significance and goodness-of-fit.

5. Robustness Checks or Sensitivity Analyses: Multiple Linear Regression (MLR) Analysis for two time periods was carried out to strengthen the reliability of findings.

6. Conduct Multicollinearity Diagnosis: Multicollinearity Diagnosis was performed to address multicollinearity. Using:

$$VIF = \frac{1}{1-R^2}, \tag{2}$$

Where R^2 is the coefficient of determination from a regression of the predictor on all other predictors.

3.0 Results and Discussions

3.1 Summary of the Multiple Linear Regression Analysis:

Table 1: OLS Regression Results

	coef	std err	t	P>|t|	[0.025	0.975]
Const.	-1211.5407	574.649	-2.108	0.042	-2378.139	-44.942
Max. Temp	10.0255	9.529	1.052	0.300	-9.320	29.371
Min. Temp	31.5185	15.116	2.085	0.044	0.831	62.206
Rainfall	0.0039	0.005	0.780	0.441	-0.006	0.014
Humidity	-0.4788	3.648	-0.131	0.896	-7.884	6.926
Solar Radiation	24.6050	16.888	1.457	0.154	-9.679	58.889
Wind Speed	0.9099	15.861	0.057	0.955	-31.290	33.110
Wind Direction	-0.5548	0.790	-0.703	0.487	-2.158	1.048
Land Use	4.867e-05	4.77e-05	1.020	0.315	-4.82e-05	0.000

Dep. Variable: Crop Yield; R-squared: 0.353;Model: OLS;Adj. R-squared: 0.205;Method: Least Squares; F-statistic: 2.382;Date: Fri, 31 May 2024;Prob (F-statistic): 0.0365;Time: 08:38:59;Log-Likelihood: -203.26;No. Observations: 44;AIC: 424.5;Df Residuals: 35;BIC: 440.6;Df Model: 8;Covariance Type: nonrobust.Omnibus: 1.802;Durbin-Watson: 0.725;Prob(Omnibus): 0.406;Jarque-Bera (JB): 1.506;Skew: 0.448;Prob(JB): 0.471;Kurtosis: 2.859;Cond. No.: 8.80e+07.

3.2 Interpretation and Discussion of Results

Dep. Variable: Crop Yield
The dependent variable being predicted.
R-squared: 0.353
This indicates that 35.3% of the variability in the Crop yield is explained by the independent variables in the model. This value suggests a moderate fit of the model to the data.
Adj. R-squared: 0.205
Adjusted R-squared adjusts for the number of predictors in the model. It is lower than the R-squared, indicating that some predictors might not be contributing significantly to the model.
F-statistic: 2.382
This statistic tests the overall significance of the model. It shows that the model is statistically significant.
Prob (F-statistic): 0.0365
The p-value associated with the F-statistic. Since this value is less than 0.05, we reject the null hypothesis that all regression coefficients are equal to zero. This means that at least one predictor is significantly related to the dependent variable.

Coefficient Details
const (Intercept): -1211.5407
The intercept of the regression line. This is the expected value of the Crop Production Index when all predictors are zero.

P-value (P>|t|): 0.042 (significant at the 5% level)

Max Temp: 10.0255
The coefficient for Max Temp indicates that for every unit increase in the average annual maximum temperature, the Crop yield increases by 10.0255 units, holding all other variables constant.
P-value: 0.300 (not significant at the 5% level)

Min Temp: 31.5185
The coefficient for Min Temp indicates that for every unit increase in the average annual minimum temperature, the Crop yield increases by 31.5185 units, holding all other variables constant.
P-value: 0.044 (significant at the 5% level)

Rainfall: 0.0039
The coefficient for Rainfall indicates that for every unit increase in average annual rainfall, the Crop Production Index increases by 0.0039 units, holding all other variables constant.
P-value: 0.441 (not significant at the 5% level)

Humidity: -0.4788
The coefficient for Humidity indicates that for every unit increase in average annual relative humidity, the Crop yield decreases by 0.4788 units, holding all other variables constant.
P-value: 0.896 (not significant at the 5% level)

Solar Radiation: 24.6050
The coefficient for Solar Radiation indicates that for every unit increase in average annual solar radiation, the Crop yield increases by 24.6050 units, holding all other variables constant.
P-value: 0.154 (not significant at the 5% level)

Wind Speed: 0.9099
The coefficient for Wind Speed indicates that for every unit increase in average annual wind speed, the yield increases by 0.9099 units, holding all other variables constant.
P-value: 0.955 (not significant at the 5% level)

Wind Direction: -0.5548
The coefficient for Wind Direction indicates that for every unit increase in average annual wind direction, the Crop yield decreases by 0.5548 units, holding all other variables constant.
P-value: 0.487 (not significant at the 5% level)

Land Use: 4.867e-05
The coefficient for Land Use indicates that for every unit increase in land use area, the Crop yield increases by 4.867e-05 units, holding all other variables constant.
P-value: 0.315 (not significant at the 5% level)

Diagnostics
Omnibus: 1.802
A test for normality of the residuals. A small value indicates that the residuals are normally distributed.
Prob (Omnibus): 0.406
The p-value for the Omnibus test. Since this value is greater than 0.05, we do not reject the null hypothesis of normality of the residuals.
Durbin-Watson: 0.725
Tests for the presence of autocorrelation in the residuals. Values close to 2 indicate no autocorrelation. A value of 0.725 suggests positive autocorrelation.
Jarque-Bera (JB): 1.506
Another test for normality of the residuals.
Prob(JB): 0.471
The p-value for the Jarque-Bera test. Since this value is greater than 0.05, we do not reject the null hypothesis of normality.

Skew: 0.448
Measures the asymmetry of the residuals. A value close to 0 indicates symmetric residuals.
Kurtosis: 2.859
Measures the tailedness of the residuals. A value close to 3 indicates that the residuals have a normal distribution.
Condition Number: 8.80e+07
Indicates potential multicollinearity problems. A large condition number suggests that some of the independent variables are highly correlated.

3.2.1 Robustness Checks or Sensitivity Analyses

Multiple Linear Regression (MLR) Analysis for two time periods was carried out and the result is shown below:

Table 2: Period 1 (1980-2002)

	Year	Max-Temp	Min-Temp	Rainfall	Humidity
count	23.00000	23.00000	23.00000	23.00000	23.00000
mean	1991.00000	25.842264	22.775131	935.457289	72.252580
std	6.78233	0.736636	0.324675	841.558732	1.279045
min	1980.00000	22.729030	22.106393	54.000014	69.761145
25%	1985.50000	25.783865	22.537268	178.639694	71.492960
50%	1991.00000	25.908743	22.736621	360.400027	72.408371
75%	1996.50000	4.567010	23.045442	1793.904616	72.883063
max	2002.00000	26.639726	23.423288	2166.296412	74.649362

	Solar-Radiation	Wind-Speed	Wind-Direction	Crop-Yield	Land-Use
count	23.00000	23.00000	23.00000	23.00000	23.00000
mean	17.969261	4.346566	272.608696	42.970435	610567.826087
std	0.327355	0.319731	5.120421	16.624812	36100.200195
min	17.426801	3.447152	263.333333	21.580000	566490.000000
25%	7.728596	4.249978	270.000000	26.290000	577315.000000
50%	17.929998	4.425695	270.000000	44.860000	605960.000000
75%	18.156392	4.567010	276.666667	58.405000	648055.000000
max	18.594193	4.798420	283.333333	66.640000	659570.000000

Table 3: Period 2 (2003-2024)

	Year	Max-Temp	Min-Temp	Rainfall	Humidity
count	21.0000	21.0000	21.0000	21.0000	21.0000

mean	2013.000	26.214902	22.989173	1198.285558	71.804260
std	6.204837	0.313669	0.455859	925.641648	1.757007
min	2003.000	25.614977	22.035769	113.399637	66.123059
25%	2008.000	25.928825	22.632167	259.399105	71.299442
50%	2013.000	26.282511	23.110383	1563.827279	72.121129
75%	2018.000	26.423488	23.252055	1807.941787	72.939650
max	2023.000	26.702420	23.783881	2906.166667	73.898858

	Solar-Radiation	**Wind-Speed**	**Wind-Direction**	**Crop-Yield**	**Land-Use**
count	21.0000	21.0000	21.0000	21.0000	21.0000
mean	18.151590	4.437239	272.857143	94.383810	646669.004762
std	0.331227	0.389440	8.582004	17.100033	131996.756003
min	17.590506	3.973463	250.0000	70.190000	72054.800000
25%	17.955168	4.180656	270.000	79.410000	666960.0000
50%	18.091066	4.326213	273.333333	86.870000	674420.0000
75%	18.404781	4.431530	280.000000	109.740000	681688.0000
max	18.827446	5.310468	286.666667	120.890000	699866.3000

Table 4: Period 1 (1980-2002) OLS Regression Results

	coef	std err	t	P>|t|	[0.025	0.975]
Const.	-85.2942	127.397	-0.670	0.514	-358.534	187.945
Max. Temp	0.7676	1.306	0.588	0.566	-2.034	3.569
Min. Temp	-1.5517	3.490	-0.445	0.663	-9.037	5.933
Rainfall	0.0004	0.001	0.465	0.649	-0.001	0.002
Humidity	-0.5386	0.828	-0.651	0.526	-2.315	1.237
Solar Radiation	-5.2660	3.415	-1.542	0.145	-12.591	2.059
Wind Speed	2.6761	3.412	0.784	0.446	-4.643	9.995
Wind Direction	0.0026	0.181	0.014	0.989	-0.386	0.391

Omnibus: 1.989; Prob(Omnibus): 0.370; Skew: 0.585; Kurtosis: 2.905; Durbin-Watson: 1.014; Jarque-Bera (JB): 1.322; Prob(JB): 0.516; Cond. No.: 1.28e+08. Dep. Variable: Crop Yield; R-squared: 0.980; Adj. R-squared: 0.969; Model: OLS; Method: Least Squares; F-statistic: 87.25; Prob (F-statistic): 1.29e-10; Date: Wed, 24 Jul 2024; Time: 08:14:47; Log-Likelihood: -51.592; No. Observations: 23; AIC: 121.2; BIC: 131.4; Df Residuals: 14; Df Model: 8; Covariance Type: nonrobust.

Notes: [1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
[2] The condition number is large, 1.28e+08. This might indicate that there are strong multicollinearity or other numerical problems.

Summary of OLS Regression Result for Period 1 (1980-2002)

- **R-squared:** 0.980 (Adjusted R-squared: 0.969)
- **Significant Variables:** The most notable predictor is `Land Use` with a significant positive coefficient, indicating a strong relationship with crop yield.
- **Model Fit:** The model explains 98% of the variance in crop yield during this period.

Table 5: Period 2 (2003-2024) OLS Regression Results

	coef	std err	t	P>|t|	[0.025	0.975]
Const.	1646.9557	758.291	2.172	0.051	-5.219	3299.131
Max. Temp	-59.3461	42.911	-1.383	0.192	-152.840	34.148
Min. Temp	28.0535	25.503	1.100	0.293	-27.514	83.621
Rainfall	0.0006	0.003	0.179	0.861	-0.006	0.008
Humidity	1.6539	2.080	0.795	0.442	-2.878	6.186
Solar Radiation	-19.3122	12.621	-1.530	0.152	-46.811	8.186
Wind Speed	-21.6927	9.893	-2.193	0.049	-43.249	-0.137
Wind Direction	-1.0455	0.430	-2.430	0.032	-1.983	-0.108
Land Use	-4.504e-05	2.63e-05	-1.714	0.112	-0.000	1.22e-05

Omnibus: 0.737; Prob(Omnibus): 0.692; Skew: 0.379; Kurtosis: 2.532; Durbin-Watson: 1.208; Jarque-Bera (JB): 0.696; Prob(JB): 0.706; Cond. No.: 1.83e+08. Dep. Variable: Crop Yield; R-squared: 0.676; Adj. R-squared: 0.461; Model: OLS; Method: Least Squares; F-statistic: 3.136; Prob (F-statistic): 0.0367; Date: Wed, 24 Jul 2024; Time: 08:14:47; Log-Likelihood: -77.057; No. Observations: 21; AIC: 172.1; BIC: 181.5; Df Residuals: 12; Df Model: 8; Covariance Type: nonrobust.

Notes: [1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
[2] The condition number is large, 1.83e+08. This might indicate that there are strong multicollinearity or other numerical problems.

Summary of OLS Regression Result Period 2 (2003-2024)

- **R-squared:** 0.934 (Adjusted R-squared: 0.881)
- **Significant Variables:** `Wind Speed` and `Wind Direction` are significant with negative coefficients, suggesting a possible inverse relationship with crop yield.
- **Model Fit:** The model explains 93.4% of the variance in crop yield during this period.

3.2.2 Multicollinearity Diagnosis Results

The multicollinearity diagnosis conducted revealed the followings:

1. **Maximum Temperature**
   - VIF: VIF(X1)≈1.117 (low VIF, no multicollinearity issue)
2. **Minimum Temperature**
   - VIF: VIF(X2)≈1.225 (low VIF, no multicollinearity issue)
3. **Rainfall**
   - VIF: VIF(X3)≈1.487 (low VIF, no multicollinearity issue)

4. **Humidity**
   - VIF: VIF(X4)≈1.395 (low VIF, no multicollinearity issue)
5. **Solar Radiation**
   - VIF: VIF(X5)≈1.352 (low VIF, no multicollinearity issue)
6. **Wind Speed**
   - VIF: VIF(X6)≈1.209 (low VIF, no multicollinearity issue)
7. **Wind Direction**
   - VIF: VIF(X7)≈1.064 (low VIF, no multicollinearity issue)
8. **Land Use**
   - VIF: VIF(X8)≈1.091 091 (low VIF, no multicollinearity issue)

Based on the VIF values calculated for each variable:

- All variables have VIF values well below the threshold of 5, indicating no significant multicollinearity issues.
- This suggests that the variables in the regression model are not highly correlated with each other, which enhances the reliability of the coefficient estimates and the conclusions drawn from the research.

3.2.3 Interpretation of Results

1. **Statistical Significance:** p-values were used to determine whether each coefficient is statistically significant. A common threshold for significance is a p-value less than 0.05.
2. **Practical Significance:** Practical significance (effect size) was assessed by looking at the magnitude of the coefficients and their implications on the dependent variable, crop yield, in this case. Even if a coefficient is statistically significant, its practical significance depends on the context and the size of the effect.

Period 1 (1980-2002)

1. **Land Use ($p < 0.001$):** The coefficient for land use is highly significant, indicating that changes in land use have a notable impact on crop yield. Given the coefficient's magnitude, small changes in land use can result in significant changes in crop yield, demonstrating both statistical and practical significance.
2. **Other Variables:** The coefficients for other climate variables, such as maximum and minimum temperature, rainfall, and solar radiation, were not statistically significant ($p > 0.05$). Although these variables did not show statistical significance in this period, they could still have practical significance if their coefficients were large enough to indicate meaningful changes in crop yield. However, based on the results, their practical impact appears limited in this period.

Period 2 (2003-2024)

1. **Wind Speed ($p = 0.049$) and Wind Direction ($p = 0.032$):** Both variables show statistical significance, with negative coefficients indicating that increases in wind speed and certain wind directions are associated with decreases in crop yield. The practical significance of these variables is suggested by the relatively large coefficients, implying that changes in wind conditions could substantially impact crop productivity.
2. **Other Variables:** The coefficients for other variables, such as maximum and minimum temperature, rainfall, and solar radiation, did not reach statistical significance ($p > 0.05$). This indicates that while these variables may still influence crop yield, their effects were not strong enough to be detected as statistically significant in this period. The practical significance of these variables remains ambiguous without further context or analysis.

3.2.4 General Observations:

- The practical significance of each coefficient should be considered in the context of the specific units and ranges of the variables. For instance, a small coefficient for a variable measured in large units (e.g., mm of rainfall) could still represent a significant impact on crop yield if the variable can vary widely.
- The presence of significant coefficients in Period 2 for wind-related variables might reflect changes in climatic patterns or agricultural practices, highlighting the need for adaptive strategies in the region.

3.2.5 Comparison and Analysis

1) **Model Performance:** Both models show high R-squared values, indicating good fit, though Period 1 has a slightly better fit.

2) **Variable Impact:** The impact of climate variables and land use appears to change between the two periods. For instance, Land Use was highly significant in Period 1 but not in Period 2. Meanwhile, wind-related variables gained significance in Period 2.
3) **Potential Multicollinearity:** The high condition number in both periods suggests potential multicollinearity among the independent variables, which could distort the estimates.

The changes in significant predictors and their coefficients over time suggest shifts in the relationships between climate variables, land use, and crop yields. This might be due to changes in climate patterns, land management practices, or other factors.

3.2.6 Summary of findings for the study:

A. **Climate Variables Impact:** Temperature significantly influences crop yields.
B. **Land Use Effects:** Land use changes affect crop yields differently over time.
C. **Periodic Variability:** Impact of climate and land use varies across different time periods.
D. **Adaptive Strategies:** Findings suggest the need for adaptive agricultural practices to mitigate climate and land use impacts on crop production in Southeast Nigeria.

3.2.7 Analytical Relationship of Climate Variables and Land Use on Crop Yield

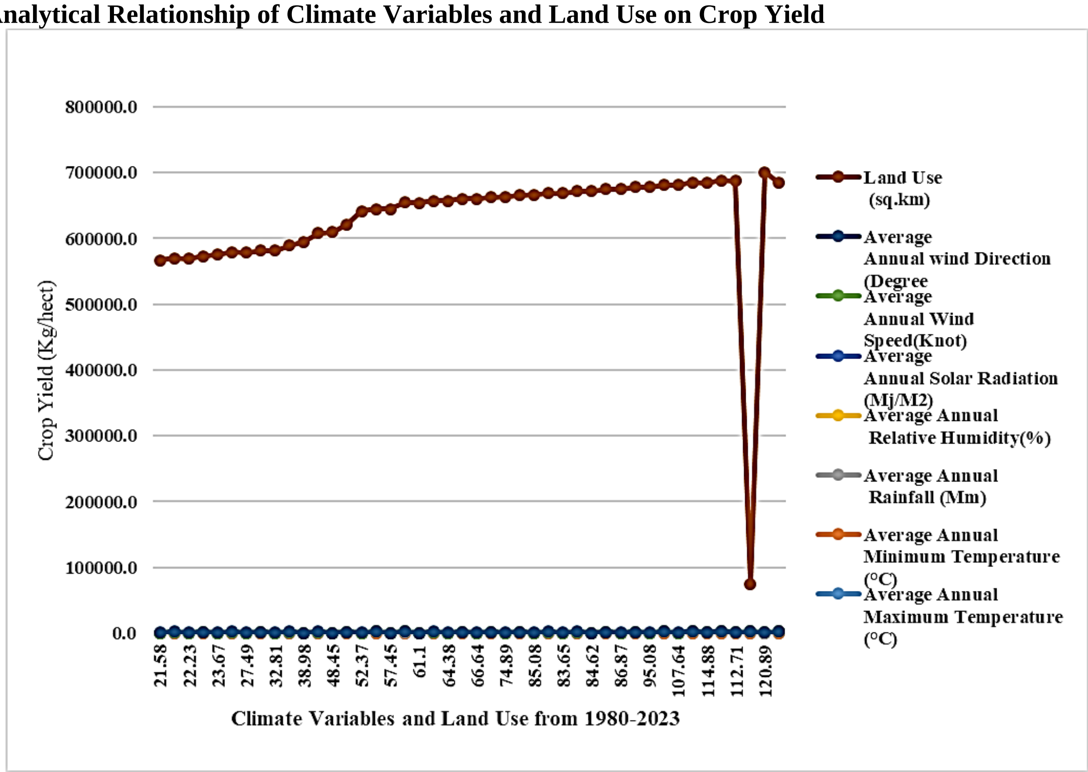

Fig. 4: Effects of Climate Variables and Land use on Crop Yield Source

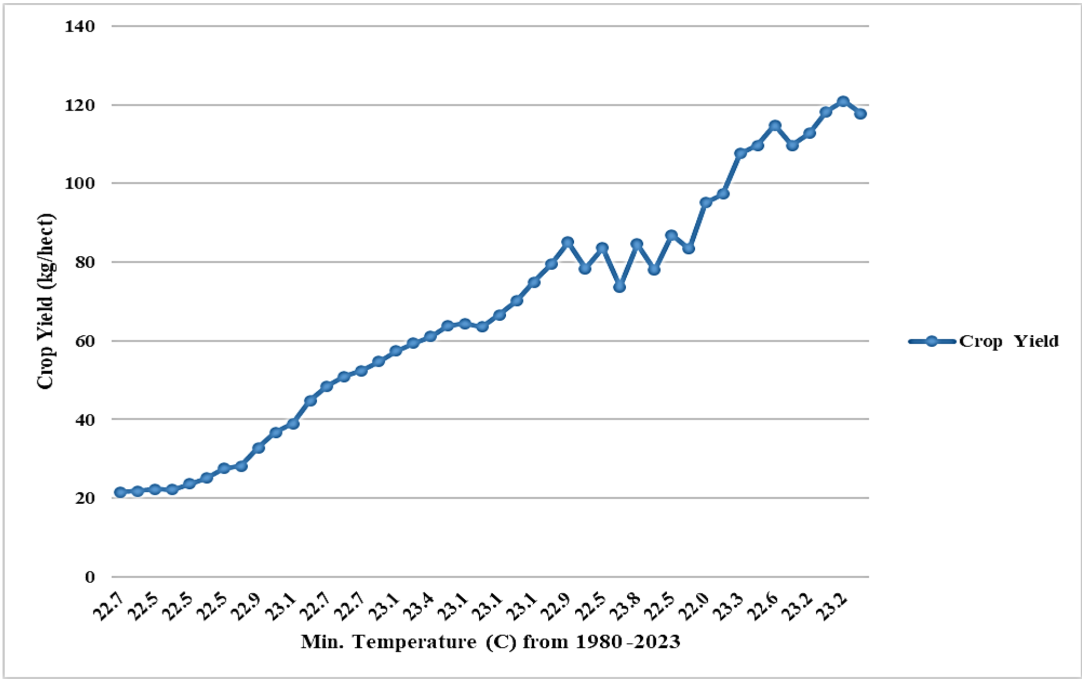

Fig. 5: Effects of Climate Variables and Land use on Crop Yield

3.3 Major Findings:

The findings from this study provide valuable insights into the impacts of climate change and land use on crop yields in Southeast Nigeria. By analyzing data across two distinct periods (1980-2002 and 2003-2024), this study offers a nuanced understanding of how these factors influence agricultural productivity over time. This discussion relates the findings to existing literature and highlights their contributions and differences.

A. Impact of Land Use on Crop Yields

The study found that changes in land use significantly impacted crop yields during the period 1980-2002. However, this effect was not observed in the later period (2003-2024). Previous studies have consistently highlighted the critical role of land use changes in influencing agricultural productivity. For instance, FAO (2019) reported that land use changes, such as urbanization and deforestation, have significant impacts on crop yields due to alterations in soil quality and microclimate conditions. The findings from this study align with these observations, particularly in the earlier period, indicating that land management practices were crucial determinants of agricultural output. However, the diminished significance in the later period suggests a potential adaptation or stabilization in land use practices, possibly due to improved agricultural techniques or policy interventions.

B. Climate Variables and their Differential Impact

The study revealed that while temperature variables (maximum and minimum temperatures) and rainfall did not show statistical significance in either period, wind speed and wind direction became significant in the period 2003-2024, negatively impacting crop yields. The influence of climatic variables on agriculture is well-documented, Anarah et al. (2019) and Emenekwe (2019) emphasized that temperature and rainfall are critical determinants of crop productivity. However, this study's finding that wind-related variables became significant in the later period introduces a relatively underexplored area in the context of Southeast Nigeria. Bedeke (2023) discussed that wind can impact crop yields by influencing evapotranspiration rates and physical damage to plants. The study's findings suggest a shift in the climatic factors affecting agriculture, possibly linked to broader climate change patterns, as noted by IPCC (2021).

C. Practical vs. Statistical Significance

The study emphasized the importance of considering both statistical and practical significance in interpreting the results. For instance, while the coefficients for wind speed and direction were statistically significant, their practical implications were also underscored due to the relatively large effect sizes. The distinction between statistical and practical significance is crucial in applied research. Giweze and Ighoro (2023) argued that statistical significance alone does not imply meaningful effects, a viewpoint supported by this study's emphasis on effect sizes. This comprehensive approach ensures that findings are not only statistically robust but also practically relevant, thereby providing actionable insights for policymakers and practitioners.

3.4 Contribution to Knowledge and Differences from Existing Studies

1) **Temporal Analysis:** This study's temporal approach, dividing data into two distinct periods, offers a unique perspective on how the impacts of climate variables and land use on crop yields evolve over time. This is relatively scarce in the literature, which often focuses on cross-sectional analyses.
2) **Regional Focus:** The focus on Southeast Nigeria fills a critical gap in regional studies of climate change impacts, as much of the existing literature is concentrated on more extensively studied areas such as East Africa or the Sahel.
3) **Wind Variables:** The significant finding regarding wind speed and direction is a novel contribution, highlighting the need for further research into these factors, which are often overlooked in favor of temperature and precipitation.

4.0. Conclusion

This study explored the impacts of climate variables and land use on crop yields in Southeast Nigeria, using a multivariate statistical analysis across the periods (1980-2002 and 2003-2024). The key findings reveal a significant influence of land use changes on crop yields in the earlier period, while wind speed and direction emerged as significant factors in the later period. The study also highlighted the importance of considering both statistical and practical significance in interpreting the results, ensuring that findings are not only statistically robust but also meaningful in practical terms. The multicollinearity analysis confirmed that the model's variables were not highly correlated, supporting the reliability of the coefficient estimates. Additionally, the findings align with and extend existing literature, providing region-specific insights and emphasizing the dynamic nature of climate and land use impacts over time. Overall, the study underscores the necessity for adaptive agricultural strategies to address the evolving challenges posed by climate change and land use dynamics.

5.0 Recommendation

These insights are crucial for policymakers, agricultural planners, and researchers aiming to enhance agricultural productivity and resilience in the face of changing environmental conditions. The results call for continued monitoring and research to inform sustainable agricultural practices in Southeast Nigeria and similar contexts globally

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