The Impact of Climate on Maize Yield in Chikun Local Government Area of Kaduna State, Nigeria

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Abstract

This study evaluated the impact of climate variability on maize production using 30 years-1994-2023-of meteorological and agricultural data in Chikun Local Government Area. The analysis of the trend was done using the Mann-Kendall test and Sen's slope estimator, while the influence of climatic variables on maize output was analyzed using multiple linear regression. Results showed that the increase in minimum temperature was statistically significant at Sen's slope ≈ +0.025°C per year (Mann-Kendall $p = 0.016$); the maximum temperature showed a slight increase that was not significant, with a Sen's slope ≈ +0.024°C per year ($p = 0.511$). There was a modest upward trend in annual rainfall of about +6.0 mm per year, though it was statistically insignificant at $p = 0.026$. Maize production had increased strongly and significantly, with a Sen's slope ≈ of +2,768 tonnes per year (Mann-Kendall $p < 0.0001$), though the year-to-year variability remained high, with a CV of about 31%. Maximum temperature, minimum temperature, and rainfall together explained about 21.5% of the variation in maize production, as indicated by the regression model with an Adjusted R^2 of 0.125. The partial effects were positive for minimum temperature-β = +28,241, $p = 0.070$, and rainfall-β = +32.97, $p = 0.112$, but negative for maximum temperature-β = -9,374.54, $p = 0.261$. However, these estimates were not statistically significant. This study concludes that climate factors influence maize production in Chikun but account for only a modest share of the variability, indicating the role of non-climatic factors. It is recommended that there is a need to strengthen climate-smart practices, improve access to inputs, and enhance agricultural extension services.

Keywords: Climate variability, Maize, Rainfall Trend, Chikun LGA, Kaduna State

INTRODUCTION

Climate plays a fundamental role in determining the productivity and sustainability of agricultural systems. It encompasses long-term patterns of temperature, rainfall, humidity, and other atmospheric conditions that influence crop performance. Among these elements, rainfall and temperature are the most critical climatic factors affecting crop growth and yield (Iizumi & Ramankutty, 2015). Rainfall provides the essential moisture required for seed germination, nutrient absorption, and overall plant development, while temperature regulates the physiological and biochemical processes that drive growth and grain formation (Haj Sghaier et al., 2022). Thus, any imbalance or fluctuation in these factors, such as prolonged dry spells, erratic rainfall patterns, or extreme heat, can significantly disrupt agricultural productivity.

In developing countries like Nigeria, where agriculture is largely rain-fed, the influence of rainfall and temperature variability is even more pronounced (Abubakar et al., 2024). Unpredictable rainfall patterns and increasing temperature trends have been linked to shifts in planting periods, shortened growing seasons, and declining soil moisture, all of which threaten crop yields and farmers' livelihoods (Sele et al., 2023). These climatic irregularities not only affect the timing of agricultural operations but also determine the success or failure of a farming season (Ariko et al., 2024). Consequently, understanding the interaction between these climatic factors and crop production has become a central concern for sustainable agricultural planning and food security.

On the other hand, maize (*Zea mays L.*) occupies a strategic position in Nigeria's agricultural and economic landscape. It serves as a staple food, a source of livestock feed, and a raw material for many agro-industries (Adeniyi & Yahaya, 2019). The crop is widely cultivated across various ecological zones due to its adaptability; however, it remains highly sensitive to fluctuations in rainfall and temperature (Sule et al., 2020). Optimal maize yield requires adequate moisture during germination and flowering, alongside moderate temperatures that support photosynthesis and grain development. Any deviation from these ideal conditions often results in yield reduction or total crop failure (Ibrahim et al., 2019).

In Chikun Local Government Area of Kaduna State, maize cultivation forms a major part of the farming system and local economy. Most farmers in the area and other parts of the state depend on seasonal rainfall for production, making maize yields highly susceptible to climate variability (Abubakar et al., 2024). However, in Kaduna State, and Chikun Local Government Area in particular, empirical evidence is limited as far as quantifying the effect of local trends in rainfall and temperature on maize yield is concerned. Therefore, this study tries to fill this gap by analyzing the impact of rainfall and temperature on maize production in Chikun LGA. By doing so, it seeks to develop location-specific evidence that can inform adaptive agriculture and enhance resilience to changing climatic conditions.

MATERIALS AND METHODS

Study Area and Location

The study was conducted in Chikun Local Government Area (LGA), one of the 23 Local Government Areas that make up Kaduna State, Nigeria, lying approximately between latitude 10°15′N and 10°45′N and longitude 7°15′E and 7°45′E, covering an estimated land area of 4,645 square kilometers. Chikun LGA is characterized by two distinct seasonal regimes, oscillating between cool to hot (dry season) non as the harmattan and humid to wet (rainy season). Temperature is highest around March and April and drops during the rainy months of July and August, as well as the harmattan months of December and February (Baba et al., 2020). Mean annual temperature in Chikun Local Government Area and across Kaduna is about 27°C, but daily temperatures could rise to about 38°C in hot months and could also fall to about 16°C in cooler months.

The relief of the area includes undulating landscape plains where the slope is greater than 5 degrees, plains dissected, and hilly landscapes dominate the relief. The valleys are broad and often stream less. While the streams have extensive flood plains and marshy lands (Gyuk et al., 2019). The major drainage that drains the study area is the River Kaduna and its tributaries, such as Rafin Giya in Kudenda, Romi River, Rimi, amongst others, that dot the area and stretch across Chikun and its adjoining areas (Musa & Okonkwo, 2017).

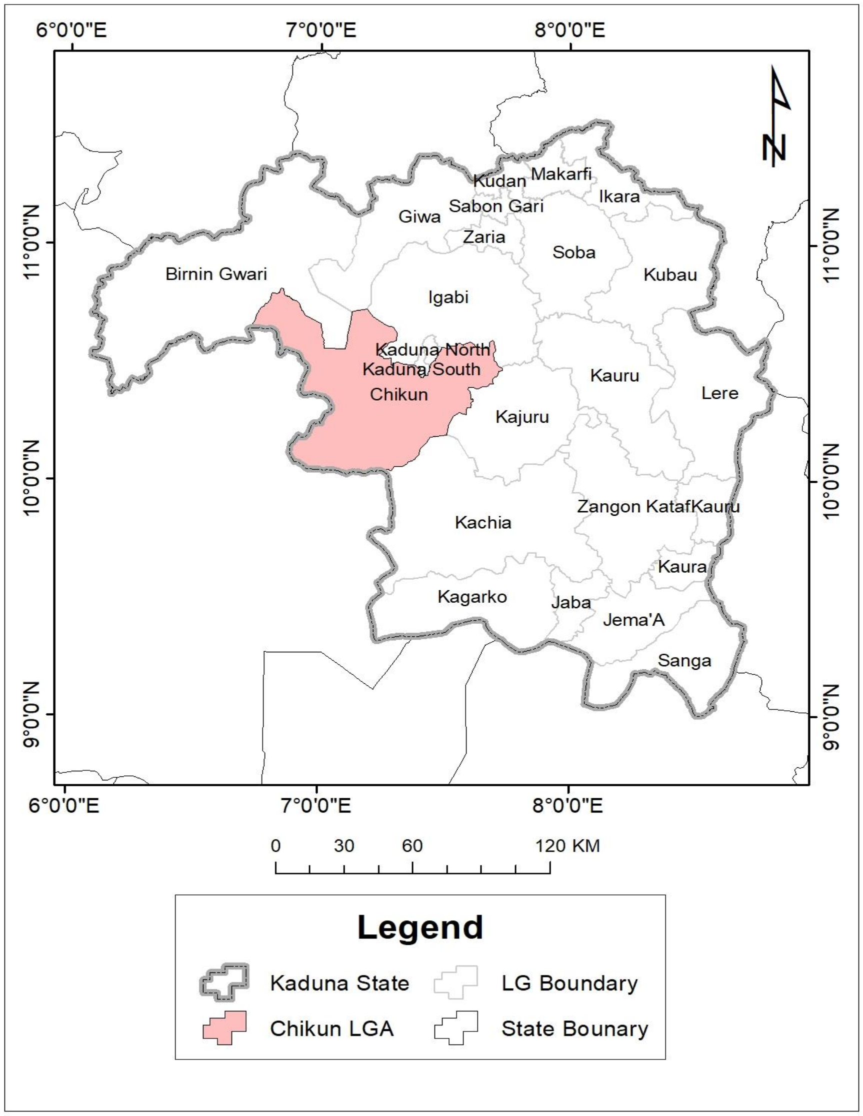


Figure 1: Map of Kaduna Showing Chikun Local Government Area

Source: GRID[3], 2023

Chikun LGA falls principally within the Guinea Savannah vegetation zone. Specifically, the vegetation of the area is characterized by grassland with scattered trees and shrubs (Abubakar & Abdussalam, 2024). Generally, the soil are typical red-brown to red-yellow tropical ferruginous soil. Those within the *fadamas* areas are richer in kaolinitic clay and organic matter, very heavy and poorly drained, which are characteristics of Vertisols (Abubakar & Abdussalam, 2024).

Agriculture is the predominant occupation of the people, and maize is one of the major staple crops cultivated alongside sorghum, millet, and groundnut. Due to its dependence on rainfall, maize production in the area is highly vulnerable to fluctuations in climatic conditions such as late rainfall onset, prolonged dry spells, and rising temperature extremes. This makes Chikun an ideal case study for investigating the effects of climate variability on maize yield (Yahaya & Mohammed, 2021).

Types and Sources of Data

The study utilized secondary data, drawn from reliable institutional and governmental sources. These data types and their corresponding sources are outlined in Table 1.

Table 1: Types and Sources of Data

Data Type	Variables	Source
Meteorological Data	Annual and monthly rainfall, minimum & maximum temperature	Nigerian Meteorological Agency (NiMet), Kaduna Office (1994–2023)
Agricultural Data	Maize yield (tonnes/hectare)	Kaduna State Ministry of Agriculture & Kaduna Agricultural Development Programme (KADP)
Supplementary Data	Literature on climate–crop interaction	FAO (2020), IPCC (2021), and related journal publications

Data Collection

Meteorological data, specifically annual rainfall and temperature records, were obtained from the Nigerian Meteorological Agency (NiMet), Kaduna Office. The data covered thirty years (1994–2023) and included variables such as total annual rainfall (in millimetres), mean monthly rainfall, and annual mean maximum and minimum temperatures (in degrees Celsius), while data on maize yield will be obtain from the Kaduna State Ministry of Agriculture and Forestry (KADMAF) and the Kaduna Agricultural Development Programme (KADP). These institutions maintain annual records on crop production, harvested area, and yield per hectare across the various local government areas. For consistency, the study will extract maize yield data (in tonnes per hectare) corresponding to the same thirty-year period as the climatic data.

Data Analysis

For trend and variability of climatic variables and maize yield, the Mann-Kendall trend test was used to examine the trend of rainfall, minimum and maximum temperatures in Chikun LGA, the Mann–Kendall trend test was used. The Mann–Kendall method (Kendall, 1948; Mann, 1945) is frequently used to identify patterns in time series data, especially in hydroclimatic studies. It is used to identify data that are not normally distributed and insensitive to outliers (Hamed, 2008). The null or alternative hypotheses are accepted or rejected. The null hypothesis states that there is no trend, whereas the alternative hypothesis states that the time series increases or decreases. The test statistic S is given as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i)$$

where n is the number of observations, x_i and x_j are the ith and jth $(j > i)$ observations in the time series, respectively, and $sgn(x_j - x_i)$ is the sign function computed as:

$$sgn(x_j - x_i) = \begin{cases} +1, if(x_j - x_i) > 0 \\ 0, if(x_j - x_i) > 0 \\ -1, if(x_i - x_j) > 0 \end{cases}$$

For the series where sample size n > 10, the test statistic S is considered to be asymptotically normally distributed, with mean $E(S)$ and variance $Var(S)$ as:

$E(S) = 0$, and

$$Var(S) = \frac{n(n-1)(2n+5)}{18}$$

The distribution of the statistics S tends toward normalcy when n is greater than 10, and there is a chance of a tie in the value of x (Kendall, 1948); thus, the variance is calculated using equation viii:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{m} t_k(t_k - 1)(2t_k + 5)}{18}$$

where m is the number of tied groups and t_k is the number of ties of extent k. The standard normal test statistic Z used for identifying a monotonic trend is given as Eq.:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, ifS > 0 \\ 0, ifS = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, ifS < 0 \end{cases}$$

In a two-tailed test, the null hypothesis of 'no trend' is accepted at the α significance level for $-Z_{1-\alpha/2} \leq Z \leq Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is the standard score (z score) of the standard normal distribution with a cumulative probability of 1 − α/2. Otherwise, the null hypothesis is rejected if a trend is detected at the α significance level. Hence, positive Z values indicate an upwards trend, while negative values indicate a downwards trend.

Sen's slope estimator is a nonparametric method that has been widely applied to determine slope trends in hydroclimatic time series (Bekele et al., 2017; Gocic & Trajkovic, 2013). It was developed by Sen (1968) and calculated using Eq.:

$$f(t) = Qt + B$$

In Eq. (9) above, *Qt* is the slope, and *B* is a constant. To estimate the slope (Q), the slopes (values) of the time series were computed using Eq.

$$\mathrm{Q}_i = \frac{X_j - X_k}{j - k}$$

where *Xj* and *Xk* are the values of the data at periods *j* and *k (j > k)*. If each period has a single datum, then $N = n(n-1)/2$, where n is the number of data points. If there are multiple observations in one or more periods, then $N < (n(n-1))/2$. Sen's slope estimator is calculated using Equation (xii):

$$Q_{med} = \begin{cases} Q * \left[\frac{(N+1)}{2}\right], if\ N\ is\ odd \\ \frac{Q * \left[\frac{N}{2}\right] + Q * \left[\frac{(N+2)}{2}\right]}{2}, if\ N\ is\ even \end{cases}$$

Finally, Q_{med} is applied using a nonparametric model to determine the trend and slope magnitude. A positive Qi indicates an upwards trend, and a negative Qi indicates a downwards trend. Likewise, if the value is zero, there is no trend.

For the variability of rainfall and temperature in Chikun LGA, this study used the Coefficient of Variation. To calculate the temporal variability, the coefficient of variation (CV) was calculated using equation (ii) below.

$$CV = \frac{\sigma}{\overline{X}} * 100$$

where σ is the standard deviation, and x¯ is the average rainfall data. Often, CV values below 20% are considered low, values between 20% and 30% are considered moderate, values between 30% and 40% are considered high, and values above 40% are considered very high (Abubakar et al., 2024).

To examine the influence of climate on maize production in Chikun LGA, this study applied multiple linear regression. The Multiple Linear Regression (MLR) model expresses the relationship between a dependent variable and two or more independent variables through a linear equation (Ahmed et al., 2024). The general formula is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta X_n + \varepsilon$$

Where: Y is the dependent variable, β is the intercept (value of Y when all predictors are zero), β_1, β_2, β_3, … , β_n are the regression coefficients representing the effect of each independent variable on Y. X_1, X_2, X_3, … ,X_n are the independent variables. Lastly, ε is the random error term accounting for unexplained variation. For this study,

$$\text{Yield} = \beta_0 + \beta_1(\text{Rainfall}) + \beta_2(\text{Tmin}) + \beta_3(\text{Tmax}) + \varepsilon$$

RESULTS AND DISCUSSION

Annual variability of maize yield and climatic variables

This study examined the annual variability of maize yield, rainfall, minimum and maximum temperatures in Chikun LGA. The result is shown in Table 2.

Table 2: Annual variability of maize yield and climatic variables

Variable	Minimum	Maximum	Mean	Std. deviation	CV
Maize	45899.00	135150.00	82292.73	25711.50	31.24
Tmax	28.43	32.79	30.46	1.20	3.93
Tmin	17.39	20.02	18.77	0.64	3.40
Rainfall	734.67	1649.17	1174.23	236.20	20.12

From Table 2, the minimum annual maize yield was 45,899 tonnes, the maximum 135,150 tonnes, and the mean 82,292 tonnes. The coefficient of variation (CV) was 31.24%, suggesting high variability. For the climatic variables, maximum temperature ranged from 28.43 ºC to 32.79 ºC, with an average of 30.46 ºC, and a standard deviation of 1.20. The minimum temperature ranged from 17.39 ºC to 20.02 ºC, with a mean Tmin of 18.77 ºC, and a standard deviation of 0.64 ºC. Rainfall ranged from 734.67 mm per annum to 1647.17 mm per annum. The mean annual rainfall was 1174.23 mm, with a standard deviation of 236.20 mm. For the climatic variables, maximum and minimum temperatures showed very low variability, 3.93% and 3.40%, respectively, while rainfall had moderate annual variability, 20.12%. This is in contrast with the findings of Abubakar et al. (2024), who found low variability of annual rainfall in Kaduna. Similarly, the highest annual rainfall is similar to the findings of Abaje et al. (2018), which revealed 1659.44 mm in the southern parts of Kaduna.

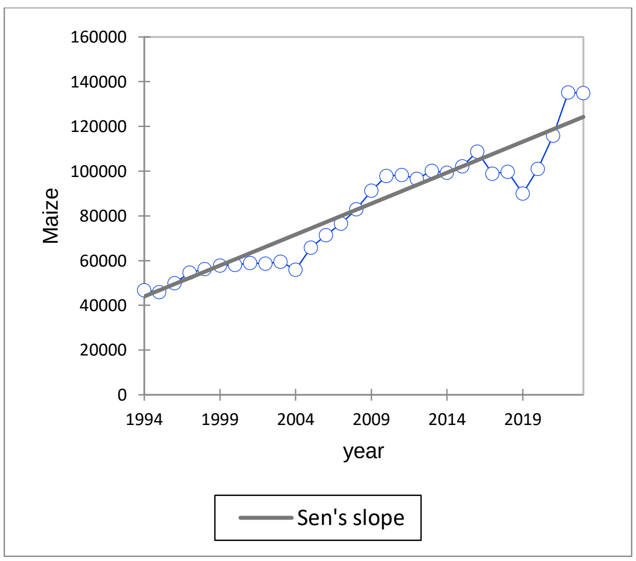
Trends of maize yields and climatic variables

The annual trend of maize yield, rainfall, maximum and minimum temperatures in Chikun LGA was assessed. The result is shown in Table 3 and Figure 2.

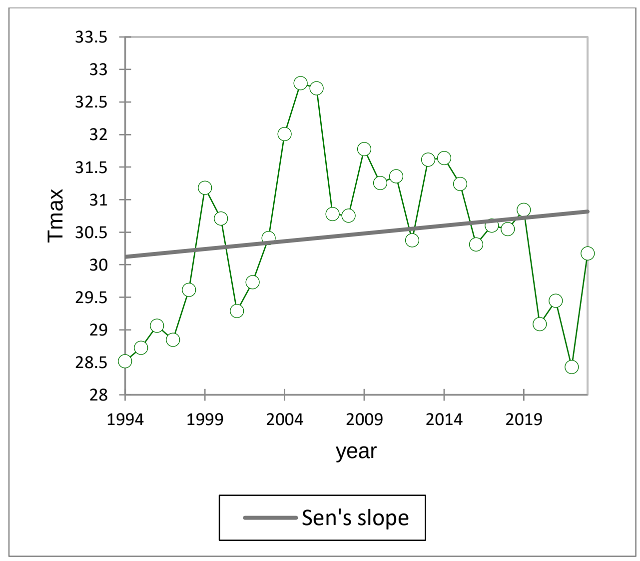
Table 3: Trend of maximum temperature

Variable	Kendall's tau	p-value	Sen's slope
Maize	0.857	**< 0.0001**	2768.167
Tmax	0.085	0.524	0.024
Tmin	0.246	0.058	0.025
Rainfall	0.143	0.269	6.000

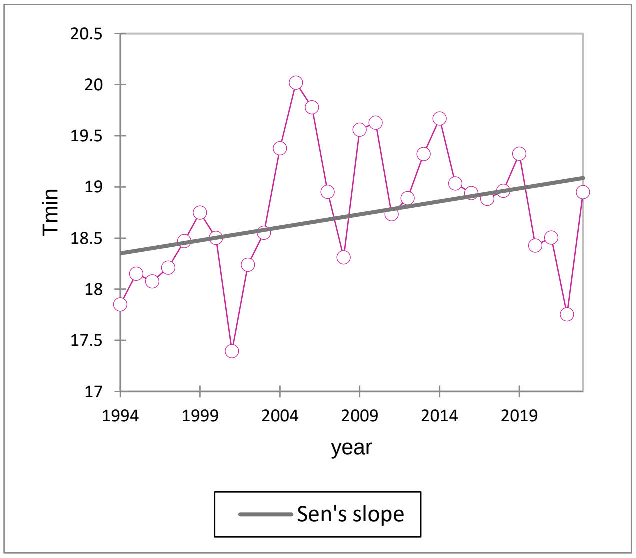
From Table 3, maize yield experienced a significantly increasing trend (tau = 0.857, p<0.0001), increasing at 2,768.17 tonnes per year. Maximum (tau=0.085) and minimum temperatures (tau=0.246) experienced nonsignificant increasing trends (p>0.05). A nonsignificant increase was also detected for annual rainfall (tau=0143, p>0.05) in Chikun LGA.



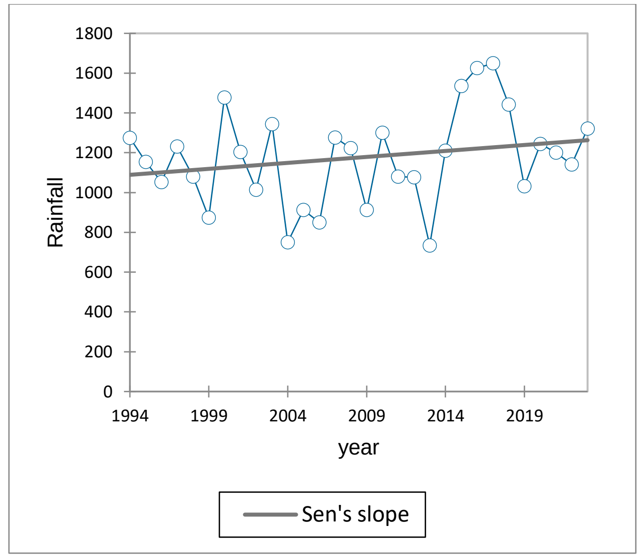
a) Maize yield



b) Maximum temperature



c) Minimum temperature



d) Rainfall

Figure 2: Annual trends of a) maize yield, b) maximum temperature, c) minimum temperature, and d) rainfall

Influence of climate on maize production

This study examined the linear relationship between maize and climatic variables in Chikun LGA using the Pearson correlation coefficient. The result is shown in Table 4.

Table 4: Correlation Matrix of Temperature, Rainfall, and Maize

Variables	Tmax	Tmin	Rainfall	Maize
Tmax	**1**	0.882	-0.324	0.084
Tmin	0.882	**1**	-0.245	0.242
Rainfall	-0.324	-0.245	**1**	0.272
Maize	0.084	0.242	0.272	**1**

From Table 4, rainfall had a modest positive correlation with annual rainfall (r=0.274), suggesting that higher annual precipitation moderately influences improved maize yields, consistent with the low rainfall nature of rainfed maize in semi-humid tropical regions of the Guinea savanna zone in Nigeria. The correlation between minimum temperature and maize yield is also weak (r=0.242), suggesting warmer nights slightly improve maize yields. However, the study found a very low correlation between maximum temperature and maize yields (0.084). This result is consistent with the findings of Ikpe et al. (2024), who found a positive relationship between total annual rainfall and maize yield (r = 0.19) in Benue State.

Table 5: Influence of climatic variables on Maize yield

Observations	30.000
Sum of weights	30.000
DF	26.000
R^2	0.215
Adjusted R^2	0.125
MSE	578717664.386
RMSE	24056.551
MAPE	23.871
DW	0.506
Cp	4.000
AIC	608.997

Table 5 revealed that rainfall, maximum and minimum temperatures explain 21.5% of the total variability of maize yield ($R^2 = 0.215$) in Chikun LGA of Kaduna State. The R^2 aligns with the weak linear relationships exhibited ($r = 0.08–0.27$). Similar studies, such as Dimes et al. (2015), reported that other factors, such as poor soil fertility and cropping system play a significant role in determining crop yield in Africa. Similarly, Atiah et al. (2022) in a study in Ghana found that climatic parameters account for 40.8% of maize yield under drier-than-normal rainfall conditions in the country. This result is illustrated in Figure 3.

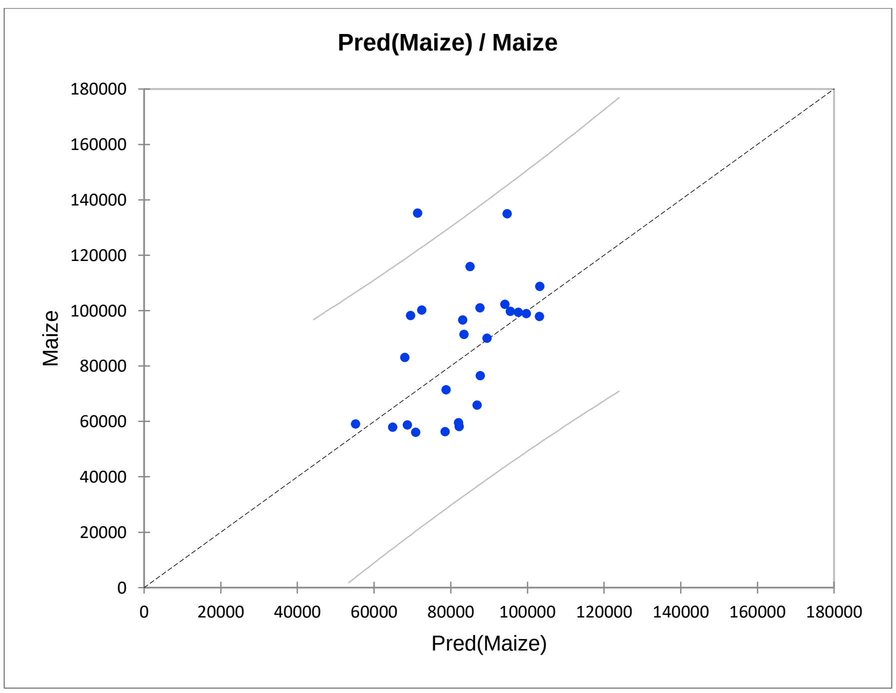


Figure 3: Linear regression between predictors (rainfall, tmin, tmax) and dependent (maize yield)

CONCLUSIONS

These findings lead to the conclusion that climate variability has a measurable but modest role in maize productivity in Chikun Local Government Area. Increasing minimum temperature and rainfall appear to favour maize productivity, while high maximum temperatures may create risks. However, the generally weak statistical power of climate variables in explaining maize productivity suggests that farm-level adaptations, such as improved farming techniques and seed varieties, have a greater influence.

The implication of the upward trend in maize production suggests that farmers are coping with the changing climatic conditions, or agricultural support and inputs are improving. Climate remains an important factor, but does not fully determine yield outcomes. Sustainable agricultural development in the study area, therefore, requires a holistic approach that considers both climatic and non-climatic influences.

Based on the findings of this study, the following recommendations are proposed:

i. The stakeholders in agriculture should involve climate information in farming decisions to reduce vulnerability to changing temperatures and rainfall.
ii. Improved access to seed varieties, including climate-smart technologies, could be strengthened as part of building resilience and productivity.
iii. Extension services need to scale up training in sustainable agronomic practices that can help farmers cope better with climatic risks. iv. Policy makers should invest in reliable climate monitoring systems and ensure that such information is made readily available to farmers.
iv. The Government, both state and federal, in cooperation with the local government, should support research, farmer education, and timely weather advisory services; this will go a long way toward minimizing adverse impacts of climatic variability on maize production.

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