

IMPACT OF CLIMATE CHANGE ON CROP PRODUCTION IN GOMBE STATE, NIGERIA

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Abstract

Climate change is accompanied by a number of changes in temperature, rainfall, relative humidity, and other climate extremes. This is further compounded by drought and flooding, which bring about changes in crop productivity. The impact of climate change on crop production in Gombe state, Nigeria, was investigated in this study. The study employed secondary data from the Gombe State meteorological weather station, the Upper Benue River Basin Development Authority Dadin-Kowa, and the Gombe State Agricultural Development Programme from 1996 to 2017. The data was analysed using descriptive statistics and the Autoregressive Distributive Lag (ARDL) Bounds technique for cointegration. The outcome showed that climatic factors (temperature, relative humidity, and rainfall) have a major impact on crop yield in the long- and short run. The study recommends that, to mitigate the consequences of climate change, the use of ecologically friendly agricultural methods should be encouraged.

Keywords: climate change, crop production, autoregressive distributive lag bounds approach.

Introduction

Climate change has been at the forefront of the United Nations discourse for quite some time. The priority given to it may not be unconnected with the happenings across the globe in terms of weather and other environmental externalities. Issues related to environmental externalities such as bush burning, deforestation, fertiliser application and other agrochemicals for the purpose of agricultural production, combustion of fossil fuels and concentration of carbon dioxide (CO₂) are some of the factors that may likely lead to changes in climate. Climate change itself could have a direct bearing on agricultural output. Depending on the nature of the change, it could ultimately reflect on food availability.

In recent decades, agriculture has been the backbone of the majority of Nigerian households and a key determinant of the country's economy. Agriculture employs more than 60% of the population in the country. Agriculture's importance cannot be overstated, since it is the primary source of food production, contributes to GDP, provides work for a growing population, supplies raw materials to agro-allied businesses, and generates foreign earnings. Despite this, food crop production is an important element of Nigeria's agricultural output and exports (Eregba, Babatolu, and Akinnubi, 2014).

Crop production is largely dependent on natural environmental resources. Crop productivity is influenced by a variety of factors, including soil, relief, diseases, and

climate, to name but a few (Akomolafe, Awoyemi, and Babatunde, 2018). In relation to climate, the main elements are temperature, rainfall, wind, solar radiation, and relative humidity, among others. As such, climate elements constitute important factors that determine the performance of not only crops but also agricultural productivity. However, according to a report published by the Food and Agricultural Organisation in 2004, poor countries lose about 25% of their cereals, 35% of their roots and tubers, and 53% of their fruits due to climatic instability.

Climate change may result in instabilities in temperature and rainfall patterns, which could have an impact on planting and harvesting schedules. As a result, extreme weather events such as heatwaves, heavy rains, or drought can disrupt crop productivity and impair pesticide efficacy and longevity. There are indeed obvious threats that may easily trigger climate change and these include; natural disasters, human pressure on arable land, demographic explosion, environmental pollution as well as deforestation, which could possibly affect the development process and yields of agricultural products (FAO, 2007).

Gombe state is naturally endowed with agricultural potential that promotes safe, adequate, and quality food crop production. However, the sufficiency or otherwise of crop production could be attributable to climate change-related hazards which seem to undermine food availability. In a bid to enhance food crop production, successive governments have formulated and implemented policies/programmes to ensure that there is adequate food for the citizens. Despite the said governmental commitments, the programmes could not yield the desired results due to unsteady or variability in rainfall and temperature, which brings about flooding or drought, among other forms of climate change. Climate change and crop production have been the subjects of numerous studies. For

example, Tingam, Rivington, Bellocchi, Azm-Ali, and Colls (2008) investigated the effect of climate change on crop production in Cameroon; Eregha, Babatolu, and Akinnubi (2014) empirically examined the effect of climate change on crop production in Nigeria; Mikova, Makufa, and Kayumba (2015) studied the effects of climate change on crop production in Rwanda; Saravanakumar (2015) examined the impact of climate change on the yield of major food crops in Tamil Nadu, India; Agba, Adewara, Adama, Adzer, and Atoyobi, (2017) explored the effect of climate change on crop output in Nigeria; Akomolafe, Awoyemi, and Babatunde (2018) investigated climate change and its effects on agricultural output in Nigeria. Also, Chandia, Ozturk, Akram, Ahmed, and Mirani (2020) studied the empirical analysis of climate change factors affecting cereal yield in Turkey. All these studies focused on the national outlook, which is more or less a macro-level assessment. Hence, an understanding of the influence of climate change on crop production is needed at a micro-level in a way that would address a specific geographical location. To address the aforementioned gap, thus this research examines the impact of climate change on crop production in Gombe State, Nigeria.

Literature Review

Conceptual Issues

According to the United Nations Framework Convention on Climate Change (UNFCCC), "climate change" means a change in the climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (UNFCCC 2007; Agba, Adewara, Adama, Adzer, and Atoyobi, 2017).

Weather data collected over a 30-year period is referred to as "climate statistics." Temperature, relative humidity, solar radiation, wind, precipitation, atmospheric

particle counts, and other meteorological parameters in a given region are tracked over time to determine it (Caray, 2009). There is a significant difference between climate and weather; weather only refers to the short-term status of the aforementioned components over a given time period. Climate change is defined as an increase in global temperature caused by the release of gases into the atmosphere such as carbon dioxide (CO₂), methane (CH₄), chlorofluorocarbons (CFCs), nitrous oxide (N₂O), and ozone (O₃) (IPCC, 2007).

Crop production, on the other hand, is the branch of agriculture concerned with the cultivation of food and fiber crops. It is influenced by a number of elements, including yields, macroeconomic instability, and consumer preferences, and it also has a significant impact on agricultural commodity prices. Crop production is calculated using the harvested area, returns per hectare, and quantity produced. Crop yields refer to how much crop product is harvested per unit of farmed land. Yield data is most commonly derived by dividing production data by harvested area data. The genetic potential of the crop, the amount of sunlight, water, and nutrients taken in by the crop, the presence of weeds and pests, and other factors all influence the actual yield harvested on the farm. Crop yields are measured in tons per hectare, thousands of hectares, and thousands of tons (OECD, 2017; Agba, Adewara, Adama, Adzer, and Atoyebi, 2017).

Empirical Review

Literature can be classified according to their methodological approaches: crop modelling (production function) approach, mathematical programming, the Ricardian approach and the Econometric approach. Although the econometric approach is newer, it has been the field with the fastest growth rate. Many researchers have used time series and panel data models to study this relationship after the pioneering work by Auffhammer, Ramanathan, and Vincent (2006), who investigated the effects of

climate change on crop yield. In this study, we followed tradition and examined our major research target using time-series econometrics approaches.

Various initiatives to explore the impacts of climate change on agricultural productivity have been launched, with the bulk of this research using diverse methodologies. Using annual time series data from 1980-2016, Chandio, Gokmenoglu, and Ahmad (2021) examined the long-run and short-run effects of climate change on major food crop production in Turkey. The ARDL approach to cointegration and Johansen and the Julius Cointegration (JJC) test were used, and the results revealed that CO₂ emissions and temperature have a negative impact on wheat production in both the long and short-runs, whereas precipitation has a positive impact in all periods. The results suggest that non-climatic factors like harvested wheat crop area and domestic credit have a favourable impact on wheat output in both the short and long-run. Furthermore, the findings demonstrated that CO₂ emissions had a negative impact on rice output in both scenarios. Temperature has no effect on rice output, although precipitation improves it in both seasons. In addition, the VECM Granger causality results for rice and wheat production reveal that both climatic and non-climatic variables have a considerable impact on both crops` output.

In Turkey, Chandio, Ozturk, Akram, Ahmed and Mirani (2020) looked into the empirical examination of climate change elements affecting cereal yield. Annual time-series data was used from 1968 to 2014. The autoregressive distributed lag (ARDL) bounds approach and the Granger Causality test were used to represent the dynamic relationship between the variables throughout the chosen time interval. The findings showed that climate change factors and cereal yield have a long-run equilibrium relationship. CO₂ emissions and temperature have variable effects on cereal output, but rainfall has a positive long-term

and short-term influence on cereal yield. The Granger causality test reveals that climate change variables have a considerable impact on cereal yield. Temperature and rainfall variables appear to have a unidirectional causal relationship. As a result, the findings show that climate variables like rainfall and temperature, as well as land and labor, have a bigger influence on cereal production than land and labor. According to the findings, agricultural research and development should focus on cereal crop varieties that can endure high temperatures and rain.

In the Southwest of Nigeria, Oparinde and Okogbue (2018) explored climate-related risk and maize production. The Autoregressive distributive lag model, Growth function, and J-P model were used to analyse the data from 1981 to 2012. The findings revealed that maize production, rainfall, temperature, and relative humidity are all in a long-run equilibrium. Furthermore, the climate-related risk study found that increasing temperatures increased the risk of maize farmers' production. It concluded that farmers face climate-related risk, as rising temperatures increased the risk of maize farmers' production in the study area.

Agba, Adewara, Adama, Adzer, and Atoyebi (2017) looked into the effects of climate change factors and non-climate change factors on crop output in Nigeria. Annual time-series data from 1980 to 2013 was used. An Error correction mechanism was applied to the analysis. It was found that only rainfall, among the change components, was determined to be considerably favourable to crop productivity in the short run. Climate change variables such as temperature, carbon dioxide, and emissions from manufacturing and industrial operations, however, have been shown to have a small impact on crop output over time. Other crop production drivers, such as gross capital formation, and economically active population in agriculture, and land area

equipped for irrigation, will have a significant positive impact on crop productivity in Nigeria in the long run, with only agricultural tractors and machinery having a minor negative impact.

Obasi and Uwanekwu (2015) studied the effects of climate change on maize production in Nigeria. Using data from 1980 to 2010. Descriptive tools and Ordinary Least Square Regression models were used to analyse the data. The study revealed that climate change has a major impact on maize crop productivity in Nigeria. The study found that as temperature and rainfall increased, there were increases in the output of maize, which may have been induced by climate change. As a result, the study came to the conclusion that climate variability is a significant factor in agricultural output in Nigeria.

Eregha, Babatolu, and Akinnubi (2014) used an error correction modelling approach to investigate the effects of climate change and crop production in Nigeria from 1970-2009. The study used three climate parameters, namely: temperature, rainfall, and carbon in the atmosphere. Maize, beans, millet, rice, sorghum, yam, groundnut, cocoa, cassava, and potato were among the ten crops chosen for the study. An error correction technique was applied for the data analysis. According to the findings, the impact of climate variables on agricultural yield varies depending on the type of crop, season, and crop day duration. This is inferred from the fact that some seasonal crops gathered during the rainy season have been proven to be negatively affected by rainfall. During the study period, carbon emissions in the atmosphere were discovered to have influenced the productivity of almost all the crops. The study recommends that various mitigation and adaptation strategies necessary for increased output of these crops should be adopted by farmers.

Akinseye, Ogunjobi, and Okogbue (2012) studied climate variability and food crop

production in Nigeria. Using bivariate correlation and multiple regression models to investigate the relationship between crop yields, precipitation, and temperature from 1971 to 2005. The result showed a significant low trend in both seasonal and annual means in temperature. The correlation coefficient between monthly rainfall, growing season temperature and crop yield shows the importance of onset and cessation of rainfall as it affects the growth and development and yield maturity of crops, which in-turn measures the level of sensitivity of crops to climate variables employed.

The retrospective causal relationship between climate variability and crop production in Nigeria was investigated by Oyinbo, Adegboye, and Sulaiman (2012) using time series data from 1970 to 2008. For data analysis, the Vector Auto-regression (VAR) lag order selection test and Granger Causality test were employed. The findings revealed a bidirectional association between climate variability and crop production, implying that climate variability had a major impact on crop production and crop production activities had a considerable impact on climate variability over the study period. The study recommends that a policy framework should be set up to ensure proper sensitization of farmers on coping strategies to adopt in response to climate variability so as to ensure sustainable crop production towards achieving the goals of the agricultural transformation agenda of Nigeria.

Aondoakaa (2012) investigated the impact of climate change dynamics on agricultural production in the FCT (Abuja) from 2000 to 2009, using some measure of central tendency to link the relationship between rainfall, temperature, and crop yield. The study showed that there is a positive association between each climate element and crop yield, but it is only marginally significant, and that temperatures have been steadily rising over the years, with the peak

being 35°C in 2009. There has been a drop in rainfall over the years, resulting in a subsequent decline in crop productivity. Ayinde, Muchie and Olatunji (2011) used time-series data from 1980 to 2005 to investigate the effect of climate change on agricultural productivity in Nigeria. Descriptive statistics and cointegration were used for the analysis. The findings revealed that temperature has a detrimental impact on agricultural productivity, whereas rainfall has a favourable impact. The study concluded that climate change has a significant impact on agricultural output in Nigeria.

Methodology

Study Area

The selected area for study is Gombe State, Nigeria. It lies in the Centre of the Northeast geopolitical zone. The Greenwich Meridian runs through the State, with latitude 10°17`N and longitude 11°09`E. It has a land area of 20,265km² and is bordered on the West by Bauchi State, on the South by Adamawa and Taraba States, on the East by Borno and North by Yobe State (Saidu, 2013). Gombe State had by 2006, a population of 2,365,040 people, 1,244,238 males and 1,120,802 females, the population was projected to be 3,370,903 in 2017 at a rate of 3% each year. Its lowest and highest altitudes are 793 meters above sea level at Deba and 2,939 meters above sea level at Kushi, respectively, with maximum and minimum temperatures of 39.8 and 32.1 degrees (NPC, 2006). The State's rainfall is unimodal, with an annual average of 880mm and a mean of 12 days per month. This number of rainy days could be attributed to a dry spell that used to occur around July-August, resulting in low crop yield. From April to October, there was a significant amount of rain. The State was characterised by savanna grassland, with occasional woody trees varying in height from 2m to 8.5m.

Data Description

The study's data came from secondary sources and were obtained from published

works, for example, data from Gombe State Meteorological Weather Station, Upper Benue River Basin Development Authority, Dadin-Kowa on climate parameters (relative humidity, rainfall and temperature) and Nation Bureau of statistics as well as Gombe State Agricultural Development Programme for data on food crop production (like maize and the cultivated land per hectare). The study uses quarterly seasonal unadjusted data spanning from a period of 1997Q1 to 2017Q4. The reason for chosen quarterly data period was because Gombe State was created in 1996 and data became readily available from 1997.

Analytical Procedure

The studies were analysed using descriptive statistics and a cointegration approach based on Autoregressive Distributive Lag (ARDL) Bounds. The ARDL cointegration methodology provides a number of advantages over other cointegration methods established by Pesaran, Shin, and Smith (2001):

- It can be used whether the variables being studied are purely cointegrated at I(0), I(1), or a combination of both integration orders,
- The method can be used with small sample sizes,
- The method estimated both long- and short-term cointegration relationships at the same time.

Model Specification

The model guiding this study was adopted and modified from the work of Oparinde and Okogbue (2018); Eregha, Babatolu and Akinnubi (2014). With the exception of relative humidity (RHDT), which utilises percentage (%) as its unit of measurement, all variables were converted to natural-log form to make the equation estimable due to variances in units of measurement. This aids in the analysis of the dependent variable's elasticity in relation to any of the regressors.

Pre-estimation test

The study employed Augmented Dickey-Fuller (ADF) to assess the stationarity level of the data set to avoid the problem of spurious regression, which is frequent in time series analysis of nonstationary variables. The model for detecting the presence of a unit root is as follows:

$$\Delta Y = \beta_0 + \beta_1 t + \delta Y_{t-1} + \sum_{i=1}^n \alpha_i \Delta Y_{t-i} + \mu_t \quad \text{--- (1)}$$

ARDL Approach to Regression

To evaluate the effect of the dependent variable (food crop production) on the independent variable (climate change). The dependent variable, which is food crop production, was expressed in kilograms (kg) or metric tons (mt) of product per hectare (ha). Estimating crop yield involves calculating both the crop area and the quantity of product produced from that area. Hence, crop yield equals the amount of harvested product divided by the crop area (Fermont and Benson, 2011). The independent variables include data on relative humidity, rainfall, and temperature. The following is the link between crop yield and selected climatic variables:

$$CRPY = f(RNFL_t, TEMP_t, RHDT_t) \quad \text{--- (2)}$$

The model's functional form will be as follows:

$$CPRY = \beta_0 + \beta_1 RNFL_t + \beta_2 TEMP_t + \beta_3 RHDT_t + \varepsilon_t \quad \text{--- (3)}$$

The study employed all the variables in their natural logarithmic form to reduce the multicollinearity and volatility of the annual time series data. A log-linear model is stated as follows by applying the natural logarithm to equation (3):

$$\log CPRY = \beta_0 + \beta_1 \log RNFL_t + \beta_2 \log TEMP_t + \beta_3 RHDT_t + \varepsilon_t \quad \text{--- (4)}$$

where:
 CRPY = Crop yield/output
 TMP =Average temperature (degree Celsius), RNF = Rainfall (mm), RHD =

Relative humidity (%), ln=Natural logarithm,

β_0 = Constant term, ε_t = White noise: error term.

Crop output's long-run elasticity with respect to rainfall, relative humidity, and temperature are represented by parameters $\beta_1 - \beta_3$, respectively.

Thus, Autoregressive Distributed Lag bound testing approach developed by Pesaran and Shin (1999) and Pesaran, Shin and Smith (2001), as used by Oparinda and Okogbue, (2018); Agba, Adewara, Adama, Adzer, and Atoyobi, (2017) and Eregha, Babatolu and Akinnubi (2014) was adopted to determine the long-term association between the output of crop production, rainfall, relative humidity, and temperature.

The ARDL approach is mathematically represented as follows:

$$\Delta \ln CRPY_t = \beta_0 + \beta_1 \sum_{i=1}^n \Delta \ln CRPY_{t-1} + \beta_2 \sum_{i=0}^n \Delta \ln RNFL_{t-i} + \beta_3 \sum_{i=0}^n \Delta \ln TEMP_{t-i} + \beta_4 \sum_{i=0}^n \Delta RHDT_{t-i} + \beta_5 \ln CRPY_{t-i} + \beta_6 \ln RNFL_{t-i} + \beta_7 \ln TEMP_{t-i} + \beta_8 RHDT_{t-i} + \varepsilon_t \quad (5)$$

Where: Δ represent change (first difference); n is the optimal delay lengths.

The significance of the lagged levels of variables is tested using the F-statistic or Wald-coefficient test to see if there is a cointegration relationship between the variables in equation (4).

Pesaran et al. (2001) proposed testing $H_0: \beta_5 = \beta_6 = \beta_7 = \beta_8 = 0$, which implies the absence of cointegration, against $H_1: \beta_5 \neq \beta_6 \neq \beta_7 \neq \beta_8 \neq 0$, which implies the existence of cointegration among variables.

There are two steps to the ARDL approach. The first step is to use the F-statistic or Wald-coefficient test to see if there is a long-run cointegration relationship between the variables, then compare the critical values put out by Pesaran et al. (2001). According to Pesaran, Shin, and Smith

(2001), lower and upper bounds are two types of critical values. The lower-bounds critical values indicate vital values for I (0) variables, while upper-bounds critical values describe critical values for I (1) variables. If the estimated F-statistics is greater than the upper-bound critical value, the null hypothesis of no cointegration is rejected, showing evidence of long-run equilibrium between the variables regardless of the order in which they are integrated. We cannot reject the null hypothesis of cointegration if the calculated F-statistic is less than the lower-bound critical value, implying that there is no long-run equilibrium link.

Without knowing the sequence of integration of the underlying regressors, it is impossible to make a conclusive inference if the estimated F-statistics are between lower and upper-bounds critical values. The estimation of long and short-run coefficients is the second step.

The long-term relationship is estimated using the conditional ARDL model, which is defined as:

$$\ln CRPY_t = \beta_0 + \beta_1 \ln CRPY_t + \beta_2 \ln RNFL_t + \beta_3 \ln TEMP_t + \beta_4 RHDT_t + \varepsilon_t \quad (6)$$

Where: $\beta_1 - \beta_4$ = long-run elasticity (coefficients of the explanatory variables).

An error correction model is used to estimate the short-run dynamic relationship, which is specified as:

$$\Delta \ln CRPY_t = \beta_0 + \beta_1 \sum_{t=1}^n \Delta \ln CRPY_{t-i} + \beta_2 \sum_{i=0}^n \Delta \ln RNFL_{t-i} + \beta_3 \sum_{i=0}^n \Delta \ln TEMP_{t-i} + \beta_4 \sum_{i=0}^n \Delta RHDT_{t-i} + ecm_{t-1} + \varepsilon_t \quad (7)$$

where: $\beta_1 - \beta_4$ = Short-run elasticities (coefficients of the first-differenced explanatory variables); Ecm (-1) term= is a lagged value of the residual of the model in which the long term relationship is derived. Ecm (-1) denotes the speed of the adjustment parameter, which is expected to be negative and statistically significant.

Variables Definition and Units of Measurement

Variables	Definition	Unit of measurement
COPY	Crop yield = Output food crop production	Metric tons/kilogram
RNFL	Annual rainfall	Millilitre (mm)
TEMP	Annual temperature	Degree centigrade °C
RHDT	Mean annual relative humidity	Percentage (%)

Result and Discussions***Descriptive Statistics***

The data for the study is summarised in Table 1. The variables employed in the

research were annual time series data but were converted to quarterly frequencies for convenience purposes.

Table 1: Descriptive Statistics

	CARY	TEMP	RNFL	RHDT
Mean	248.19	34.29	909.1	48.47
Median	174.51	34.83	897.3	48.67
Maximum	526.9	35.92	1119.3	55.08
Minimum	78.94	31.67	724.8	44.33
Std. Dev.	172.66	1.34	102.74	2.68
Skewness	0.85	-0.40	0.33	0.69
Kurtosis	1.88	1.80	2.45	3.35
Jarque-Bera	3.66	1.83	3.62	7.39
Probability	0.16	1.83	0.64	1.81
Sum	51211	720.18	19091.5	1017.9
Sum Sq. Dev.	596295	36.27	21113	143.69
Observations	80	80	80	80

Notes: CARY, TEMP, RNFL and RHDT refer, respectively to the crop yield, temperature, rainfall and relative humidity.

Crop yield (CRPY) has a maximum value of 526.9mt (000) and a minimum value of 78.94mt (000), with a mean value of 248.1, as shown in table 1. The standard deviation value of 172.7 indicates the degree of dispersion of CRPY, while the skewness value of 0.85 indicates that the variable is positively skewed and platykurtic (because $1.88 < 3$). The Jarque-Bera value of 3.66 and the probability value of 0.16 suggest that the variable CRPY is normally distributed. The temperature (TEMP) reached a maximum of 35.92°C and a minimum of 31.67°C during the study period, with a mean of 34.29 °C. The standard deviation value of 1.34 indicates that the temperature is dispersed, while the skewness value of -0.40 indicates that the variable is skewed negative (has a long-left tail) and platykurtic (because $1.80 < 3$). The variable TEMP is normally distributed, as evidenced by the Jarque-Bera value of 1.83 and the probability value of 1.83.

The mean value of rainfall (RNFL) is 909mm, with a maximum of 897mm and a minimum value of 724mm. The standard deviation value of 2111.3 indicates the RNFL measure of dispersion, while the skewness value of 0.33 indicates that the variable is positively skewed (has a long-right tail) and leptokurtic (because $3.11 > 3$). The Jarque-Bera value of 3.62 and the probability value of 0.64 indicated that the variable for RNFL is normally distributed. Furthermore, the mean value of relative humidity (RHDT) is 48.47, with a maximum value of 55.08% and a minimum value of 44.33%. The standard deviation value of 2.68 represents the measure of dispersion of RHDT, while the skewness value of 0.69 indicates that the variable is positively skewed (has a long-right tail) and leptokurtic (because $3.35 > 3$). The Jarque-Bera value of 7.39 and the probability value of 1.81 indicate that the null hypothesis for RHDT is normally distributed.

Trend Showing the Yearly Impact Between Crop Yield and Climate Parameters (Temperature, Rainfall and Relative humidity)

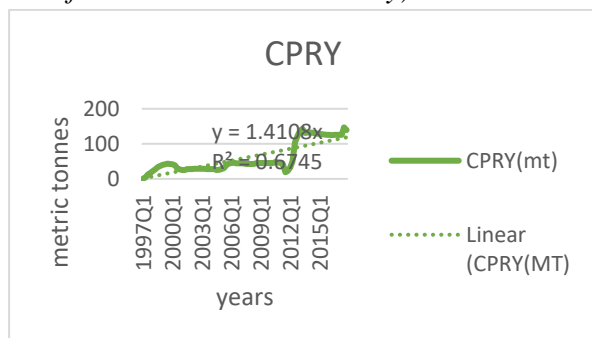


Figure 1 Crop Output Trend

As shown in Figure 1, the green line represents the annual crop output, and the dotted line represents the line trend of annual crop output in the period under study. There is persistent reduction in crop yield between 2000 to 2004 in the study area, since then crop yield has been experiencing unsteady trend. This is as a result of variability in climate parameters. The blue line in Figure 2 represents the

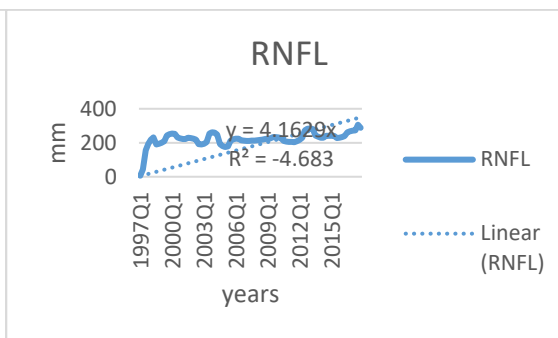


Figure 2 Rainfall Trend

annual rainfall and the dotted line depicts the annual rainfall trend in the period under investigation. Rainfall fluctuation and unreliability are common in Gombe State, especially over the years investigated. The lowest point in time was in 2005, and the highest was in 2012. This implies that climate change has been observed, particularly since 1997.

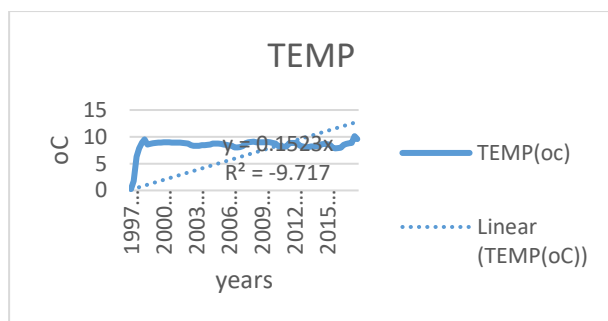


Figure 3 Temperature Trend

Figure 3 illustrates that temperatures do not remain roughly consistent across the study period. In 2015, the yearly temperature in Gombe State dropped dramatically, and since then it has been fluctuating. The variation in the temperature variable across the study period is as a result of changes in the climate, and this may have a significant impact on crop growth and development. Figure 4 shows that there are substantial fluctuations in relative humidity in the study area. The period from 2012 to 2014 experienced the lowest relative humidity, while the highest was experienced around 1998, and this implies that there is evidence

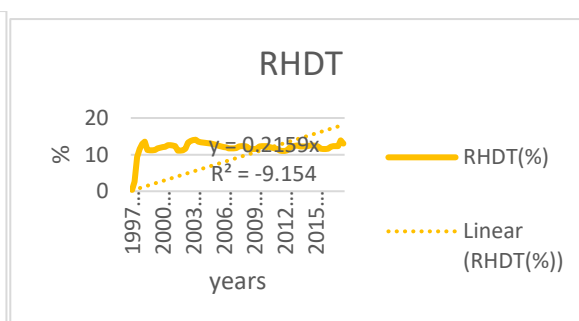


Figure 4 Relative Humidity Trend

of changes in relative humidity since 1998, and this may not be unconnected with the changes in climate.

Unit Root Test

As one of the pre-requisite in estimating time series models. Table 6 shows the ADF (Augmented Dickey-Fuller) unit root test estimates for all the variables. These comprises of crop yield (CPRY), temperature (TEMP), rainfall (RNFL) and Relative humidity (RHDT). Due to variation in unit of measurement the variables were all transformed into natural-log form to make the equation estimable.

Table 2: Unit Root Test with Augmented Dickey-Fuller (ADF)

Series	ADF Statistics	Critical value	No. of diff	Prob.
lnCRPY	-6.1318	-3.5203***	I(1)	0.0000
lnRNFL	-3.1211	-3.5215**	I(0)	0.0292
lnTEMP	4.4411	-3.5166***	I(0)	0.0005
RHDT	-3.6502	-3.5166***	I(0)	0.0068

Note: ***, ** and * represent significance at 1%, 5% and 10% respectively.

Source: Author`s Computation

Table 2 demonstrates that the LNTEMP, LNRNFL, and RHDT series were stationary at levels at the conventional 1% and 5% levels of significance, except for LNCPRY, which was found to be stationary after first varying at a 1% level of significance, according to the ADF results. Hence, due to the series not being integrated in the same order, the study used an Autoregressive Distributed Lag (ARDL) Bound technique. The ARDL technique is the appropriate method of estimating the relation where the dependent and independent variables are made up of a mixture of I (0) and I (1) as

used by Pesaran, Shin and Smith (2001). In small sample sizes, such as this study, the ARDL model is more efficient. It can be used to calculate both short- and long-run coefficients simultaneously.

Bounds Cointegration Test

The bounds testing approach was used to determine if there is a cointegration relationship among the variables in the ARDL model, and the findings are displayed in table 3. The test confirmed the existence of three cointegration vectors among the four-vectorvectors.

Table 3: ARDL Bounds Test for Cointegration

Model	F-Stat.	Sig. Level.	Critical Value	
			I(0)	I(1)
$lnCPRY = F(lnTEMP, LNRNFL, RHDT)$	4.4599***	10%	2.72	3.77
$lnTEMP = F(lnCPRY, LNRNFL, RHDT)$	3.8243****	5%	3.23	4.35
$lnRNFL = F(lnCPRY, LNTEMP, RHDT)$	5.7733*	2.5%	3.69	4.89
$RHDT = F(lnCRPY, LNTEMP, LNRNFL)$	1.6867	1%	4.29	5.61

Note: *, **, *** and **** represent significance level at 1%, 2.5%, 5% and 10% respectively.

Source: Author`s Computation

The null hypothesis of no cointegration between temperature, rainfall, and relative humidity is rejected at a 5% level of significance when crop yield is the dependent variable. This is because the F-statistics of 4.46 is higher than the upper critical value of 4.35, showing that lnTEMP, lnRNFL, RHDT, and lnCRPY are cointegrated. In Table 3, cointegration exists at 10% when lnTEMP is considered as the dependent variable. This is because the F-statistics of 3.82 is higher than the upper critical value of 3.77, denoting the existence of cointegration. Similarly, the null hypothesis of no cointegration is rejected at 1% when lnRNFL is considered as the dependent variable. This is because

the F-statistics of 5.77 is greater than the upper critical value of 5.61 at 1%, indicating the existence of cointegration in the model.

Evidence of cointegration was not found in Table 3 when RHDT was considered the dependent variable in the model. This is because the F-statistics of 1.69 is lower than the lower critical value of 2.72 at 10%, hence the null hypothesis is not going to be rejected. In a nutshell, the bounds testing has indicated the existence of strong cointegration among the series as revealed by the F-statistics and the critical values. This is in line with results of Oparinde and Okogbue (2018) who explored the climate-

related risk and maize production in Southwest, Nigeria.

Estimation of ARDL Long Run

Table 4 shows the long term association between lnCRPY, lnTEMP, lnRNFL and RHDT, taking into account the occurrence

of cointegration among the explanatory variables. The ARDL model is estimated by manually picking a maximum lag length of 5 and utilising Akaike Information Criteria to choose the model's best lag order. The specification finally selected ARDL (2,2 5, 1).

Table 4: Long Run Coefficients

Variables	Coefficient	Standard error	T-statistics	P-value
lnRNFL	3.261812	1.279351	2.549584**	0.0133
lnTEMP	-18.62547	5.287106	-3.522810***	0.0008
RHDT	-32.67252	19.27456	-1.695112*	0.0952

Note: *** (**) * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Source: Author's Computation

Table 4 shows that lnRNFL coefficient (3.26) infers a long-term positive link with crop yield; the coefficient is significant at 5% level. This indicates that a rise in rainfall increases the crop output by 32.6%. This is because adequate rainfall is required not just for excellent production but also regular rainfall, as irregular rainfall has a negative impact on crop yield. This is in conformity with the findings of Agba, Adewara, Adama, Adzer, and Atoyobi, (2017). The coefficient lnTEMP is -18.63 showing that temperature has a negative influence on crop yield in the long run. Because the coefficient is significant at 1% level, a unit increase in temperature reduces crop yield by about 18.63%. This indicates that there is a possibility that the temperature may rise to deplete the soil nutrient, resulting in severe heat that is bad for some

crops' performance. This outcome is inconsistent with the findings of Ayinde, Muchie and Olatunji (2011).

The coefficient of RHDT (-32.67) signifies in the long run, at 10% level there is a negative relationship with crop yield. The crop output is reduced by 32.67% for every unit increase in relative humidity. This is against the argument made by Oparinde and Okogbue (2018) who reported a positive but insignificant effect of relative humidity to crop output.

Error Correction Model

The error correction model was used to predict the short-run association between the independent variables and crop yield, and the findings are shown in table 5.

Table 5: Error Correction Model

Variables	Coefficient	Standard error	T-statistics	P-value
D(lnCPRY(-1))	0.298875	0.091370	3.271033***	0.0018
D(lnRNFL)	1.295968	0.202904	6.387105***	0.0000
D(lnTEMP)	-2.627914	0.488443	-5.380191***	0.0000
D(RHDT)	10.06968	3.182819	3.163761**	0.0024
C	3.005558	0.693052	4.336696***	0.0001
CointEq(-1)*	-0.099041	0.022893	-4.326336***	0.0001

R² = 0.67
 F = 13.1 (0.0000)
 DW Stat = .91

Note: *** (**) * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Source: Author's Computation

The negative and statistical error correction coefficient (ECM) demonstrated that the adjustment process is effective in restoring equilibrium. The negative and low ECM (-1) in its absolute value indicates a slow rate of adjustment. As a result, it is obvious that ECM is statistically significant at 1% level with a value of -0.0990. as a result, about 9.9% of the crop output disequilibrium from the previous year's shocks converge to the long-run equilibrium in the current year. Except lnTEMP which was found to be negative and statistically significant in the long run estimation, all of the corresponding explanatory variables have

the predicted signs and are statistically significant. In a nutshell, the coefficient of lnTEMP (-2.62) has a negative statistical relationship with crop yield at 1% level, lnRNFL (1.29) has a positive statistical relationship with crop yield at 1% level, and RHDT (10.06) has a positive statistical relationship with crop yield at 1%.

Diagnostic Tests

The study examines the consistency of the coefficients of the estimates based on Chi-Square and Lagrange Multiplier (LM) tests as well as stability test using recursive residuals.

Table 6: Diagnostic Test

Diagnosics Test	Problem	F-Stat	Probability	Decision
LM	Serial Correlation	0.9052	0.8813	There is no serial correlation
ARCH	Heteroscedasticity	0.3428	0.3360	There is no heteroscedasticity
CUSUM	Stability	-	-	The model is stable

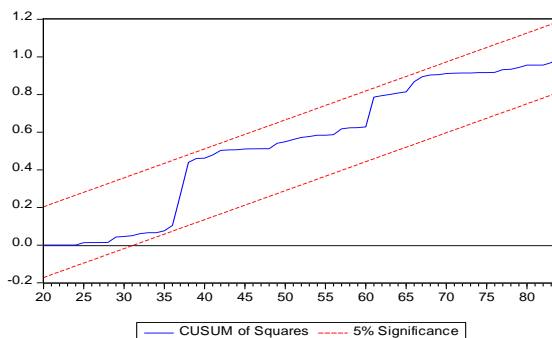
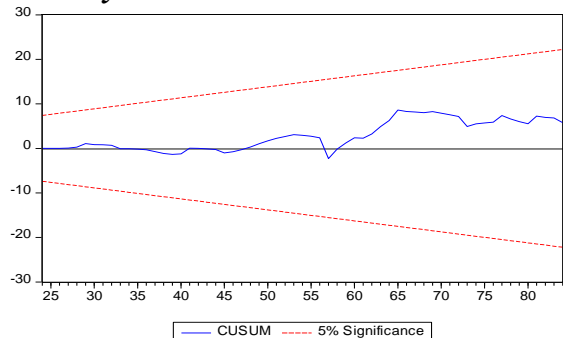
Note: Serial correlation was examined using Lagrange Multiplier test of residual and Heteroscedasticity was based on squared residuals on squared fitted values

Source: Author's Computation

The null hypothesis for the respective diagnostic tests is that the residuals have no serial correlation and are homoscedastic, as shown in table 6. At any conventional level of significance, the test statistics for each null hypothesis could not be rejected. As a result, we came to the conclusion that the model passes the diagnostic test for serial correlation and heteroscedasticity. As a consequence, the diagnostic test revealed that the calculated model coefficients are efficient and consistent.

The estimated coefficients` stability was tested using the cumulative sum of recursive residuals (CUSUM). At 5% level of significance, figure 6 and 7 clearly shows that the coefficients are within the upper and lower critical boundaries for the model. Thus, over the study period, the coefficients are determined to be steady. Therefore, we can conclude that the parameters are stable and reliable in explaining deviations in crop production in Gombe State.

Stability Test



Conclusion and Recommendation

The overall purpose of the study was to investigate the impact of climate change on crop production in Gombe State, Nigeria. The research was based on information from climate variables, which included; temperature, rainfall, and relative humidity, as well as data on food crop production. The findings using the ARDL bound approach revealed that the effect of climate change on crop output was obvious in the research area due to the effects of increased temperature, variability in rainfall, and relative humidity in the long and short-run, which led to poor quality of farm produce. The study concluded that climate change is accompanied by an increased incidence of changes in temperature, rainfall, relative humidity, and other climate extremes based on the findings. This is further compounded by drought and flooding, which bring about changes in crop productivity. Hence, to mitigate the consequences of climate change, the use of ecologically friendly agricultural methods should be encouraged.

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