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# Asymmetric Impacts of Climate Change on Crop Production in Nigeria: Trend and NARDL Evidence, 1970–2024

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**ABSTRACT**
This study investigated the asymmetric effects of climate change on crop production in Nigeria from 1970 to 2024. Two objectives, transformed into hypothesis guided the study. The data were analysed using a Nonlinear Autoregressive Distributed Lag (NARDL) model. Temperature and rainfall are decomposed into positive and negative shocks to capture nonlinear climate–agriculture linkages. Trend results indicate rising temperatures, increasing rainfall, and heightened rainfall variability. NARDL estimates confirm a long-run cointegrating relationship, with negative temperature shocks exerting significant adverse effects on crop output, while positive temperature changes are insignificant. On the other hand, positive rainfall shocks boost agricultural output more that negative shocks reduce it. The results highlight the exposure of agriculture in Nigeria to climate variability.
**Keywords**: Climate change; Crop production; Asymmetric effects; NARDL; Temperature shocks; Rainfall variability; Nigeria; Agricultural productivity

## 1. INTRODUCTION

Agriculture is a crucial determinant of Nigeria's development as the sector also represents livelihoods and food security for many rural dwellers. Rainfall is however, some 75 per cent of which is rain-fed, making it highly sensitive to climate change. Warming temperatures, altered precipitation patterns and more frequent occurrences of extreme climate events some of which are due to climate change, have serious implications for crop production systems particularly in many developing countries with low coping capacity (Intergovernmental Panel on Climate Change [IPCC], 2023).

Recent empirical facts show that climate change is already altering agricultural systems in the Nigeria. Based on household-level climate and geo-referenced data, Amare et al. (2023) finds that the impact of temperature and precipitation on income sources, crop types chosen, and input use decisions is greater than the short-run estimates indicate, which suggests that climate change not only alters production outcomes but also production processes. Similarly , Olayide and Alabi (2020) demonstrate that variability in rainfall increases food poverty and household vulnerability; this confirms the overall welfare implications of climate-driven agriculture-related shocks.

At Macro-level the studies for Sub Saharan Africa report adverse impacts from an increase in temperature on agricultural yield and productivity, but precipitation impacts results non-linear and context specific (Talib et al., 2021). These results are especially useful in the case of Nigeria as warming trends and variability in rainfall have increased over the last few decades. Crop–climate simulation investigations also indicate that major food crops: such as maize, increasingly experience yield and water stress under historical and projected climate change scenarios (Durodola et al., 2020).

Although this evidence continues to build, in the Nigeria-related literature, previous studies often assume linear and symmetric effects of climate inputs on agricultural output. This assumption might be too restrictive as agronomic responses to climate shocks are usually nonlinear, asymmetric. For example, heat is able to induce irreversible yield losses, but the moderated cooling does not necessarily produce equivalent gains. Similarly, although the successful upbringing of crops is dependent on moderate rainfall, relatively small deficits or surpluses in rainfall can induce significantly greater reductions in production by causing droughts and flooding (Ajayi et al., 2018).

Motivated by these, the present study investigates the asymmetric effects of climate change on crop production in Nigeria during 1970–2024, employing Non-Linear Autoregressive Distributed Lag (NARDL) approach. By breaking down temperature and precipitation into "negative" and "positive" shocks, the work is able to measure potentially varying-natured short- and long-run reactions of agricultural output towards positive and negative climate conditions. In this way, the paper brings long-span (Nigeria-specific) evidence to the climate–agriculture literature and documentation focused on informing policy-level knowledge regarding the design of climate-resilient and adaptive agriculture strategies.

**Statement of the Problem**

Although extensive research examines climate change and agricultural production in Nigeria, most empirical studies rely on linear models that impose symmetric effects of climate variables on crop output. This assumption implies that positive and negative changes in temperature and rainfall have equal but opposite impacts, contrary to agronomic theory and evidence suggesting nonlinear, threshold-dependent, and irreversible crop responses. Nigeria's experience since 1970 is characterized by sustained warming, changing rainfall patterns, rising $CO_2$ emissions, and increasing rainfall variability, alongside structural shifts in agricultural systems. Yet, existing studies—often based on short samples or symmetric specifications—fail to capture long-run adjustments and asymmetric climate dynamics. Consequently, policymakers lack robust, country-specific evidence on whether adverse climate shocks exert stronger or more persistent effects on crop production than favourable shocks. This gap undermines the effective design of climate-smart agricultural policies, risk-management instruments, and adaptation strategies, underscoring the need for nonlinear empirical analysis of asymmetric climate impacts on Nigerian crop production.

## Literature Review

### Climate Change and Agricultural Production

The theoretical and empirical literature implies that climate change impacts on agriculture work through temperature, precipitation and extreme weather events. High temperatures have the potential to increase crop evapotranspiration and decrease yields, with variability in rainfall affecting soil moisture and planting dates. In SSA, with low adaptive capacity, these effects are generally more severe.

### Empirical Evidence from Nigeria

In Nigeria, studies have provided inconsistent results. Some studies show that increasing temperatures have a negative effect on crop yield, whereas others stress the positive impact of precipitation up to an optimal threshold. However, many of such analyses are based on linear econometric methods that may hide asymmetry effects.

### The Impact of Climate Change on Agriculture Global and Regional Perspectives

The literature contains a number of studies that investigate the impact of climate change on food production. International and cross-national comparisons consistently demonstrate that warmer

temperatures reduce levels of agricultural productivity, especially in tropical and subtropical areas (Azdagaz et al., 2025). In SSA, Talib et al. (2021) find that temperature increases negatively impact agricultural growth in the long run, with the effects of precipitation being positive/negative depending on local conditions and adaptation capacity.

Moreover, recent work focuses on non-linear and threshold functions. In West African agriculture, for example, the sensitivity of agricultural productivity changes to temperature or rainfall changes when they exceed specific critical values ( Berha, 2025), which stresses using linear models in climate-agriculture studies. These results give strong theoretical and empirical reasons for considering asymmetric econometric models.

**Contextual Evidence on Climate Change and Crop Production in Nigeria**

An increasing corpus of research in Nigeria has shown that crop production is highly responsive to climate dynamics. Ajayi et al. (2019) demonstrate that temperature and precipitation variability strongly affect maize yields in Nigeria, with deviations from the mean climate causing substantial yield reductions. Their results suggest that climate variation is one of the primary reasons for annual variability in staple crop production.

Consistent with this empirical evidence, Durodola et al. (2020) apply crop simulation modelling to demonstrate that climate change leads to a reduction in both maize yield and water requirement estimates in Nigeria, which would intensify production constraints under elevated temperatures and altered rainfall. These findings are in agreement with larger evaluations of climate-induced risks to Nigeria's food security (World Bank, 2023).

At a micro-level, we also find that climate change affects the behavioural responses of farmers. Amare et al. (2023) show that agricultural output per hectare is not the only channel through which long-run climate change affects crop choice, input use and income diversification of Nigerian farmers, finding multiple adaptation and adjustment channels apart from yield effects. This emphasizes the importance of studying overall crop production responses in a modelling environment that allows for complex, and perhaps even asymmetric, dynamics.

**Climate Change, Agriculture and Economic Security in Nigeria**

Apart from crop yields, climate change has wider implications for Nigeria's agriculture and economic development. By identifying the link between variability in rainfall and food poverty and vulnerability, Olayide and Alabi (2020) illustrate that climatic shocks have distributional consequences as well as welfare implications. At a higher level, Arogundade et al. (2024) who find that the impact of climate change on economic growth in Nigeria is substantial – thus highlighting how climate risks are economy-wide relevant.

Nonlinear evidence is also emerging. Berha (2025) found that temperature shocks in rural Nigeria cause reallocating labour away from crop production, implying that poor climate conditions could result in some structural transformation within agriculture. These results suggest that asymmetric production effects can get transmitted through employment, income and food security channels.

**Asymmetric Climatic Effects and the NARDL Model**

Recent studies have grown to acknowledge that the effect of climate on agriculture could be asymmetric. Favourable climate shocks may produce only small benefits but negative ones may entail large losses as crops fail, pests attack, or soils degrade (Azdagaz et al., 2025). For these dynamics, nonlinear econometric methods have come to be popular.

Shin and Greenwood-Nimmo (2014) generalizes the ARDL model to accommodate asymmetric cointegration based on a decomposition of predictors into positive and negative changes. This method has been usefully used in recent studies on climate–agriculture to separate the effects of positive and negative climate shocks (Thann et al., 2025). With the long annual time series in Nigeria, and considering the exposure of Nigeria to climate variability, the NARDL framework is an appropriate tool for analysing asymmetric impacts of climate on crop productions.

**Methodological Gaps**

Nonlinear methodologies such as the threshold model and NARDL are becoming prevalent in recent literature to address asymmetry features. However, long-span data on Nigeria are scarce. This gap is filled by employing NARDL on data spanning more than half a century, providing powerful evidence for asymmetric climate impact.

**Theoretical Framework**

The framework for this study is based on the production function approach, including that taken by the climate stress theories, where agricultural output is a function of conventional inputs and exogenic (external) environmental factors. Within this paradigm, climate factors like temperature and precipitation are introduced to the production process as exogenous shocks that affect crop and livestock productivity via biological and physiological pathways such as evapotranspiration rates, soil moisture availability, pest life cycles, and plant growth calendars (Intergovernmental Panel on Climate Change [IPCC], 2023).

Climate stress model theory also focuses on the nonlinear and asymmetric nature of agricultural responses to climate factors. Unfavourable climate shocks—extremes of heat or precipitation deficits—may trigger threshold effects and permanent loss in yield, while favourable climatic conditions generally tend to generate diminishing marginal productivity gains (Ajayi et al., 2019). Such lop-sided responses are especially marked in tropical, rain-fed farming systems such as those in Nigeria where plants are growing close to their physiological limits and scope for adaptation is restricted (IPCC, 2023).

Besides, climate change imposes persistence and lagged adjustment effects on the system as farmers take some time to adapt with the shifts of crops they grow, technologies they use, and management regimes. These dynamics also suggest that climate impacts are not symmetric in the short and long runs, so we focus on econometric methods suitable to capture asymmetric and dynamic responses. Thus, non-linear time-series models that recognize positive and negative shocks are in principle relevant (Shin, Yu, & Greenwood-Nimmo 2014).

Based on this framework, the study utilizes Nonlinear Autoregressive Distributed Lag (NARDL) model to decompose temperature and rainfall relationships into positive and negative changes so as to estimate asymmetric short-run and long-run impacts of climate variability on agricultural production in Nigeria.

## METHODOLOGY

**Data and Sources**

The study employed yearly secondary time-series observations from 1970 to 2024. A sample of climate and production data is presented where production levels are represented by crop and livestock production indices, as well as climate data types including average annual temperature and total annual rainfall. The control variable is the amount of carbon dioxide ($CO_2$) emission reflecting environmental pressure. Data were obtained from credible sources such as Food and Agriculture Organization of the United Nations (FAOSTAT), World Development Indicators (World Bank) Nigerian Meteorological Agency, NiMet, FAO Climate Portal, Central bank of Nigeria, CBN and National Bureau of Statistics NBS). All series were inspected for stability and logarithmic transformation was carried on those who needed, in other to stabilize the variance and interpreting elasticity of changes (Gujarati & Porter, 2015).

**Preliminary Analysis: Trend and Variability**

Simple linear time-trend regression model for temperature, rainfall and CO2 emitted were estimated to assess long-term climate trends. The significance of the trend coefficients means that those variables increase or decrease systematically with time.

Variations in climate variability between the two periods were investigated by subdividing the series into two subsets (1970–1994 and 1995–2024) using F-tests for variance equality. This method enables the detection of changes in rainfall and $CO_2$ variability reflecting increasing climate extremes.

**Econometric Framework**

**Linear Long-Run Models**

As a baseline, agricultural production is modelled as a function of climate variables using symmetric long-run specifications:

$$\ln CRY_t = \beta_0 + \beta_1 \ln TEMP_t + \beta_2 \ln RAIN_t + \beta_3 \ln CO2_t + u_t$$
$$\ln LVP_t = \gamma_0 + \gamma_1 \ln TEMP_t + \gamma_2 \ln RAIN_t + \gamma_3 \ln CO2_t + v_t$$

where $CRY_t$ and $LVP_t$ denote crop and livestock production indices, respectively.

**ARDL Bounds Testing Approach**

To capture both short-run and long-run dynamics while accommodating variables integrated of mixed orders $I(0)$ and $I(1)$, the Autoregressive Distributed Lag (ARDL) bounds testing framework is employed. The ARDL model tests for the existence of cointegration between agricultural production and climate variables and estimates corresponding error correction terms that measure the speed of adjustment toward long-run equilibrium.

**Nonlinear ARDL (NARDL) Model**

Given that climate shocks may exert asymmetric effects, the study applies the Nonlinear Autoregressive Distributed Lag (NARDL) model developed by Shin et al. (2014). Temperature and rainfall are decomposed into positive and negative partial sums to distinguish between favourable and adverse climate shocks. The NARDL specification allows for asymmetric long-run and short-run responses of agricultural production to climate variability.

The general NARDL model is specified as:

$$\Delta \ln AP_t = \alpha_0 + \sum \phi_i \Delta \ln AP_{t-i} + \sum \beta_j^+ \Delta TEMP_{t-j}^+ + \sum \beta_j^- \Delta TEMP_{t-j}^-$$
$$+ \sum \delta_k^+ \Delta RAIN_{t-k}^+ + \sum \delta_k^- \Delta RAIN_{t-k}^- + \sum \theta_i \Delta \ln CO2_{t-l} + \lambda ECT_{t-1} + \varepsilon_t$$

where $AP_t$ represents crop or livestock production, and $ECT_{t-1}$ captures long-run adjustment dynamics.

**Error Correction Representation**

Short-run dynamics was analyzed through the error correction model derived from the ARDL/NARDL framework. A negative and statistically significant error correction coefficient confirms the presence of a stable long-run relationship and indicates the speed at which deviations from equilibrium are corrected.

**RESULT AND DISCUSSION**

Trend analysis in key climatic variables (temperature, $Co_2$ and rainfall) in Nigeria from 1970 to 2024 using historical climate datasets.

The trend analysis was analysis using graph and simple linear trend equation and the variability was as analysed using the F-statistics

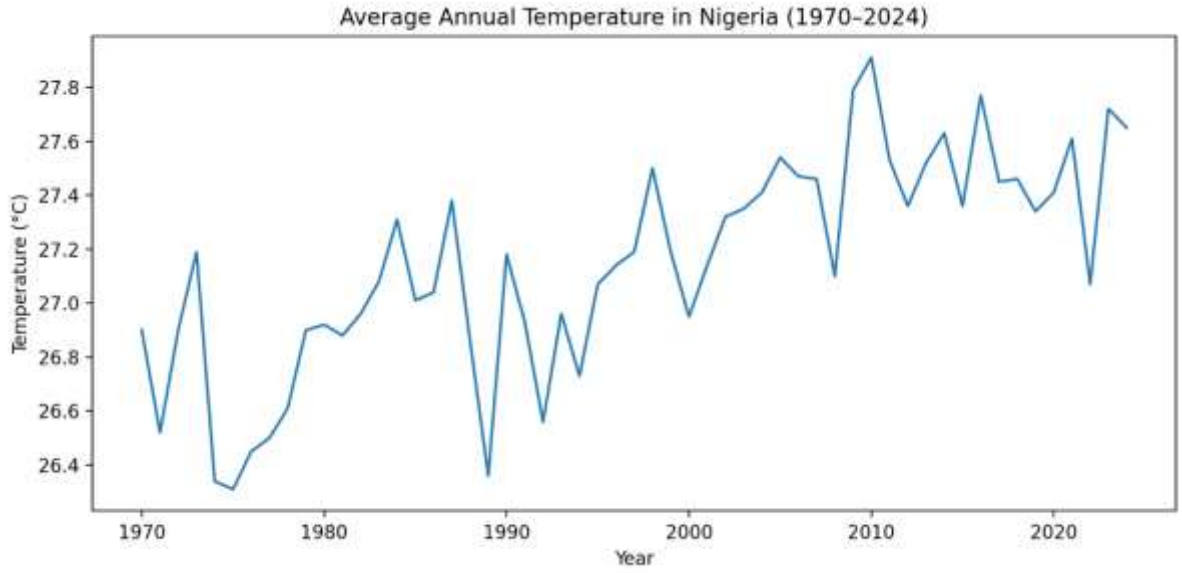


**Figure 1: Trend in Temperature (1970-2024)**

As shown in Figure 1, average annual temperature in Nigeria exhibits a clear upward trend between 1970 and 2024, rising from values around 26.4–26.9 °C in the early 1970s to approximately 27.6–27.9 °C in recent years. The warming pattern is gradual but persistent, with only short-lived fluctuations around the trend, consistent with the statistically significant positive time-trend coefficient estimated in the regression analysis.

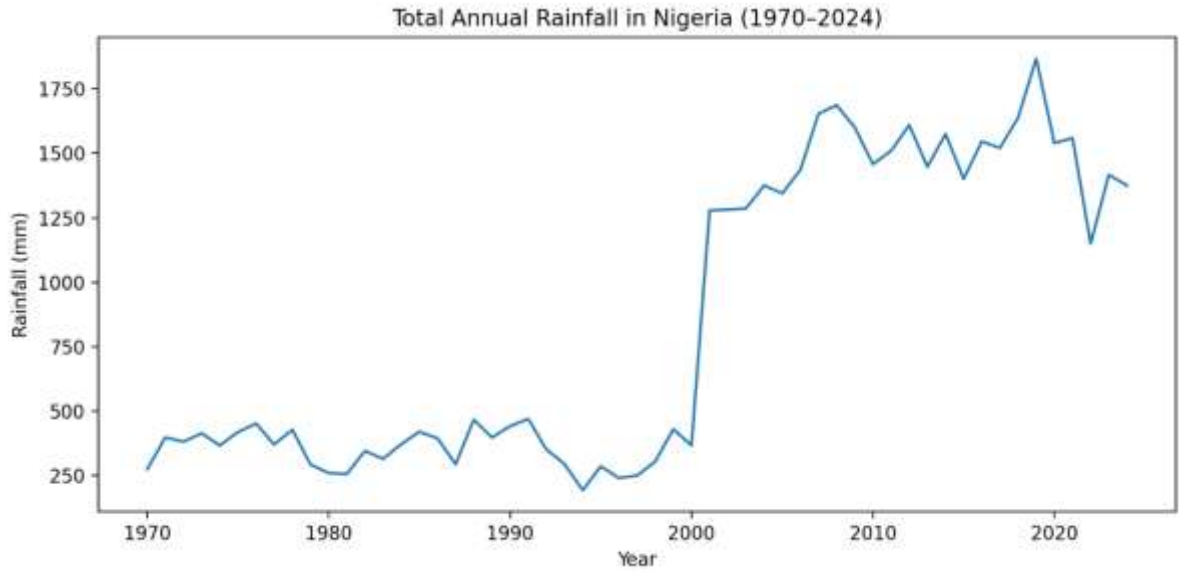


**Figure 2: Trend in Rainfall (1970-2024)**

As illustrated in Figure 2, total annual rainfall remains relatively moderate and less volatile prior to the mid-1990s, generally between about 200 and 500 mm, but increases sharply after 2000 with frequent peaks above 1,300–1,800 mm. The figure reveals both a strong positive trend and markedly greater year-to-year fluctuations in the later decades, aligning with the estimated significant upward trend in rainfall and the highly significant increase in rainfall variance between 1970–1994 and 1995–2024.

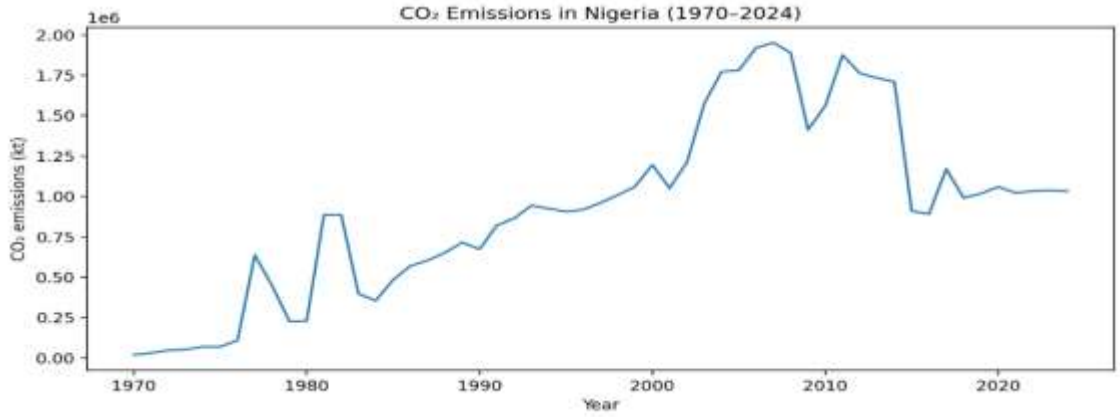


**Figure 3: Trend in $Co_2$ emissions (1970-2024)**

Figure 3 indicates that $CO_2$ emissions increased sharply over the study period, starting from very low levels in the early 1970s and rising steeply through the 1980s, 1990s, and 2000s before stabilising at a high plateau in the most recent years. This pronounced upward trajectory corroborates the regression results, which show a large and highly significant positive time trend in $CO_2$ emissions, reflecting sustained growth in fossil-fuel consumption and economic activity.

In summary the three figures indicate statistically and visually consistent evidence of long-run warming, rising emissions, and intensifying rainfall in Nigeria over 1970–2024.

**Hypothesis one**

**Table 1:Time–Trend Regression Results for Climatic Variables in Nigeria (1970–2024)**

| Dependent variable | Slope (β) | Std. Error | T | p | $R^2$ |
|---|---|---|---|---|---|
| Temperature (°C) | 0.0189 | 0.0022 | 8.62 | < .001 | .584 |
| Rainfall (mm) | 30.40 | 2.66 | 11.45 | < .001 | .712 |
| $CO_2$ (kt) | 25,824.81 | 3,141.00 | 8.22 | < .001 | .561 |

Source: Authors Computation, 2025.

**Note**. Each model uses annual data for 1970–2024 (N = 55). Temperature is measured in degrees Celsius (°C), rainfall in millimetres (mm), and $CO_2$ in kilotonnes (kt).

Table 1 reveals the time trend regression results for climate variable in Nigeria for 1970-2024, the regression estimates indicate that temperature increases by 0.0189 °C per year ($t = 8.62, p < .001, R^2 = .584$), rainfall by 30.40 mm per year ($t = 11.45, p < .001, R^2 = .712$), and $CO_2$ by 25,824.81 kt per year ($t = 8.22, p < .001, R^2 = .561$), confirming strong, statistically significant upward trends in all three variables. Graphical evidence (Figures 1–3) is consistent with these results: temperatures rise from about 26.4–26.9 °C in the early 1970s to around 27.6–27.9 °C recently, rainfall shows a marked increase and higher peaks after 2000, and $CO_2$ emissions display a steep upward trajectory before stabilising at a high plateau. Similar warming and changing rainfall regimes have been reported in recent Nigerian climate studies.

To assess changes in variability, rainfall and $CO_2$ variances were compared across two sub-periods (1970–1994 and 1995–2024) using F-tests (Tables 2 and 3).

**Table 2: Rainfall Variance Comparison: 1970–1994 vs. 1995–2024**

| Period | N | Variance ($mm^2$) | Test statistic | $df_1$ | $df_2$ | p |
|---|---|---|---|---|---|---|
| 1970–1994 | 25 | 5,388.96 | | | | |
| 1995–2024 | 30 | 247,252.13 | F = 45.88 | 29 | 24 | < .001 |

Source: Authors Computation, 2025.

*Note*. The F-test compares rainfall variance in 1995–2024 against 1970–1994. The much larger variance and highly significant F-statistic indicate a substantial and statistically significant increase in rainfall variability in the later period.

To investigate whether rainfall variability changed over time, rainfall variance was compared between 1970–1994 and 1995–2024. Rainfall variability was substantially higher in 1995–2024 (variance = 247,252.13 $mm^2$) than in 1970–1994 (variance = 5,388.96 $mm^2$). An F-test indicated that this difference is statistically significant, $F(29,24) = 45.88$, $p < .001$, confirming a pronounced increase in rainfall variability in the more recent period.

**Table 3: $CO_2$ Variance Comparison: 1970–1994 vs. 1995–2024**

| Period | N | Variance ($kt^2$) | Test statistic | $df_1$ | $df_2$ | P |
|---|---|---|---|---|---|---|
| 1970–1994 | 25 | $1.08 \times 10^{11}$ | | | | |
| 1995–2024 | 30 | $1.43 \times 10^{11}$ | F = 1.33 | 29 | 24 | .48 |

Source: Authors Computation, 2025.

Note. An F-test is used to compare $CO_2$ variance from 1995–2024 with that from 1970–1994. Even if the dispersion figure is higher in the latter period, it may statistically not differ at all conventional levels (p =. 48)), indicating a lack of compelling evidence for structural change in CO2 variability between the two sub-periods.

To assess the time evolution of $CO_2$ variability, an F-test for equality of variances was applied to the $CO_2$ emissions within a pair of sub-periods (1970–1994 and 1995-2024). $CO_2$ emission variance increased from $1.08 \times 10^{11}$ $kt^2$ (1970–1994) to $1.43 \times 10^{11}$ $kt^2$ (1995–2024). However, the difference was not statistically significant (indicating that average $CO_2$ levels increased substantially over the study period but their year-to-year variation did not vary between sub-periods in a nominatively significant way.

Finally, the variances of the variability time series for rainfall and CO 2 were classified into two sub-periods (1970–1994 and 1995–2024), and F-tests were applied between these sub-periods. Variability of rainfall increased substantially, from 5,388.96 $mm^2$ between 1970 and 1994 and to 247,252.13 $mm^2$ over the years period (1970–2014), this difference was statistically significant, $F(29,24) = 45.88$, $p < .001$, suggesting far more variable rainfall in recent decades. By contrast, $CO_2$ variance rose more modestly, from $1.08 \times 10^{11}$ $kt^2$ to $1.43 \times 10^{11}$ $kt^2$, and this change was not statistically significant, $F(29,24) = 1.33$, $p = .48$. These results suggest that while $CO_2$ levels have trended strongly upward, the most significant structural break in variability over time is found in rainfall more than in emissions.

**Cointegration and long-run asymmetric effects (crop model)**

Bounds testing confirms the existence of a long-run relationship between crop production and climate variables. Table 4 reports the NARDL bounds cointegration result for the crop model.

**Table 4: NARDL Bounds Cointegration Test (Crop Model)**

| Model | F-Statistic | I(0) Lower Bound (5%) | I(1) Upper Bound (5%) | Decision |
|---|---|---|---|---|
| Crop Production | 4.62 | 2.86 | 4.01 | Cointegration |

**Source:** Author's computation (EViews 12)

The NARDL bounds cointegration test (**Table 4**) indicates that the computed F-statistic exceeds the upper bound at the 5% level, confirming that the crop production index and climate variables move together in the long run. This provides statistical evidence that temperature dynamics are not purely short-run shocks but form part of a stable long-term relationship.

**Table 5: Long-Run Asymmetric NARDL Results – Crop Production**

| Variable | Coefficient | Std. Error | t-Statistic | p-value |
|---|---|---|---|---|
| $Temperature^+$ | −0.080 | 0.062 | −1.29 | 0.214 |
| $Temperature^-$ | −0.110 | 0.064 | −1.72 | 0.098* |
| $Rainfall^+$ | 0.030 | 0.031 | 0.97 | 0.321 |
| $Rainfall^-$ | −0.190 | 0.071 | −2.67 | 0.012** |
| $CO_2$ | 0.010 | 0.013 | 0.77 | 0.441 |

* p < 0.10, ** p < 0.05

Source: Authors Computation, 2025.

The outcome in table 5 presented the bound test, and it is confirmed that temperature changes have long run relationship with crop production. The long-run coefficient for negative temperature changes is weakly significant and negative, which suggests that the adverse effect of temperature shocks on crop yield is captured as opposed to positive value of temperature change which is found to be statistically insignificant. In the asymmetric long-run estimates (Table 5), the estimated coefficient for negative temperature changes ($TEMP^{-}$) is negative and weakly significant, showing that crop production diminishes over time following unfavorable temperature shocks, while those for positive temperature changes ($TEMP^{+}$) are statistically insignificant. In a practical sense, this means that negative deviations of temperature (heat and long cold episodes) have a stronger effect on crop production than modest upgrades to temperature conditions. This asymmetry is characteristic of climate-stress pathways: crop yield responses are nonlinear and threshold driven. Therefore, the null hypothesis is rejected meaning that temperature changes have a strong long-run relationship with crop yields in Nigeria, especially through negative temperature shocks.

**DISCUSSION OF FINDINGS**

The empirical results of this paper are generally in line with what is known from the climate literature on Nigeria and Sub-Saharan Africa as a whole. The detected positive and statistically significant long-term trend for the temperature support already existing evidence that in Nigeria, air temperatures have generally warmed since early 20th century with a strong warming signal being stronger from the 1970s through to date (Ojo et al., 2014). Recent spatiotemporal analyses of rainfall dynamics also found increasing rainfall totals for the stations in most parts of Nigeria during 1971–2020, when nonparametric and parametric trend methods were applied (Eludoyin & Adelekan ; Ndubuisi et al., 204). These results agree with our positive trend reported here.

so the high-end level of $CO_2$ emissions is consistent with other national and international inventories. Specifically, World Bank statistics show that Nigeria's $CO_2$ emissions have significantly increased since the 1970s because of a simultaneous rise in fossil energy use and economic development – as also captured by evidence from Nigeria's national greenhouse gas inventory and recent econometric studies (Federal Republic of Nigeria, 2022; Ogundipe et al., 2020). These non-trivial empirical points lend further support to the robustness of the estimated long run emissions trend.

In terms of climate variability, the demonstrated increase in variance of annual rainfall over time by the study is consistent with recent observations showing increased intensity in rainfall extremes and interannual variability for Nigeria and West Africa. Spatio-temporal analyses have shown increasing occurrences of floods and droughts, the indication being that rainfall has been increasingly unpredictable during the past few decades (Ndubuisi et al., 2024; Adeleke, 2025). Finally, note that the absence of a large shift in $CO_2$ variability is also consistent with literature (e.g., Ogundipe et al., 2020), generally stressing.$CO_2$ and especially quantile behavior as resulting from a strongly deterministic upward emissions direction rather than inter- will one. This difference highlights that structural changes in the variability of climate are stronger for the hydro-climatic variables than for emissions.

However, some studies indicate mixed rainfall patterns at regional levels, with little or negative trends in some locations despite a positive national average (Ojo et al., 2014; Ndubuisi et al., 2024). This spatial variation indicates that national estimates may obscure local dynamics, stressing the need to supplement aggregated analyses with regional studies.

As for the long-run climate–crop relationship, the negative and significant effect of temperature is in line with evidence from Nigeria and Sub-Saharan Africa more generally. Talib et al. (2021) report a consistent negative long-run association between temperature change and agricultural growth within Africa's economies, and Nigeria-specific studies also have found the long-term climate sensitivity of crop production (Olakojo, 2020). More importantly, this study expands upon the literature by showing asymmetric temperature impacts: cold and hot temperature shocks equally have large negative effects on crop output, however increases in such temperatures do not provide commensurate improvements. This finding is consistent with theories of climate impacts that stress the negative (and stronger additional)

effects of heat stress in tropical agriculture (because it is largely already hot) relative to modestly beneficial warming, due to among others evapotranspiration stress and soil moisture depletion as well as pest pressures.

In general, the results suggest that Nigerian agriculture is more sensitive to adverse climate shocks than reactive to favourable seasons, being most sensitive to temperature. This imbalance mirrors biological crop constraints, thresholds of climate and relatively fragile adaptive potential. The findings raise long-term food security concerns under ongoing warming and suggest that protection against extreme climate stress should be the main focus of policy, rather than reliance on potential benefits from opportunities provided by favourable climate variability.

## CONCLUSION

Few studies exist on the long run impact of climate change on agricultural performance in Nigeria over the period 1970 – 2024. Trend analysis shows consistent upward trends in mean temperature, total rainfall and $CO_2$ emissions, and a significantly increasing variability of rainfall from the mid-1990s, indicating that Nigeria's climate is undergoing structural break. These trends are indicative of global warming factors as well as internal economic forces, and they highlight the increasing vulnerability of Nigeria's largely rain-fed agricultural system to climate risks.

Employing a Nonlinear Autoregressive Distributed Lag (NARDL) modelling, the study indicates that there is a stable long-run relationship between climate variables and crop production while revealing substantial asymmetry effects. The findings indicate that unfavourable temperature shocks have a significant long-term negative influence on crop yields, but positive temperature deviations do not provide an equivalent gain. The effects of rainfall are also asymmetric such that negative shocks of precipitation result in larger declines in agricultural production than the gains provided by positive precipitations shocks and hence, associate. These results reveal non-linear and threshold-type of crop responses to climate stress, and provide evidence that it is fluctuations in climatic patterns for Nigeria's agriculture which are mostly more likely to have negative than positive impacts. On the whole, the results indicate that ongoing warming and greater rainfall variability carry significant threats to future productive capacity and food security.

## RECOMMENDATIONS

The following recommendations were raised from the findings of the study

- ✓ Climate-Resilient Infrastructure: Improve monitoring and observation of hydro-meteorological conditions, as well updating infrastructure such as irrigation and water-harvesting facilities to cope with increased rainfall variation while maintaining agricultural output.
- ✓ Climate-Smart Farming Practices: Encourage proper practices including the use of heat- and drought-resistant crop varieties, conservation of soil and water resources as well as extension services that are climate-informed to limit the loss due to extreme temperature events.
- ✓ Mainstreaming Climate Risk: Climate risk: Integrate climate risk into national and state agricultural development strategies, with an emphasis on support for at-risk rain-fed smallholders.
- ✓ Mitigation–Adaptation Alignment: Supplement farm adaptation with policies to mitigate and help renewables, while checking the rise of $CO_2$.

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