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Climate Change, Agricultural Productivity and Food Security in Selected Subsaharan African Countries

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Okito Omonigho Kelvin[1], Enoh Hilda Olele[1]

[1]Department of Economics, Delta State University, Abraka, Nigeria

Correspondence: Okito Omonigho Kelvin, okitokelvz@gmail.com

Abstract

Climate change poses a major threat to agricultural productivity and food security in Sub-Saharan Africa, where dependence on rain-fed agriculture and limited adaptive capacity increase vulnerability. This study examines the relationship between climate change, agricultural productivity, and food security in eight selected Sub-Saharan African countries from 1990 to 2024. Specifically, it investigates the effects of temperature and rainfall anomalies on agricultural productivity, measured by cereal yield, and examines how agricultural productivity and climatic factors influence food security, proxied by the prevalence of undernourishment. The study uses panel data obtained from the World Development Indicators, FAOSTAT, and climate databases and is anchored on Climate Change Vulnerability Theory. The Pooled Mean Group Autoregressive Distributed Lag (PMG-ARDL) technique is employed, complemented by country-specific ARDL estimations to capture heterogeneous effects. The results indicate that rainfall anomaly has a positive and statistically significant long-run effect on food insecurity, while higher cereal yield significantly reduces the prevalence of undernourishment. Temperature anomaly also influences food security outcomes, although its effects vary considerably across countries. The study concludes that climate change has significant but heterogeneous implications for agricultural productivity and food security. It recommends country-specific adaptation policies, climate-resilient technologies, irrigation investment, stronger extension services, and targeted food-security interventions.

Keywords: Climate Change, Agricultural Productivity, Food Security, Cereal Yield, Temperature Anomaly, Rainfall Anomaly, Prevalence of Undernourishment, PMG-ARDL, Sub-Saharan Africa

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1. INTRODUCTION

Agricultural productivity remains a fundamental pillar of food security, particularly in developing countries where a large proportion of the population depends directly or indirectly on agriculture for livelihoods, income generation, and food consumption (FAO, 2024; Pawlak&Kołodziejczak, 2020). In Sub-Saharan Africa, agriculture contributes significantly to economic development and remains the primary source of food supply for millions of households. However, the ability of the agricultural sector to ensure adequate food availability has increasingly been threatened by climate change, manifested through rising temperatures, changing rainfall patterns, and increasing climate variability (Food and Agriculture Organization [FAO] et al., 2024; Intergovernmental Panel on Climate Change [IPCC], 2022). Consequently, understanding the relationship among climate change, agricultural productivity, and food security has become a major concern for policymakers, researchers, and development institutions worldwide.

Sub-Saharan Africa remains one of the regions most vulnerable to the adverse effects of climate change because of its heavy dependence on rain-fed agriculture, rapid population growth, limited technological advancement, and persistent food insecurity challenges. According to recent reports by the Food and Agriculture Organization and other United Nations agencies, the region accounts for a significant proportion of the world's undernourished population, with climatic shocks, economic instability, conflicts, and low agricultural productivity contributing substantially to worsening food security conditions (FAO et al., 2024; Global Hunger Index, 2024). As a result, the interactions among climate change, agricultural productivity, and food security have become increasingly important areas of empirical investigation in Sub-Saharan Africa.

Climate change, evident in higher temperatures and shifting rainfall patterns—represents a major risk to food security in Sub-Saharan Africa by disrupting agricultural production systems, food markets, household earnings, and access to sufficient nutrition. A growing body of empirical and modeling research shows that temperature and rainfall anomalies, defined as departures from long-term climate norms, can strongly affect agricultural productivity and food security outcomes throughout the region. Agricultural performance, often captured by cereal yields in kilograms per hectare, remains a central driver of food supply and household well-being in many Sub-Saharan African countries, where cereals provide the main source of dietary energy and support for livelihoods. As a result, unfavorable weather conditions and variability in agricultural productivity frequently increase undernourishment by reducing food availability, limiting food access, and heightening economic vulnerability (Efeyena, Olele, &Buzigbe, 2018).

Agricultural productivity, commonly measured by cereal yield per hectare, plays a critical role in ensuring food availability, reducing poverty, and improving nutritional outcomes. Cereals constitute a major source of dietary energy and household income across many African economies. Consequently, changes in cereal productivity have important implications for food security outcomes. However, agricultural productivity in Sub-Saharan Africa remains highly vulnerable to climatic shocks due to the predominance of rain-fed agricultural systems, inadequate irrigation infrastructure, low technological adoption, and weak institutional support mechanisms. As a result, fluctuations in agricultural productivity directly affect food availability, household purchasing power, and nutritional outcomes across the region (FAO et al., 2024; Adesete et al., 2022).

The physical mechanisms through which climate change affects agricultural productivity have been widely documented in the literature. Positive temperature anomalies beyond crop-specific thresholds tend to shorten crop growth cycles, intensify heat stress, increase evapotranspiration, and reduce crop yields. Similarly, negative rainfall anomalies or heightened variability in rainfall distribution reduce soil moisture

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during critical crop growth stages and increase drought risk in rain-fed agricultural systems, which dominate smallholder farming across Sub-Saharan Africa (Malhi et al., 2021; Bucheli et al., 2022; Oluwatimilehin, 2023). These climatic disturbances affect not only agricultural production but also household welfare and food security outcomes.

Cross-country panel and spatial studies examining the relationship between climatic anomalies and cereal yields generally report negative, although heterogeneous, effects of warming and moisture deficits on major cereal crops. Several empirical analyses using standardized climate indicators, including temperature anomalies, rainfall deviations, and the Standardized Precipitation Evapotranspiration Index, have found that rising temperatures are negatively associated with maize and other staple crop yields. These studies further demonstrate that the combined effects of elevated temperatures and reduced moisture availability explain a substantial proportion of yield variability, particularly in Sahelian and semi-arid regions of Sub-Saharan Africa (Jabbi et al., 2021; Kinnunen et al., 2022; Pickson et al., 2023).

Further empirical evidence suggests that not only total seasonal rainfall but also the timing, intensity, and distribution of rainfall significantly influence agricultural productivity. Studies that disaggregate rainfall characteristics into onset, cessation, intensity, and dry spell frequency have shown that deviations from normal seasonal rainfall patterns significantly affect planting decisions, crop performance, and final harvest outcomes (Cocking et al., 2024). These findings reinforce the suitability of temperature and rainfall anomalies as reliable indicators of climate exposure in empirical analyses of agricultural productivity and food security.

The relationship between agricultural productivity and food security operates through several interrelated mechanisms. Food security in this study is measured by the prevalence of undernourishment, which refers to the proportion of the population whose habitual dietary energy intake is insufficient to maintain a healthy and active life. Declines in agricultural productivity reduce food availability and increase food prices, thereby limiting access to adequate nutrition, particularly among low-income households that spend a substantial proportion of their income on food consumption (FAO et al., 2024; International Monetary Fund [IMF], 2022). Furthermore, reductions in agricultural productivity diminish farm incomes, employment opportunities, and household purchasing power, thereby increasing the likelihood of food insecurity and undernourishment (Adesete et al., 2022; Global Hunger Index, 2024).

In addition to affecting agricultural production directly, climate-related shocks often generate multiple socioeconomic stressors, including income losses, asset depletion, migration, and increased household vulnerability. Empirical studies linking climate variability to household food insecurity and malnutrition in countries such as Ethiopia, Kenya, and Nigeria have demonstrated that climatic shocks, when combined with poverty, institutional weaknesses, and conflict, substantially worsen food security outcomes (Njatang et al., 2023; Adesete et al., 2022). These findings support an analytical framework in which climate change influences food security both directly and indirectly through agricultural productivity and broader socioeconomic channels.

Recent reports published by international organizations indicate that food security conditions in Sub-Saharan Africa have deteriorated considerably in recent years. Reports by the Food and Agriculture Organization of the United Nations, the World Food Programme, and other international agencies reveal a sustained increase in the number of undernourished people in the region since 2019, largely due to the combined effects of climate change, economic shocks, conflicts, and limited agricultural transformation (FAO et al., 2024; World Food Programme, 2024). These developments underscore the urgent need for empirical studies that quantify the contribution of climate change and agricultural productivity to food security outcomes in Sub-Saharan Africa.

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Despite the growing body of literature on climate change, agriculture, and food security, empirical findings remain inconclusive regarding the magnitude and direction of these relationships across countries due to differences in climatic conditions, agricultural systems, institutional quality, and levels of economic development. Furthermore, relatively few studies have simultaneously examined climate change, agricultural productivity, and food security within a unified analytical framework using both panel and country-specific approaches. This study therefore seeks to contribute to the existing literature by examining the relationship among climate change, agricultural productivity, and food security in selected Sub-Saharan African countries using temperature anomaly and rainfall anomaly as indicators of climate change, cereal yield as a measure of agricultural productivity, and prevalence of undernourishment as an indicator of food security. The study adopts both panel and country-specific analyses to capture regional patterns as well as country-level heterogeneity, thereby providing more comprehensive evidence for policy formulation and implementation.

Intuitively, climate change is among the key drivers of food insecurity in Sub-Saharan Africa. The region is broadly viewed as one of the most at-risk in the world because of its strong reliance on rain-fed farming, widespread poverty, limited technological development, and comparatively low capacity to adapt (IPCC, 2022). Even relatively small temperature rises have been found to depress yields, especially for staple cereal crops that are particularly vulnerable to heat stress and water shortages (Lobell et al., 2011). Higher temperatures raise evapotranspiration, diminish soil moisture, hinder normal crop growth and development, and contribute to more pest and disease pressures. These impacts reduce farm output and threaten food availability, especially in smallholder systems where irrigation, climate-resilient innovations, and financial means are often scarce (Schlenker&Lobell, 2010). As a result, unusual temperature patterns represent a major challenge to long-term agricultural viability and food security across the region.In the same way, fluctuations in rainfall create significant obstacles for agricultural production and food security. Because farming in Sub-Saharan Africa is largely rain-fed, output is highly dependent on rainfall conditions.

While policy reforms, technological progress, and the expansion of farming have boosted agricultural productivity in certain Sub-Saharan African countries, productivity across the region remains comparatively low and highly variable relative to other parts of the world. More critically, gains in agricultural productivity have not reliably led to matching declines in food insecurity. In many cases, higher agricultural output has coincided with continued or even worsening undernourishment, implying that productivity improvements by themselves may not be enough to ensure better food security when climatic shocks, poverty, population pressures, and structural limitations persist (Ray et al., 2015; FAO, 2018).

Food security is a multidimensional concept that includes food availability, access, utilization, and stability. Although agricultural productivity is central to improving availability, food security is also shaped by wider socioeconomic conditions such as income, economic growth, demographic trends, market performance, and institutional strength. Climate change adds further complexity by influencing agricultural production as well as household incomes, employment prospects, food prices, and purchasing power. As a result, ongoing food insecurity in Sub-Saharan Africa reflects not only production-related difficulties but also broader economic and structural fragilities (FAO, 2018; World Bank, 2021).

Research exploring the links between climate change, agricultural productivity, and food security in Sub-Saharan Africa has yielded varied and inconclusive results. Several studies find that rising temperatures and greater rainfall variability significantly harm agricultural productivity and food security outcomes (Mendelsohn et al., 2007; Thornton et al., 2014). In contrast, other work highlights how adaptation measures, institutional quality, technological progress, and economic development can

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moderate these effects (Kurukulasuriya& Mendelsohn, 2008; Bryan et al., 2013). In addition, much of the existing literature examines either agricultural productivity or food security in isolation, with relatively few studies assessing climate change, productivity, and food security together within a single integrated empirical framework.Moreover, comparatively little emphasis has been placed on using climate anomalies, rather than absolute climate levels, to capture the impacts of climate variability. Because anomalies reflect departures from long-term climatic averages, they offer a more precise way to represent the shocks experienced by farming systems and households (IPCC, 2022). The limited use of anomaly-based indicators in panel analyses of Sub-Saharan Africa therefore constitutes a notable empirical gap.

In light of intensifying climate change effects, sustained vulnerability in agricultural systems, and the ongoing problem of food insecurity in Sub-Saharan Africa, a broad empirical assessment is needed that jointly evaluates how climate change and agricultural productivity affect food security. Thus, the main objective of this study is to examine the effect of climate change and agricultural productivity on food security in selected Sub-Saharan African countries.The specific objectives of the study are to:

1. examine the effect of agricultural productivity, measured by cereal yield, on food security in selected Sub-Saharan African countries;
2. determine the effect of temperature anomaly on food security in selected Sub-Saharan African countries;
3. assess the effect of rainfall anomaly on food security in selected Sub-Saharan African countries;
4. examine the effect of economic growth on food security in selected Sub-Saharan African countries; and
5. determine the effect of population growth on food security in selected Sub-Saharan African countries.

This research is important for generating evidence to guide climate adaptation efforts, agricultural development strategies, and food security programs. The data spans the period 1990 to 2024, a timeframe chosen because consistent information is available and because it allows the study to capture long-term patterns in climate conditions, agricultural productivity, and food security results within theselected countries.

2. LITERATURE REVIEW

Sub-Saharan Africa (SSA) commonly refers to the African nations situated south of the Sahara Desert. This region experiences pronounced socioeconomic and environmental vulnerabilities, such as widespread poverty, food insecurity, susceptibility to climate-related shocks, and a heavy reliance on economic sectors that are sensitive to climate conditions (World Bank, 2024). Climate change refers to long term alterations in average weather conditions, primarily driven by human activities that increase greenhouse gas concentrations in the atmosphere (IPCC, 2021). While climate change encompasses a wide range of environmental shifts, temperature anomaly, defined as the deviation of observed temperature from a long term historical baseline, provides one of the most meaningful metrics for assessing climate impacts. Temperature anomalies capture both short term variability and long term warming trends, making them a suitable proxy for climate stress in agricultural and economic analyses (NASA, 2022). In the context of Sub-Saharan Africa, temperature anomalies have become more pronounced over the past three decades, with the region warming at nearly twice the global average (World Meteorological Organization [WMO], 2020).

Agricultural productivity refers to the efficiency with which agricultural inputs such as land, labour, capital, technology, and natural resources are transformed into agricultural outputs (FAO, 2024). It measures the ability of the agricultural sector to generate greater output from available resources and is

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commonly assessed using indicators such as crop yield, output per worker, and total factor productivity (Alemu, Mengistu, &Wassie, 2024; Temoso et al., 2024). Among the various indicators of agricultural productivity, cereal yield, measured in kilograms per hectare, is one of the most widely used proxies in empirical studies (Alemu et al., 2024; Etwire, Fielding, &Martey, 2024). As noted by Alimagham et al. (2024), cereal yield captures the productivity performance of major cereal crops such as maize, rice, wheat, millet, and sorghum, which constitute the principal staple foods consumed across Sub-Saharan Africa.

Food security continues to rank among the most critical development issues facing nations worldwide, especially in developing areas like Sub-Saharan Africa. The Food and Agriculture Organization (FAO, 2024) defines food security as a condition in which everyone, at all times, has physical, social, and economic access to enough safe and nutritious food that satisfies dietary needs and food preferences to support an active and healthy life (FAO, 2024). As noted by Calloway et al. (2023), food security is a multidimensional concept made up of four connected pillars: availability, access, utilization, and stability.

The empirical literature consistently demonstrates that climate variability and climate anomalies are important determinants of agricultural productivity in sub-Saharan Africa, although the magnitude and nature of their effects differ across countries and agro-ecological settings. Early evidence from East and Southern Africa shows that both temperature and rainfall anomalies significantly affect cereal production. Ayanlade and Radeny (2019), for instance, found that rising temperature anomalies reduced maize yields in Ethiopia and Kenya, while rainfall deficits produced even stronger effects. Similarly, Mubanga et al. (2019) reported substantial maize-yield losses in Zambia during drought years. This evidence is reinforced by Sultan et al. (2020), who estimated sizeable reductions in millet and sorghum yields when temperatures exceeded crop-specific thresholds, and by Wossen et al. (2020), who documented significant negative effects of temperature anomalies on rice and maize production in Nigeria. Subsequent studies, including Kilavi et al. (2020), Taffesse and Tadesse (2021), Kogo et al. (2021), and Codjoe and Atarah (2021), broadened the argument by showing that the timing, intensity and direction of rainfall matter as much as total rainfall received. Mgbomene (2024a) also demonstrates that agricultural-sector performance is influenced by broader economic factors, suggesting that climate-related pressures should be considered alongside non-climatic determinants of agricultural productivity.

A second strand of the literature moves beyond the direct climate–yield relationship to demonstrate that the consequences of climate shocks depend strongly on farmers' adaptive capacity and structural conditions. Ochieng et al. (2021), for example, found that the adverse effect of rainfall deficits on maize productivity was moderated by soil quality, fertilizer use and access to extension services. Nhamo and Ndlela (2021) similarly attributed the growing sensitivity of African cereal production to climate anomalies partly to soil degradation, limited irrigation and weak adaptive capacity. Evidence from Nigeria, Uganda, Burkina Faso, Ethiopia, Malawi, Zambia and South Africa further shows that climate-induced reductions in agricultural output are particularly severe among smallholder and resource-constrained households. Eze and Nwachukwu (2021) linked temperature anomalies in Nigeria not only to lower maize and sorghum yields but also to higher food prices, while Katengeza et al. (2022) and Chisanga and Zulu (2022) associated climatic shocks with seasonal hunger and malnutrition. Mgbomene (2025) used food insecurity as one of its explanatory variables and applies an ARDL framework to Nigerian data for 1990–2023. The study reports a significant long-run relationship between food insecurity and life expectancy.

More recent evidence increasingly establishes the complete climate–agricultural productivity–food security transmission mechanism, thereby connecting earlier agricultural studies with the broader food-security literature. Studies by Abdou et al. (2023), Abebe et al. (2023), Ndungu et al. (2023), Faye et

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al. (2023) and the FAO (2023) consistently show that temperature and rainfall anomalies reduce cereal productivity and subsequently worsen food insecurity. This relationship is made particularly explicit by Jabbi et al. (2024), whose 34-country analysis found that persistent temperature anomalies reduced maize, sorghum and rice yields, while declining cereal productivity significantly increased the prevalence of undernourishment. Pickson, He, and Boateng (2023) similarly identified both direct and indirect effects of climate shocks on undernourishment, with reduced cereal yields providing an important transmission channel. Njatang et al. (2023), Adesete, Osabohien, and Matthew (2024), and Kinnunen et al. (2024) further confirmed that climate-induced production instability is closely associated with food-supply stress and chronic undernourishment.Mgbomene (2024b) found that environmental degradation, particularly air pollution, adversely affected food productivity, while rainfall significantly influenced food production.

Despite growing evidence that climate variability affects agricultural productivity and food security in Sub-Saharan Africa, three important gaps remain. First, much of the existing literature examines the climate–agricultural productivity or climate–food security relationship separately, with limited empirical attention to the complete pathway linking climate anomalies, agricultural productivity and food insecurity. Second, existing studies often focus on individual countries or specific crops, providing limited comparative evidence across diverse Sub-Saharan African countries and agro-ecological settings. Third, relatively little attention has been given to distinguishing short-run and long-run effects while simultaneously accounting for population and income conditions.

3. METHODOLOGY

This study adopts a quantitative, ex-post facto research design within a panel data framework to examine the relationship between climate change, agricultural productivity, and food security in selected Sub-Saharan African countries.The panel data framework combines cross-sectional and time-series dimensions, thereby making it possible to examine variations across countries and over time while accounting for unobserved country-specific characteristics that may influence food-security outcomes. The study covers eight purposively selected Sub-Saharan African countries namely Cameroon, Democratic Republic of Congo, Kenya, Nigeria, Senegal, South Africa, Uganda, and Zimbabwe, for the period 1990–2024. The countries were selected to provide geographical and contextual diversity in terms of agricultural systems, climate exposure, economic conditions, demographic characteristics, and food-security situations.

The study utilizes annual secondary data obtained from internationally recognized and reliable databases. Data on prevalence of undernourishment, cereal yield, population, and GDP per capita were obtained from the World Bank's World Development Indicators (WDI). Temperature anomaly data were sourced from the Berkeley Earth Climate Database, while rainfall anomaly data were obtained from the National Aeronautics and Space Administration (NASA) POWER Climate Data Portal.The methodology comprises descriptive statistics, correlation analysis, panel unit-root testing, Pooled Mean Group Autoregressive Distributed Lag (PMG-ARDL) estimation, country-specific ARDL estimation, error-correction analysis, and post-estimation diagnostic tests.

Model Specification

The study examines the effect of climate change and agricultural productivity on food security in selected Sub-Saharan African countries. Food security is measured by the prevalence of undernourishment, while climate change is represented by temperature anomaly and rainfall anomaly. Agricultural productivity is proxied by cereal yield, while GDP per capita and population are included as control variables. Cereal yield is measured in kilograms per hectare and is adopted as a measure of agricultural productivity because it provides a direct indication of agricultural land productivity and is particularly relevant to food

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availability in Sub-Saharan Africa.

The functional form of the model is specified as:

$$POU = f(CY, TA, RA, LNGDPPC, LNPOP) \quad (1)$$

This functional relationship is transformed into the following econometric form:

$$POU_{it} = \beta_0 + \beta_1 CY_{it} + \beta_2 TA_{it} + \beta_3 RA_{it} + \beta_4 LNGDPPC_{it} + \beta_5 LNPOP_{it} + \varepsilon_{it} \quad (2)$$

Where:

POU_{it} = prevalence of undernourishment in country i at time t;

CY_{it} = cereal yield in country i at time t;

TA_{it} = temperature anomaly in country i at time t;

RA_{it} = rainfall anomaly in country i at time t;

$LNGDPPC_{it}$ = natural logarithm of GDP per capita in country i at time t;

$LNPOP_{it}$ = natural logarithm of population in country i at time t;

β_0 = intercept term;

β_1–β_5 = slope coefficients of the explanatory variables; and

ε_{it} = stochastic error term.

Here, i represents the cross-sectional unit (country), while t represents the time period. The model therefore allows the study to investigate how variations in climate conditions and agricultural productivity are associated with changes in food-security outcomes while controlling for differences in economic development and population size.

PMG-ARDL Specification

Given the dynamic nature of the relationship under investigation, the empirical model is estimated within a panel ARDL framework. In general terms, the panel ARDL specification can be expressed as:

$$POU_{it} = \mu_i + \Sigma\varphi_{ij} POU_{i,t-j} + \Sigma\beta_{1ij} CY_{i,t-j} + \Sigma\beta_{2ij} TA_{i,t-j} + \Sigma\beta_{3ij} RA_{i,t-j} + \Sigma\beta_{4ij} LNGDPPC_{i,t-j} + \Sigma\beta_{5ij} LNPOP_{i,t-j} + \varepsilon_{it}$$

The PMG estimator permits the short-run coefficients, error variances, and adjustment speeds to differ across countries, while the long-run coefficients are constrained to be common across the panel. This structure enables the analysis to recognize the substantial short-run heterogeneity among the selected countries while testing whether a common long-run relationship exists between climate change, agricultural productivity, and food security.

The selection of appropriate lag lengths is guided by information criteria, particularly the Akaike Information Criterion (AIC) and Schwarz Bayesian Criterion (SBC). The selected lag structure is then used in estimating the dynamic model and identifying the short-run and long-run effects.

Measurement of Variables

The variables used in the empirical model are defined and measured as follows:

Variable	Description	Measurement	Source
POU	Prevalence of undernourishment	Percentage of population	World Bank WDI

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CY	Cereal yield	Kilograms per hectare	World Bank WDI
LNPOP	Population	Natural logarithm of total population	World Bank WDI
LNGDPPC	GDP per capita	Natural logarithm of GDP per capita	World Bank WDI
TA	Temperature anomaly	Degrees Celsius deviation from long-term average	Berkeley Earth
RA	Rainfall anomaly	Millimetres deviation from long-term average	NASA POWER

The a-priori expectations is that higher cereal yield and GDP per capita are expected to reduce the prevalence of undernourishment, while higher temperature anomalies and population growth are expected to increase food insecurity. The effect of rainfall anomalies is expected to be ambiguous, since both rainfall deficits and excessive rainfall can adversely affect agricultural production and food security. This can be shown mathematically as: $\beta_1 < 0$, $\beta_2 > 0$, $\beta_3 > 0$, $\beta_4 < 0$, $\beta_5 > 0$, where β_1 represents cereal yield, β_2 temperature anomaly, β_3 rainfall anomaly, β_4 GDP per capita, and β_5 population.

4. DATA ANALYSIS AND DISCUSSION

Table 1: Descriptive Statistics of the Study Variables (1990–2024)

Variable	Mean	Std. Dev.	Min	Max	Skew.	Kurt.	JB	Prob.
POU	20.34	11.44	3.30	49.50	0.05	1.83	16.18	0.000
LNPOP	17.32	0.85	15.86	19.27	0.37	2.31	12.00	0.002
LNGDPPC	6.89	0.96	4.57	9.06	0.09	2.66	1.71	0.425
CY	1565.71	916.60	309.70	5703.00	2.29	9.13	682.58	0.000
RA	0.00	290.50	-837.73	1902.64	1.63	14.57	1686.64	0.000
TA	0.38	0.11	0.16	0.83	0.79	3.84	37.34	

Source: Author's Computation (2026)

Table 1 report that the mean prevalence of undernourishment (POU) in the sampled countries was 20.34%, with values ranging from a low of 3.30% to a high of 49.50%. These points to wide differences in food security conditions across the countries examined. A standard deviation of 11.44 also signals notable variation in undernourishment across both countries and time.For population, the average log value (LNPOP) was 17.32, with a minimum of 15.86 and a maximum of 19.27. Its comparatively small standard deviation of 0.85 suggests only moderate differences in population size among the selected countries. In the same vein, the mean log of GDP per capita (LNGDPPC) stood at 6.89, spanning from 4.57 to 9.06, indicating variation in income levels and stages of economic development within the sample.

Regarding agricultural performance, cereal yield (CY) averaged 1,565.71 kg/ha, with observations between 309.70 kg/ha and 5,703.00 kg/ha. The large standard deviation (916.60) reflects substantial differences in productivity across countries and years, which could be linked to variation in farming

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methods, climate conditions, and technology uptake.

The statistics also indicate that rainfall anomaly (RA) has a mean close to zero, consistent with anomalies being calculated relative to a long-run average. Nonetheless, the high standard deviation (290.50) and broad range—from −837.73 to 1,902.64—show marked variability in rainfall over the period studied. Similarly, temperature anomaly (TA) averaged 0.381°C, with values between 0.157°C and 0.825°C, underscoring the continuing increase in temperature anomalies across Sub-Saharan Africa.

Skewness results suggest that most variables are positively skewed, meaning their distributions are moderately skewed to the right. Kurtosis values further indicate that cereal yield and rainfall anomaly are strongly leptokurtic, implying the presence of extreme values or outliers. In addition, the Jarque–Bera test outcomes imply that all variables except GDP per capita deviate from normality at conventional significance levels. Nevertheless, this is not a major issue for panel data analysis, especially when using large-sample estimation methods such as the Pooled Mean Group (PMG) estimator.

Table 2: Correlation Matrix of the Study Variables

Variables	POU	LNPOP	LNGDPPC	CY	RA	TA
POU	1.000					
LNPOP	-0.316	1.000				
LNGDPPC	-0.570	0.198	1.000			
CY	-0.502	0.230	0.645	1.000		
RA	0.065	0.008	0.026	0.020	1.000	
TA	0.266	-0.197	-0.285	-0.227	-0.092	1.000

Source: Author's computation (2026)

Table 2 show that the prevalence of undernourishment (POU), used as a measure of food insecurity, has negative correlations with population (LNPOP), gross domestic product per capita (LNGDPPC), and cereal yield (CY). In particular, POU is correlated with LNPOP, LNGDPPC, and CY at -0.316, -0.570, and -0.502, respectively. These inverse associations imply that better economic performance and higher agricultural productivity are linked to lower levels of undernourishment in the selected Sub-Saharan African countries.The most pronounced negative relationship is between POU and GDP per capita (r = -0.570), suggesting that higher income levels are generally connected with better food security outcomes. Likewise, the negative correlation between POU and cereal yield (r = -0.502) indicates that greater agricultural output helps reduce food insecurity.

Rainfall anomaly (RA) shows a weak positive correlation with POU (r = 0.065), implying that variations in rainfall may negatively affect food security, though the relationship is small in magnitude. By comparison, temperature anomaly (TA) displays a moderate positive correlation with POU (r = 0.266), pointing to the possibility that increasing temperatures may worsen food security conditions in the region.Looking across the explanatory variables, the largest correlation appears between GDP per capita (LNGDPPC) and cereal yield (CY), with a coefficient of 0.645. Since this value is still below the common 0.80 cutoff used to signal serious multicollinearity, the correlation matrix indicates that multicollinearity is not likely to be a major concern in the subsequent econometric analysis.

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Table 3: Levin, Lin and Chu (LLC) Panel Unit Root Test Results

Variable	Level Statistic (Prob.)	First Difference Statistic (Prob.)	Order of Integration
POU	-2.1560 (0.0155)	—	I(0)
LNPOP	-2.6057 (0.0046)	—	I(0)
LNGDPPC	0.4521 (0.6744)	-7.3714 (0.0000)	I(1)
CY	0.2743 (0.6081)	-13.3281 (0.0000)	I(1)
RA	-3.8097 (0.0001)	—	I(0)
TA	-1.4484 (0.0738)	-7.0313 (0.0000)	I(1)

Source: Author's Computation (2026)

To determine the stationarity characteristics of the variables used in this study, the Levin, Lin and Chu (LLC) panel unit root test was applied. The outcomes reported in Table 3 indicate that the variables have a mixed integration order. In particular, prevalence of undernourishment (POU), population (LNPOP), and rainfall anomaly (RA) were stationary in levels, meaning they are integrated of order zero, I(0). The LLC test statistics for these variables were statistically significant at conventional significance levels.In contrast, gross domestic product per capita (LNGDPPC), cereal yield (CY), and temperature anomaly (TA) were non-stationary at levels but became stationary after first differencing, suggesting they are integrated of order one, I(1). The LLC statistics based on first differences for these variables were significant at the 1 percent level.

Table 4: Panel Cointegration Test Results

Test	Statistic	Probability	Decision
Pedroni Panel v	-0.8078	0.7904	No cointegration
Pedroni Panel rho	2.0596	0.9803	No cointegration
Pedroni Panel PP	1.8414	0.9672	No cointegration
Pedroni Panel ADF	3.2835	0.9995	No cointegration
Group rho	3.0655	0.9989	No cointegration
Group PP	2.4771	0.9934	No cointegration
Group ADF	3.6287	0.9999	No cointegration
Kao ADF	-0.9914	0.1608	No cointegration

Source: Author's Computation (2026)

The Pedroni and Kao residual-based panel cointegration tests were employed to determine whether a long-run equilibrium relationship exists among food security, climate change, and agricultural productivity variables in the selected Sub-Saharan African countries.

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The Pedroni test results indicate that none of the within-dimension or between-dimension statistics are statistically significant at the conventional 5 percent level. Consequently, the null hypothesis of no cointegration is accepted. Similarly, the Kao residual cointegration test produced an ADF statistic of -0.9914with a probability value of 0.1608**,** which is also statistically insignificant.The results therefore suggest the absence of a stable long-run equilibrium relationship among the variables over the study period. Consequently, the null hypothesis of no cointegration is accepted.

Table 5: VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-4390.781	NA	1.93E+10	40.7109	40.8047	40.7488
1	-2223.209	4194.655	51.7812	20.9742	21.6305	21.2393
2	-1898.655	610.0407	3.5822	18.3024	**19.5212***	**18.7948***
3	-1838.645	109.4625	2.8735	18.0801	19.8614	18.7997
4	-1792.178	82.1784	**2.6172***	**17.9831***	20.3271	18.9301
5	-1770.945	36.3712	3.0179	18.1199	21.0264	19.2941
6	-1730.664	66.7624	2.9254	18.0802	21.5493	19.4817
7	-1701.435	46.8201	3.1518	18.1429	22.1745	19.7717
8	-1662.175	60.7079	3.1070	18.1127	22.7069	19.9688

Source: Author's computation (2026)

The optimal lag length for the panel ARDL estimation was determined using the Vector Autoregressive (VAR) lag order selection criteria. The Akaike Information Criterion (AIC) selected lag four, while both the Schwarz Criterion (SC) and Hannan-Quinn Criterion (HQ) selected lag two. Following econometric literature, particularly in macroeconomic panel studies with relatively small sample sizes, the Schwarz and Hannan-Quinn criteria are generally preferred because they produce more parsimonious models and avoid over-parameterization. Consequently, lag two was adopted for the PMG-ARDL estimation, resulting in the specification PMG-ARDL(2,1,1,1,1,1).

Table 6: PMG-ARDL Long-Run Estimates

Variable	Coefficient	Std. Error	t-Statistic	Probability
LNPOP	5.557587**	2.398034	2.317560	0.0214
LNGDPPC	-0.219486	0.751141	-0.292203	0.7704
CY	0.001624***	0.000554	2.929053	0.0038
RA	0.000915	0.000745	1.228521	0.2206
TA	5.450663	7.535572	0.723324	0.4703

Source: Author's computation using (2026)

The long-run estimation results reveal that population growth exerts a positive and statistically significant effect on food insecurity in Sub-Saharan Africa. Specifically, the coefficient of population growth (LNPOP) is estimated at 5.5576 and is statistically significant at the 5 percent level (p = 0.0214). This implies that an increase in population growth contributes significantly to worsening food insecurity in the

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long run. This finding may be attributed to increasing pressure on food demand, agricultural resources, and household consumption requirements within the region.

Economic growth, measured by GDP per capita (LNGDPPC), exhibits a negative coefficient of -0.2195, suggesting that economic growth tends to reduce food insecurity. However, the relationship is statistically insignificant (p = 0.7704), indicating that improvements in income levels have not translated effectively into better food security outcomes in the selected countries.

Agricultural productivity, proxied by cereal yield (CY), has a positive and statistically significant coefficient of 0.001624 (p = 0.0038). This result suggests that increases in cereal yield are significantly associated with changes in food insecurity. The positive sign may reflect structural inefficiencies in agricultural production systems, poor distribution mechanisms, post-harvest losses, and unequal access to food resources across Sub-Saharan Africa.

Rainfall anomaly (RA) has a positive but statistically insignificant coefficient of 0.000915 (p = 0.2206), implying that long-run variations in rainfall do not significantly affect food insecurity in the sampled countries.

Similarly, temperature anomaly (TA) exhibits a positive but statistically insignificant coefficient of 5.4507 (p = 0.4703), suggesting that temperature variations do not exert a significant long-run effect on food insecurity during the study period.

Table 7: PMG-ARDL Short-Run Dynamics and Error Correction Model

Variable	Coefficient	Std. Error	t-Statistic	Probability
COINTEQ(-1)	-0.067698**	0.032673	-2.071976	0.0395
D(POU(-1))	0.553903***	0.098914	5.599852	0.0000
D(LNPOP)	-18.47768	26.52596	-0.696588	0.4868
D(LNGDPPC)	-0.479963*	0.268378	-1.788383	0.0751
D(CY)	0.000138	0.000715	0.192506	0.8475
D(RA)	0.000081	0.000160	0.505403	0.6138
D(TA)	0.142456	0.352522	0.404105	0.6865
C	-5.404557**	2.532492	-2.134087	0.0340

Source: Author's computation (2026)

The error correction coefficient is negative and statistically significant at the 5 percent level (β = -0.0677, p = 0.0395), indicating the existence of a long-run equilibrium relationship among the variables. The coefficient suggests that approximately 6.8 percent of short-run disequilibrium is corrected annually, implying a relatively slow adjustment process toward long-run equilibrium.The lagged dependent variable, D(POU(-1)), has a positive and highly significant coefficient (β = 0.5539, p < 0.01), indicating strong persistence in food insecurity dynamics. This suggests that previous food insecurity conditions significantly influence current food insecurity levels across the selected Sub-Saharan African countries.

Population growth exhibits a negative but statistically insignificant short-run effect on food insecurity (β = -18.4777, p = 0.4868), implying that short-run population changes do not significantly influence food insecurity outcomes.Economic growth has a negative coefficient and is weakly significant at the 10 percent level (β = -0.4800, p = 0.0751), indicating that increases in income levels may contribute to reducing food insecurity in the short run.Agricultural productivity, represented by cereal yield, does not exert a

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statistically significant short-run effect on food insecurity (β = 0.000138, p = 0.8475). Likewise, rainfall anomalies (β = 0.000081, p = 0.6138) and temperature anomalies (β = 0.1425, p = 0.6865) do not significantly influence food insecurity in the short run.

Table 8: Summary of Country-Specific Long-Run ARDL Estimates

Country	LNPOP	LNGDPPC	CY	RA	TA
Cameroon	-16.3682	-1.0106	-0.0210*	-0.0021	-94.5915*
	(0.1973)	(0.8904)	(0.0080)	(0.6203)	(0.0098)
DR Congo	-40.5097	6.6554	0.1616	0.0143	-11.9036
	(0.8171)	(0.0214)	(0.1811)	(0.3852)	(0.7896)
Nigeria	6.1687	0.8535	0.0013	-0.0007	-2.1863
	(0.0836)	(0.3875)	(0.7461)	(0.4257)	(0.8119)
Senegal	-46.8372*	-4.6593	0.0127*	0.0038	-27.1272
	(0.0000)	(0.1586)	(0.0001)	(0.4156)	(0.0182)
South Africa	3.2035	-2.2403*	0.0024*	0.0055*	-5.7250
	(0.6890)	(0.0324)	(0.0198)	(0.0104)	(0.4747)
Zimbabwe	-66.6765*	8.6267*	-0.0131*	0.0052	3.6283
	(0.0000)	(0.0002)	(0.0464)	(0.1885)	(0.6725)

Note: Figures in parentheses are probability values. * denote statistical significance at the 5% level. Kenya and Uganda are not included because their ARDL bounds tests did not establish a long-run relationship.

The country-specific long-run estimates reveal substantial differences in the relationship between climate change, agricultural productivity and food insecurity across the selected countries. Cereal yield (CY) has a statistically significant effect in Cameroon, Senegal, South Africa and Zimbabwe, although the direction varies across countries. In Cameroon and Zimbabwe, higher cereal yield is associated with lower prevalence of undernourishment, consistent with the expectation that improvements in agricultural productivity strengthen food availability. However, the positive coefficients for Senegal and South Africa suggest that higher cereal yield does not necessarily translate directly into improved food security, possibly reflecting country-specific structural and distributional conditions.

The results also show important differences in the effects of temperature anomalies (TA) and economic conditions. Temperature anomalies significantly reduce undernourishment in Cameroon and Senegal, while their effects are statistically insignificant in the other countries. GDP per capita is significant in DR Congo, South Africa and Zimbabwe, but its direction differs across countries. Population is statistically significant only in Nigeria, Senegal and Zimbabwe.

Table 9: Summary of Country-Specific Long-Run ARDL Estimates

Country	D(POU(-1))	D(LNPOP)	D(LNPOP(-1)	D(LNGDPPC)	D(RA)	D(RA(-1))	D(TA)
Kenya	0.5581*	0.000022*	-0.000025*	—	0.001081	—	—

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	(0.0001)	(0.0368)	(0.0256)	—	(0.3143)	—	—
Uganda	0.3456*	—	—	-1.8713	0.0002	0.0053*	12.2908*
	(0.0140)	—	—	(0.3721)	(0.8990)	(0.0033)	(0.0120)

Note: p-values are reported in parentheses. * denote statistical significance at the 5% level. A dash (—) indicates that the variable/lag was not reported in the corresponding short-run specification.

For Kenya, the lagged dependent variable is positive and statistically significant, while population growth has a small but statistically significant short-run effect in both the current and first-lagged changes. The current change in rainfall anomaly is statistically insignificant.For Uganda, the lagged dependent variable is positive and significant. Changes in GDP per capita and the contemporaneous rainfall anomaly are statistically insignificant, whereas the lagged rainfall anomaly and temperature anomaly are statistically significant in the short run.

Discussion of the Findings

The findings reveal that the determinants of food insecurity in the selected Sub-Saharan African countries are multidimensional, with population pressure, agricultural productivity, economic conditions and climate variability producing different effects across countries. The positive and statistically significant long-run effect of population growth (5.5576; p = 0.0214) suggests that increasing demographic pressure can worsen food insecurity by raising food demand and pressure on land and other agricultural resources. This finding is consistent with the broader evidence of Katengeza et al. (2022) and Chisanga and Zulu (2022), who associate climatic and agricultural pressures with seasonal hunger and malnutrition. The country-specific results, however, show that the population effect is not uniform, being significant in Senegal and Zimbabwe and only weakly significant in Nigeria. This variation supports the argument of Nhamo and Ndlela (2021) that structural and adaptive conditions determine the extent to which pressures on agricultural systems translate into food insecurity.

The coefficient of GDP per capita is negative but statistically insignificant in the long run, while its short-run coefficient is negative and weakly significant. This suggests that improvements in income may reduce food insecurity, but the effect is not sufficiently strong to guarantee sustained long-run improvements. The country-specific estimates reinforce this mixed outcome, with GDP per capita significantly reducing food insecurity in South Africa but showing positive significant effects in DR Congo and Zimbabwe. This finding is consistent with the broader argument in Ochieng et al. (2021) that socioeconomic and productive capacity influence the ability of households and agricultural systems to withstand shocks. It also complements Abdou et al. (2023) and Abebe et al. (2023), who demonstrate that vulnerability to food insecurity is strongly conditioned by socioeconomic and structural circumstances.

The result for cereal yield (CY) is particularly important. Its positive and statistically significant pooled long-run coefficient (0.001624; p = 0.0038) differs from the expected negative relationship. This does not necessarily imply that greater agricultural productivity causes food insecurity; rather, it suggests that increases in cereal production do not automatically translate into improved food access. Problems of distribution, market access, post-harvest losses, food prices and unequal purchasing power may weaken the transmission from agricultural production to food security. This interpretation is consistent with Eze and Nwachukwu (2021), who show that climate-related agricultural effects can extend beyond production to food prices, and with Pickson, He, and Boateng (2024), who identify both direct and indirect climate effects on undernourishment, with agricultural productivity serving as an important transmission channel. The country-specific estimates strengthen this interpretation: cereal yield significantly reduces food

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insecurity in Cameroon and Zimbabwe but increases it in Senegal and South Africa. Thus, the findings demonstrate that agricultural productivity alone is not sufficient to guarantee food security.

The insignificant pooled effects of rainfall and temperature anomalies also require careful interpretation. The absence of significant direct effects in the pooled model does not contradict the substantial evidence that climate variability affects agricultural production. Ayanlade and Radeny (2019) found that temperature increases and rainfall deficits adversely affected maize yields in Ethiopia and Kenya, while Mubanga et al. (2019) documented substantial maize-yield losses during drought years in Zambia. Similarly, Sultan et al. (2020) found that temperatures exceeding crop-specific thresholds reduced millet and sorghum yields, while Wossen et al. (2020) reported significant temperature effects on rice and maize production in Nigeria. These studies focus primarily on the climate–agricultural productivity link, whereas the present study examines the subsequent food-security outcome. Climate shocks may therefore affect food insecurity indirectly through cereal yields, prices, household income and food availability, causing their direct pooled effects to become statistically insignificant.

The country-specific estimates nevertheless provide clear evidence that climate effects remain important in particular national contexts. Temperature anomalies significantly affect food insecurity in Cameroon and Senegal, rainfall anomaly is significant in South Africa, while lagged rainfall and temperature anomalies are significant in Uganda in the short run. These findings closely correspond with Kilavi et al. (2020), Taffesse and Tadesse (2021), Kogo et al. (2021), and Codjoe and Atarah (2021), who emphasize that the effects of rainfall depend not only on its amount but also on its timing, intensity and distribution. Excess rainfall can generate flooding and erosion, whereas insufficient or delayed rainfall can produce drought and disrupt agricultural calendars. The findings also support Alimagham et al. (2024), whose evidence on rain-fed cereal crops in Sub-Saharan Africa highlights substantial differences in climate impacts and adaptation across production environments.

The significant error-correction coefficient confirms the existence of a long-run adjustment mechanism, with approximately 6.8% of disequilibrium corrected annually. The relatively slow speed of adjustment is consistent with the adaptive-capacity argument advanced by Ochieng et al. (2021) and Nhamo and Ndlela (2021). Where irrigation, improved seeds, fertilizer, extension services, storage and market integration are weak, climate and agricultural shocks can have persistent consequences. The findings therefore support the more recent evidence of Jabbi et al. (2024), Njatang et al. (2024) and Kinnunen et al. (2024) that climate-induced instability in agricultural production can translate into persistent food-supply stress and undernourishment. The positive and highly significant lagged dependent variable indicates strong persistence in food insecurity. This is consistent with the broader evidence of Katengeza et al. (2022) and Chisanga and Zulu (2022), which links climatic and agricultural shocks to recurring seasonal hunger and malnutrition. The persistence observed in the present study suggests that food insecurity is not simply a temporary consequence of a particular year's climatic shock; rather, it can become entrenched where households and agricultural systems lack sufficient capacity to recover. The findings therefore complement the recent evidence of FAO, IFAD, UNICEF, WFP, and WHO (2024), which continues to emphasize the interconnected nature of climate vulnerability, agricultural instability and food insecurity in Africa.

5. CONCLUSION

This study examined the relationship between climate change, agricultural productivity and food security in selected Sub-Saharan African countries over the study period. The findings demonstrate that food security is influenced by a combination of agricultural, climatic, demographic and economic factors, although the magnitude and direction of these effects vary considerably across countries. The PMG-ARDL results indicate the existence of a long-run relationship among the variables, while the country-specific

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ARDL estimates reveal substantial heterogeneity in the responses of individual countries.The study finds that agricultural productivity remains an important component of food security, although its effect is not uniform across countries. Similarly, population growth exerts significant food-security pressure in some countries, while economic development provides varying degrees of protection against food insecurity. Although the pooled results do not establish significant direct long-run effects of rainfall and temperature anomalies, the country-specific estimates demonstrate that climate variability remains an important source of food-security vulnerability in particular national contexts. This suggests that climate shocks may operate partly through agricultural productivity and wider socioeconomic channels.

Thus, the study concludes that food security in Sub-Saharan Africa cannot be addressed through a single policy intervention. Sustainable improvement requires an integrated approach combining climate adaptation, agricultural productivity enhancement, economic development, institutional strengthening and appropriate demographic and food-system policies. At the same time, the substantial country-level differences identified by the study demonstrate the need for policies that are tailored to national climatic, agricultural, economic and institutional circumstances.Based on the empirical findings and the objectives of the study, the following recommendations are proposed:

Governments in Sub-Saharan Africa should strengthen investments in agricultural productivity through improved seed varieties, fertilizer use, agricultural research, extension services, mechanization and modern farming technologies. Access to affordable agricultural finance should also be expanded, particularly for smallholder farmers. These measures should be complemented by investment in rural roads, storage facilities, electricity and agricultural marketing infrastructure to reduce post-harvest losses and improve the movement and availability of food. Given the significant role of cereal productivity in the estimated models, strengthening the agricultural production base remains central to improving food security.

Countries exposed to temperature-related agricultural risks should strengthen climate adaptation measures, including the development and dissemination of heat-tolerant and drought-resistant crop varieties, climate-smart agricultural practices, improved extension services and reliable climate information. Weather forecasting and early-warning systems should also be strengthened to enable farmers and policymakers to anticipate temperature-related risks and respond before they translate into significant agricultural and food-security losses.

Governments should reduce excessive dependence on rain-fed agriculture by expanding irrigation and water-management infrastructure. Investment should also be directed towards drought preparedness, improved drainage, water conservation, climate-smart farming and seasonal weather forecasting. Effective early-warning systems should be developed to enable farmers to respond to both rainfall deficits and excessive rainfall. These measures are particularly important given the country-specific evidence that rainfall variability can affect food-security outcomes.

Economic growth should be accompanied by policies that improve household purchasing power and access to food. Governments should therefore promote employment creation, rural development, agricultural investment and social and productive infrastructure alongside broader economic expansion. Particular attention should be given to vulnerable rural households whose livelihoods depend heavily on agriculture. Economic development should be made more inclusive so that improvements in national income translate into improved food access and living standards.

Countries experiencing substantial demographic pressure should integrate population dynamics into agricultural and food-security planning. Food production, rural infrastructure, employment opportunities and food-distribution systems should expand in line with population growth. Agricultural intensification and productivity-enhancing investments should receive particular attention in areas where increasing

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population is placing pressure on available land and food resources. This is especially relevant to the evidence of significant population effects in some of the countries examined.

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