

Mitigating Climate-Induced Decline in Agricultural Production in the SADC Region: Towards A Climate-Smart Agriculture

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Abstract

Agriculture, a cornerstone of global food security and economic development and the main source of income for millions of people in Southern Africa, faced unprecedented challenges stemming from climate change. The study examined the impact of climate change variables on agricultural output in selected SADC countries to recommend strategies to reduce climate-induced declines in agricultural productivity. Using panel data analysis from 2000 to 2021, the study revealed that temperature negatively and precipitation positively influenced agricultural production in SADC countries. Thus, the study revealed that higher rainfall was associated with increased agricultural productivity. The study findings aligned with a priori expectations as most SADC countries relied heavily on rain-fed agriculture. The study also revealed that trade openness and population growth had a statistically insignificant effect on agricultural output. Thus, the study concluded that agriculture in the SADC region was highly sensitive to climatic conditions. Therefore, the study recommended promotion and strengthening of climate-smart agriculture through conservation farming, crop diversification, drought-tolerant seed varieties and efficient irrigation systems. In addition, the study recommended increased irrigation infrastructure, regional collaboration in research and technology transfer and integration of climate adaptation strategies into agricultural development policies. These helped in promoting resilience, food security and sustainable livelihoods in the SADC region.

Keywords: Food Security, Agriculture Productivity, Climate-smart Agriculture

Introduction

Agriculture, which was a cornerstone of global food security and economic development and the main source of income for millions of people in Southern Africa, faced unprecedented challenges stemming from climate change. (Semosa, 2025; Farah et al., 2025). This was because climate change and agriculture were inextricably linked. (Nugroho et al., 2023). Rising temperature changes, erratic rainfall patterns and extreme weather events led to the disruption of the agriculture sector, posing threats to food security and rural livelihoods globally. (Mirzabaev et al., 2023). According to Farah et al. (2025), climate change directly impacted agricultural productivity through accelerating soil erosion, depleting soil fertility, intensifying drought and increasing pests and disease prevalence. These disruptions negatively affected food production systems, thereby reducing crop yields and livestock production. As a result, this increased food insecurity at both local and global levels. Thus, global projections indicated that food production could decline by 14% by 2050, with most affected areas being Sub-Saharan Africa, Asia and Latin America. (Akpa, 2024; Farah et al., 2025).

Literature shows that as agricultural productivity shrank due to climate change effects, food shortages became more frequent, which further increased malnutrition and economic instability. (Kompas et al., 2024). In addition, with increased climate change, climate induced-stressors disrupted global supply chain, food distribution and destabilised trade, thereby increasing food prices and financial strain on both consumers and producers (Farah et al., 2025). The Southern African Development Community (SADC) was not an exception as most developing countries in the region depended on agriculture, particularly farming. (Semosa, 2025). This warranted an investigation to unearth whether extreme temperature changes were the leading cause of agricultural productivity decline in the SADC region.

The SADC region was currently experiencing and would continue to experience several climate hazards such as drought, extreme rainfall, strong winds and heat waves, among others. According to the IPCC 6th assessment report of 2022, the average annual surface temperature in Southern Africa increased between 1.04 °C and 1.44 °C from 1961 to 2015. (IPCC, 2022). Heatwaves increased over the last four decades owing to human-induced climate change, mean precipitation has decreased since the 1980s, the number and intensity of extreme rainfall events have increased and drought periods have also increased in the region (IPCC, 2022). The occurrence of droughts in the region was likely to worsen owing to increases in temperature and fluctuations in precipitation. (SADC Secretariat, 2021; IPCC, 2022).

As the region grappled with climate change effects, agricultural production needed to increase by approximately 50% by 2050 to meet the demands of the growing population. (SADC Secretariat, 2021). Thus, these extreme shifts could exacerbate years of investment and progress in national development. Thus, the agricultural sector remained highly vulnerable to climate change as it was largely rainfed. Farmers tended to have limited access to finance, disparate access to information and poor access to infrastructure. It was noteworthy that climate change affected the whole chain of actors in the sector. Thus, there was a need for action to support the whole value chain and increase agriculture's contribution to the Gross Domestic Product (GDP) of SADC countries. It was against this background that the study sought to estimate the extent to which climate change affected agricultural output in the SADC region and proffered solutions. Thus, the main objective of the study was to determine the impact of climate change, proxied by temperature changes, on the climate change in the SADC region. The study also estimated the impact of climate stressors (precipitation) on agricultural production in the SADC region.

Literature Review

Theoretical literature

The Ricardian Theory of Agricultural Land Rent theory, adapted for environmental economics, states that the economic value of farmland is capitalised from its long-term productivity, which is inherently dependent on climate conditions. (Bidard, 2014). Through analysis of ways fluctuations in climate variables (temperature, precipitation) affect land values and farm revenues, this theory captures the net effect of climate change, inclusive of the autonomous adaptations farmers make. (Ayub et al., 2024). It moves beyond simple crop yield models, not providing a more comprehensive economic assessment.

Furthermore, Adaptive Capacity Theory explains from vulnerability and resilience literature, arguing that the impact of a shock like climate change is not determined by the exposure alone. (Andrijevic et al., 2023). It is explained by the system's ability to adapt. This framed

agricultural outcomes as a function of a farmer's or nation's access to resources (technology, credit, information), institutions (governance, policies), as well as social capital. This theory was essential for explaining heterogeneous impacts across Zimbabwe and for identifying key leverage points for building resilience through targeted interventions.

The Global and Regional Empirical Studies

The empirical evidence showed the impact of climate change on agriculture; the impact, magnitude and nature of these effects varied significantly.

Negative Yield and Productivity Effects

A consistent theme across the literature is the direct negative impact of rising temperatures and changing precipitation patterns on crop yields. Regan et al. (2019) estimate that extreme weather disasters have reduced global crop yields by up to 10%. This is corroborated by large-scale analyses by Burke and Tanutama (2019), using data from over 11,000 districts, found out that economic output peaks at cool temperatures and declines steeply thereafter. Warming since 2000 has already cost the global economy trillions in lost output. In China, Chen and Gong (2021) found out that extreme heat negatively affected agricultural Total Factor Productivity (TFP), which was a measure of overall efficiency. Similarly, in India, Guntukula (2020) observed that variations in rainfall and temperature significantly impacted the yields of major staples like rice and wheat, threatening national food security.

Heterogeneity of Impacts and the Important Role of Adaptive Capacity

A critical insight from the literature is the unambiguous heterogeneity in how different regions experience climate change. Regan et al. (2019) explicitly link this heterogeneity to a country's adaptive capacity, which is largely a function of policy choices and structural preparedness. This was unambiguously illustrated by the finding that anthropogenic climate change reduced global agricultural TFP by about 21% since 1961, with warmer, less-developed regions, for example, Africa and Latin America, suffering reductions of 26–34%. (Aragón et al., 2021). This difference arose not necessarily because poor regions were more sensitive to a given temperature shock, but because they were far more frequently exposed to damaging temperature levels. (Burke & Tanutama, 2019).

The capacity for adaptation is a key differentiator. Chen and Gong (2021) demonstrated that in China, longer-run adaptation, through adjustments in labour, fertiliser and machinery, offset 38% of the short-run TFP losses from extreme heat. Conversely, Nkwi et al. (2023) note that smallholder farmers in Africa are usually slow to adapt to weather variations due to poverty, low infrastructural development and compounding socioeconomic challenges, for example, health crises and food insecurity. This pointed out that adaptive capacity was not automatic but must be intentionally built.

The Duality of the Agriculture-climate Relationship

The literature also recognises the dual role of agriculture as both a victim and a contributor to climate change. As pointed out by Praveen and Sharma (2019), agricultural practices are significant sources of greenhouse gases (GHGs), for example, methane and nitrous oxide. This created a feedback loop, where efforts to expand agricultural land in response to climate-driven food shortages led to further GHG emissions and forest loss, as identified in sub-Saharan

Africa. (Nkwi et al., 2023). Therefore, effective responses must address both adaptation and mitigation, a concept central to Climate-Smart Agriculture (CSA).

Thematic Findings for Policy and Adaptation

The reviewed empirical studies pointed to several critical areas for intervention.

The Imperative of Technological Innovation and Climate-Smart Agriculture (CSA)

Technological progress is identified as a primary avenue for building resilience. Adamu and Negeso (2020) specifically recommend technological innovation to counteract rising temperatures in Ethiopia. Guo et al. (2022) conclude that the impact of climate change on technical progress is greater than on technical efficiency, urging a focus on developing new agricultural technologies suited to changing climates. The promotion of Climate-Smart Agriculture (CSA) is a direct policy response to this need. However, Barasa et al. (2021) caution that in Africa, while many countries have endorsed CSA, most lack the national Climate-Smart Agriculture Investment Plans (CSAIPs) necessary to guide effective integration of policies and stakeholder inputs.

The Critical Role of Policy and Financial Development

Sound agricultural policy is a recurring recommendation. Khan et al. (2020), in their study on Pakistan, stress that a sound agricultural policy is necessary for successful adaptation to ensure high production and net returns. Chandio et al. (2023) highlight the role of financial development in Southeast Asia, finding that stable financial systems could enhance farmers' ability to adapt. However, they note an inverted U-shaped relationship, suggesting that beyond a point, financial development may not yield further benefits without robust governance of climate finance.

The Importance of Regional Specificity and Long-Run Planning

The spatial variability of climate impacts necessitated localised responses. Zhou et al. (2024) projected that in China, while northern regions may benefit from climate change, major agricultural areas, for example, the Huang-Huai-Hai Region, would be negatively affected. Similarly, Ortiz-Bobea et al. (2018) found out that the climate sensitivity of US agriculture was increasing in the Midwest due to regional specialisation in climate-sensitive crops. This underlined the need for location-specific adaptation strategies. Furthermore, distinguishing between short- and long-run impacts was crucial. Chandio et al. (2020) found out that in East Africa, temperature variability had a long-run impact while precipitation variability was a short-run shock. This meant that adaptation measures must be tailored to different time horizons.

Synthesis of Literature and Implications for Zimbabwe

An extensive literature review clearly established that climate change had a significant negative impact on agricultural output globally, with developing nations experiencing disproportionately severe effects due to lower adaptive capacity, reliance on rain-fed agriculture and heightened exposure to damaging climatic changes. Studies from Ethiopia, India, Pakistan and China consistently showed yield and productivity losses attributed to rising temperatures and erratic precipitation. Research across Africa underscored the critical roles of

policy, financial development and Climate-Smart Agriculture (CSA) in building resilience. On the other hand, there was a notable gap in context-specific empirical evidence for Zimbabwe. While the country shared vulnerabilities common to the region such as economic reliance on climate-sensitive agriculture the existing literature lacked a comprehensive study that quantified the magnitude and transmission channels (for example, average annual temperature, average annual precipitation, trade openness and population growth) impact on agricultural output. This gap was particularly urgent given Zimbabwe's unique agro-ecological zones and socioeconomic landscape, highlighting the need for the current study to generate localised, empirical data that can inform effective, context-specific adaptation policies and investment strategies to safeguard national food security and economic stability.

In brief, the global literature unequivocally confirmed the severe threat climate change posed to agriculture, mainly for developing nations with limited adaptive capacity. While this established a clear context for Zimbabwe, a significant research gap persisted. The absence of a dedicated, empirical study quantifying the specific impacts on Zimbabwe's unique agricultural systems hindered the development of effective, localised adaptation strategies. This study was therefore essential to providing the evidence base needed to inform resilient and sustainable agricultural policies for the nation.

Research Methodology

The study employed a panel dataset that included Angola, Botswana, DRC, Eswatini, Madagascar, Mauritius, South Africa, Tanzania and Zimbabwe. The dependent variable of the study was crop production index and the independent variables were yearly average air temperature and average yearly precipitation. The control variables were trade openness and population growth. The study employed the Panel Regression analysis. Diagnostic tests for serial correlation, autocorrelation and heteroscedasticity were conducted to ensure model robustness. STATA 16 was used to carry out all the estimations.

Data Description

The study employed a balanced panel dataset that included Angola, Botswana, DRC, Eswatini, Madagascar, Mauritius, South Africa, Tanzania and Zimbabwe from 2000 to 2021 due to data availability. This resulted in 198 observations in total. The countries used were chosen based on data availability and the significance of agriculture and trade to their economies. The dependent variable was agricultural output and the independent variables were yearly average temperature and overall yearly precipitation. The control variable was trade openness. All data used was taken from the World Bank data repository. These variables were summarised and justified as follows:

Agricultural output (Crop production index) ($cpind_t$) - Crop production index measures the amount of crops produced from the agricultural sector as compared to the base period values from 2014 to 2016, with a value of 100.

Air temperature ($temp_t$) - Air temperature in degrees Celsius ($^{\circ}\text{C}$) measures the effect of climate heat stress on agricultural production levels.

Precipitation ($precip_t$) - Precipitation measures the annual precipitation in millimetres, which affected the soil moisture and water availability for agricultural production

Trade Openness ($topen_t$) - Trade openness measures the extent to which the economy is engaging in trade activities with other countries.

Model specification

The study used the panel regression analysis. Following the empirical studies and theoretical arguments on the determinants of agricultural output, the following multiple regression model was estimated.

$$CPIND_{it} = \beta_0 + \beta_1 TEMP_{it} + \beta_2 PRECIP_{it} + \beta_3 TOPEN_{it} + \beta_4 POPG_{it} + \mu_{it} \dots \dots \dots (1)$$

Where.

CPIND - crop production index, TEMP- average annual temperature, PRECIP – average annual precipitation, TOPEN – trade openness and POPG – population growth, μ - error term

Model Estimation

Regression analysis required the variables to be tested for the unit root and confirm the order of integration. Therefore, the following procedures were followed in the model estimation.

Pre-estimation Tests

Descriptive statistics were provided for each variable, which showed the summary of the data by outlining the key features of the dataset. Measures of central tendency, dispersion and range were used to summarise the data. The presence of a unit root in a time series suggested that the series was non-stationary, which led to spurious regressions if not addressed appropriately. This study used the Augmented Dickey-Fuller (ADF) test and Phillips-Perron (PP) Fisher, which were among the frequently used methods to test for a unit root. All the variables were tested using both methods and were considered stationary if it was stationary according to both methods. The null hypothesis of the tests was that there was a unit root. Additionally, the study checked for multicollinearity using the correlation matrix. If the correlation coefficient was equal to or greater than 0.8 (rule of thumb), then there was a presence of multicollinearity. The presence of multicollinearity could be dealt with by dropping the correlated variables.

Hausman Test

The Hausman test was used to detect the violation of the assumption of the Random Effects Model (REM) that the independent variables were not correlated to the unit effects. If they were not correlated, then the coefficient estimates in the Fixed Effects Model (FEM) estimation ($\hat{\beta}_{FE}$) would be like the coefficient estimates in the REM ($\hat{\beta}_{RE}$). If these effects were correlated with the independent variables, the FEM estimator was consistent and efficient, while the REM would be inconsistent. (Baltagi, 2008). In using the Hausman test, the null hypothesis was that the FEM and REM were not different; thus, if the p-value of the test was less than 5% (rule of thumb), this null hypothesis was rejected and the REM was rejected in favour of FEM. If the null hypothesis was not rejected, the REM was safely free from bias; it was chosen over the FEM.

Post-estimation Tests

The study estimated the FEM based on the outcome of the Hausman test. The post-diagnostic tests were conducted on the FEM and it failed some of these tests. To choose between the fixed effects model and the pooled OLS model, the p-value for the F-test in the fixed effects was used. The diagnostic tests showed that the model failed the heteroscedasticity, autocorrelation

and cross-sectional dependency test since the values were less than 5%, 5% and 10%, respectively. Since the model failed the diagnostic tests, the study resorted to the OLS model with panel corrected standard errors (PCSE). PSCE model accounted for cross-sectional dependence, autocorrelation and heteroscedasticity, hence improving the reliability of statistical inferences. (Franzese, 1996).

Results and Discussion

Descriptive Statistics

The descriptive statistics in Table 2 showed that the average crop production index over the period of study was 91.88, while air temperature, average annual precipitation, trade openness and population growth had averages of 21.97, 46.61, 76.57 and 1.2, respectively. The standard deviations showed that trade openness had the highest volatility, followed by crop production index, average annual precipitation, air temperature and the least was population growth.

Table 1: Descriptive statistics

	CPIND	TEMP	PRECIP	TOPEN	POPG
Mean	91.87859	21.9701	46.6102	76.57406	1.995462
Std. Dev	24.21363	1.879432	20.28061	30.60927	1.134931
Min	25.49	17.22	20.57	23.98087	0.0022907
Max	179.04	24.88	142.19	175.798	3.758796
Observation	198	198	198	198	198

Panel unit root test

Table 2 shows the unit root tests for all variables. All variables except POPG were stationary at the level, while POPG was stationary after being differenced once. Ensuring that all the variables were stationary ensured that the study did not produce spurious regressions.

Table 2: Panel unit root test

	P-value at level	P-value at first difference	Order of Integration
CPIND	0.0000		I(0)
TEMP	0.0000		I(0)
PRECIP	0.0000		I(0)
TOPEN	0.0180		I(0)
POPG	0.6885	0.0000	I(1)

Multicollinearity Test

Table 3 gives the correlation matrix, which shows that all the correlation coefficients were less than 0.8 (rule of thumb) hence there is no multicollinearity among the variables in the model.

Table 3: Multicollinearity test

Variables	Temp	precip	topen	D.popg
temp	1.000			
precip	0.124	1.000		
topen	0.013	0.102	1.000	
D.popg	-0.058	-0.098	-0.072	1.000

Hausman Test

In Table 4, the Hausman tests are presented. Since the p-value was less than 5%, the null hypothesis that the difference in coefficients is not systematic is rejected and the fixed effects model was chosen.

Table 4: Hausman Test

Chi-square test statistic	P-value
16.96	0.0020

PCSE Model

To choose between the fixed effects model and the pooled OLS model, the p-value for the F-test in the fixed effects is used. Since the p-value was 0.0000, the null hypothesis was rejected and therefore the fixed effects model was chosen. The diagnostic tests showed that a p-value of 0.0000 for the heteroscedasticity leads to the rejection of the null hypothesis, hence there is the presence of heteroscedasticity. The presence of autocorrelation was also detected since the p-value was 0.0940. The errors show a cross-sectional correlation with a p-value of 0.0000. Since the model failed the diagnostic tests, the study resorted to the OLS model with panel corrected standard errors. (PCSE). The results of the PCSE model are shown in Table 5.

Table 5: Panel Corrected Standard Errors (PCSE)

Dependent Variable: CPIND				
Variable	Coefficient	Std. error	z- statistic	Prob > z
TEMP	-1.411437***	0.5317062	-2.65	0.008
PRECIP	0.2413779 ***	0.0798564	3.02	0.003
TOPEN	0.0146887	0.0409824	0.36	0.720
D.POPG	-12.97519	9.17823	-1.41	0.157
CONS	111.4406***	12.21538	9.12	0.000

*** means that coefficients are significant at 1% Significance level.

From Table 5, the estimated regression results show that the coefficient of temperature was statistically significant at 1% since the p-value is less than 5%. The coefficient of temperature was negative, which was according to the a priori expectations; therefore, a 1⁰C increase in air temperature reduced the crop production by 1.411437 basis points. As a result, agricultural productivity was negatively impacted by temperature increases. The increase in temperature could cause the crops to dry if the rainfall was insufficient or if there was a prolonged dry spell, especially for farmers who do not use irrigation to complement rainfall. Additionally, the increase in temperature may result in environmental conditions which are not conducive for crop growth such as increased evapotranspiration and reduced soil moisture. Regardless of the availability of rainfall, crops were affected by high temperatures, thus agricultural output would be reduced. Climate change increased the air temperature due to global warming; hence these results mean that climate change harmed agricultural output. These findings were like the findings of Semosa (2025), which found temperature to be insignificant in explaining agricultural output. Abegaz and Kebede (2022) also found that climate variability reduces agricultural output through prolonged periods of high temperatures.

Table 5 shows that the coefficient of precipitation was statistically significant at 1% since the p-value was less than 5%. The coefficient of precipitation was positive, according to the a priori expectations, it meant that a 1-millimetre increase in precipitation raised crop production by 0.2413779 basis points. This meant that the increase in average annual precipitation increased the agricultural output. Water is a key input in agriculture and hence increasing water supply resulted in increased agricultural output. Precipitation was the major source of water for agricultural purposes in the SADC region; hence it necessitated agricultural production and increased output. The climate change phenomenon was associated with reduced precipitation due to global warming; these results implied that there is an inverse relationship between climate change and agricultural output. Abegaz and Kebede (2022) also found out that climate variability reduced agricultural output through prolonged periods of reduced precipitation. These results also aligned with the work of Semosa (2025), who contended that consistent rainfall was crucial for agricultural performance in the SADC region, which relied on rainfall while lacking access to established irrigation systems.

The coefficients of trade openness and differenced population growth were not statistically significant at all conventional levels. This meant that opening the selected SADC countries to trade did not influence the agricultural output. Furthermore, the population growth of these nations had no effect on agricultural productivity.

Conclusion and Recommendations

The study examined the impact of climate change variables on agricultural output in selected SADC countries. The main aim was to recommend strategies to reduce climate-induced decline in agricultural output. The findings revealed that temperature negatively influenced agricultural output, which implied that an increase in average air temperature reduced crop production. Conforming to a priori expectations, higher temperatures adversely affected agricultural performance. On the other hand, the findings showed a positive relationship between precipitation and agricultural output, suggesting that higher rainfall enhanced agricultural productivity. As most SADC countries depended heavily on rain-fed agriculture, adequate rainfall remained critical for agricultural performance. However, trade openness and population growth were found to be statistically insignificant. Thus, the findings showed that agricultural production in the SADC region was highly sensitive to climatic conditions, which reinforced the need to devise adaptive and mitigation strategies to foster food security and rural livelihoods.

Considering the findings, the study recommends the promotion of Climate-Smart Agriculture. Thus, governments in SADC should strengthen and encourage the adoption of conservation agriculture, drought-tolerant seed varieties, crop diversification and water-efficient irrigation systems that mitigate the effects of rising temperatures. In addition, governments should scale up investments in irrigation infrastructure by expanding irrigation networks, especially small-scale and community-based schemes. This helps to reduce vulnerability to drought and irregular precipitation patterns. There is also a need for SADC member states to collaborate in terms of research, capacity building and technology transfer in climate-smart agricultural practices, which helps to strengthen resilience across the region. Moreover, climate adaptation strategies need to be streamlined into agricultural development plans and national climate policies and strengthened implementation practices.

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