THE IMPACT OF CLIMATIC VARIABLES ON AGRICULTURAL PRODUCTIVITY IN SADC: FROM 2003 TO 2023

A Thesis

Submitted to the Master's Study Economics at the Faculty of Economics & Business fulfillment of the requirements for the degree of

Master of Arts (M.A)

by

Abubakari Ali Mtitu

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UNIVERSITAS ISLAM INTERNASIONAL INDONESIA

DEPOK

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ABSTRACT

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Agriculture is important in Southern African Development Community (SADC) because it creates job opportunities in the sector, alleviate poverty and promotes economic growth. But climate change – with higher temperatures, altered rainfalls and increased greenhouse gas emissions – is a major risk to agricultural production. The study looks at the effect of climate change on agricultural production in some countries of the SADC and also explores the differences between the low income and high-income countries. The study is grounded in the Sustainable Livelihoods (SL) Framework which provide insights into how productive inputs, economic factors, climate conditions and institutions affect agricultural production. Secondary data for this period 2003–2023 was accessed from the World Development Indicators (WDI) and the World Bank Climate Change Knowledge Portal. Crop Production Index was used to measure agricultural productivity. Precipitation, average temperature, carbon dioxide (CO_2) emissions, fertilizer use, growth in urban population, government effectiveness, and Gross Domestic Product (GDP) growth were considered as control variables. Climatic variables were considered to be: precipitation, average temperature, carbon dioxide (CO_2) emissions, while other where control variables such as fertilizer use, growth in urban population, government effectiveness and Gross Domestic Product (GDP) growth. GDP growth was added in as it brings more resources for investment in agriculture, such as irrigation, better technologies, research and infrastructure, to improve agricultural productivity. The study used the panel data estimation techniques such as the Pooled Ordinary Least Squares (OLS), Fixed Effects (FE), and Random Effects (RE). The findings show that there are significant differences in the reaction of the income groups to climate change. The Fixed Effects model was determined to be the preferred estimator for low-income SADC countries. The results reveal that the growth of GDP, consumption of fertilizers, precipitation and CO_2 emissions are significant positive drivers of agricultural productivity, whereas the average temperature and the government effectiveness play a significant negative role. Agricultural productivity is positively related, although not statistically significantly, to the growth of the urban population. The results indicate that, even with improved agricultural inputs and economic growth in low-income countries, they remain highly susceptible to climate variability, particularly climate warming. Gross Domestic Product (GDP) growth was included as a control variable because stronger economic growth provides greater resources for investment in agricultural infrastructure, technology, irrigation, and research, all of which can influence agricultural productivity. Considering the selected model, for high-income SADC countries, only average temperature is statistically significant and negatively associated with agricultural productivity. Precipitation, fertilizer use, government effectiveness, urban population growth, CO_2 emissions, and GDP growth exhibit the expected relationships; however, most of these variables are not statistically significant.

This implies that high-income nations are more resilient to climate shocks because of their higher adaptive capacity, better institutions, and higher level of agricultural technologies. Overall, the results confirm the Sustainable Livelihoods Framework, which indicate that climate, productive inputs, economic growth and institutional quality influence agricultural productivity. The study suggests the increased investment in Climate-Smart Agriculture, irrigation infrastructure, agricultural research, sustainable management of fertilizers, economic development and institutional strengthening for improved resilience, sustainable agricultural development and productivity within the SADC region.

Keywords**:** *Climate change, Agricultural productivity, Southern African Development Community, Government effectiveness, Fertilizer consumption, Urban population growth.*

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ABBREVIATION DIRECTORY

SADC	: *Southern African Development community*
CPI	: *Crop production index*
UNSDGs	: *United Nations Sustainable Development Goals*
IPCC	: *Intergovernmental panel on climate change*
FAO	: *Food and Agricultural Organization*
AU	: *African Union*
ECOWAS	: *Economic Community of West States*
GHI	: *Global Hunger Index*
SSA	: *Sub-Saharan Africa*
UN	: *United Nations*
WB	: *World Bank*
WDI	: *World Development Indicators*
CRU	: *Climate Research Unit*
GDP	: *Gross Domestic Product*
FE	: *Fixed Effect*
RE	: *Random Effect*
OLS	: *Ordinary Least Square*
CO2	: *Carbon emissions*
TEMP	: *Temperature*
UPG	: *Urban population growth*
GVT	: *Government*
AGDPpc	: *Agricultural Gross Domestic Product*

CHAPTER I

INTRODUCTION

1.1 Research Background

Agriculture is arguably one of the most significant sections in regard to livelihoods, food production and economic development in globe as well as the developing world. Still about a third of the labor force in the world still participates directly or indirectly in agriculture and the sector continues to be at the center of livelihoods of rural settings and poverty reduction in low- and middle-income nations (Abebaw et al., 2025; Omotoso et al., 2023). The importance of the sector is even higher in developing economies in which large proportions of the working group in Asia and the Pacific, above half of the workers in Sub Saharan Africa (SSA) remain to rely on agriculture as the primary or supplementary income and food resource, leading to its crucial role in structural transformation and SDG realization (Abebaw, 2025; J. Liu et al., 2025). Another major income generator in the gross domestic product (GDP) in the African continent is agriculture, which generates considerable value-added contribution and contributes in significant proportion to creation of employment, food security and reduction in poverty (Mugambiwa & Rapholo, 2024; Omotoso et al., 2023).

The Southern African Development Community (SADC) area could not be left behind in this development trend, as in rural areas, the agriculture sector remains a major source of livelihood, employment, and economic development in Sub Saharan Africa. It employs rural economies, supports food systems, and assists at alleviating poverty, as its population growth and urbanization are very high, and the region is rapidly advancing. In most of the SADC countries, the agricultural sector is projected to be the primary source of income among most of the rural population but its contribution to aggregate GDP is relatively low, indicative of relentless low food system productivity and structural dualism.

This imbalance not only reveals long term low productivity rates within the industry, but also, simultaneously, it reveals large untapped potentials of extensive economic transformation through inclusive productivity enhancing investments (irrigation, mechanization, agro- processing and improved integration into the market) (Jean Galbert, 2023; Mugambiwa & Rapholo, 2024). Agricultural productivity, which can be interpreted as the efficiency of the transformation of land, labor, capital and technology into agricultural products, therefore, is one of the most important driving factors of economic growth, the generation of income, and food security in SADC economies (Jean Galbert, 2023; Omotoso et al., 2023).

Despite its significance, there has been persistent problem in agricultural productivity of the member states of SADC and climate change has proved to be a structural force behind stagnant or decreasing yields. The agricultural systems in the area are mostly rainfed, hence production is very vulnerable to the changes in climatic conditions, that is, to the variations in rainfalls, changes in temperature and occurrence of extreme events like droughts and floods ((Mavodyo, 2023). Empirically, in Sub Saharan Africa, positive precipitation can lead to better food access and availability and a higher-temperature climate and more climate variation can lead to lower yield and worsened food insecurity (Abebaw, 2025; J. Liu et al., 2025). These findings highlight the two-sided nature of climatic variables: sufficient and timely precipitation may increase the productivity, whereas climate change-induced variability and warming are generally reducing the yields and destabilizing livelihoods and risking hunger (Omotoso et al., 2023).

Recent reports also suggest that climate change is already reducing crop yields in most of the developing world and causing losses to infrastructural yields in big staples in SSA in the range of 10-20 percent or more by mid-century provided warming is not remedied (Abebaw, 2025; J. Liu et al., 2025). Stable climatic conditions, average rainfall and temperatures play a significant role in promoting crop and livestock production, plant growth, quality of pasture and general output in agriculture (Abebaw, 2025). In comparison, agricultural productivity and food security in the area are highly vulnerable to climate shocks, in the form of prolonged drought, heatwaves, increased sea level, floods, and increasing climate variability (Mavodyo, 2023; Omotoso et al., 2023).

The Southern African Development Community (SADC) area could not be left behind in this development trend, as in rural areas, the agriculture sector remains a major source of livelihood, employment, and economic development in Sub Saharan Africa. It employs rural economies, supports food systems, and assists at alleviating poverty, as its population growth and urbanization are very high, and the region is rapidly advancing. In most of the SADC countries, the agricultural sector is projected to be the primary source of income among most of the rural population but its contribution to aggregate GDP is relatively low, indicative of relentless low food system productivity and structural dualism.

Frequent droughts and increased temperatures in SSA and SADC have rearranged the planting schedules, decreased soil moisture, worsened rangelands and lowered crop and livestock productivity, and lowered food availability in local markets and raised food prices

(Mavodyo, 2023). Vulnerable populations that have their lives highly reliant on agriculture are the most affected through these effects, worsening food insecurity, malnutrition and poverty (J. Liu et al., 2025; Mugambiwa & Rapholo, 2024).

In addition to precipitation and temperature, the impact of climate change on the agricultural productivity is also exacerbated by carbon dioxide (CO2) emissions. Forestry and other land use agriculture, farming land use change, livestock production, and fertilizer application contribute a significant portion to the overall global emissions of greenhouse gases, which is why the sector is a source of, as well as a victim to, climate change (Kantoğlu et al., 2025; Omotoso et al., 2023). This becomes a vicious cycle where increasing emissions, along with the shifts in the climate, temperature and rainfall regimes contribute to the amplification of climate risks, the disruption of agricultural systems and the delay of progress towards various Sustainable Development Goals (SDGs) in SADC economies (J. Liu et al., 2025).

Agricultural productivity and growth have been very different across countries, as is seen in the figure, due to differences in climate, technology, institutions and economic development. From the trends observed it can be broadly said that the countries exist in two categories. The first group is of countries where the level of agricultural production is relatively high, Seychelles, Mauritius, Zimbabwe and South Africa. The countries generally had high values of the crop production index for their crops during the study period and had high performance of their agricultural sector. Although there were some variations, they generally had higher productivity than most other countries, indicating higher agricultural capacity, availability of agricultural inputs, and relatively better supporting infrastructure and institutions

Systemic and institutional constraints further increase the productivity losses which are climatically instigated. The SADC food systems are vulnerable to deep structural problems in relation to COVID 19 and other shocks by causing disregard to labor markets, increasing the cost of inputs, and inhibiting cross border trade and value chain. Although agricultural development in the area was stifled by insufficient use of better technologies, insufficient investment in infrastructure and substandard risk management tools long before the pandemic, which diminished adaptive capacity to climate stress (Lesolle, 2003). Despite the above suppositions that recovery efforts are trying to restructure the supply chains and rural economies, climate change is an insidious threat of productivity and food security to agricultural operations (J. Liu et al., 2025; Omotoso et al., 2023).

Moving forward, figure 1. below shows the annual trends in rainfall in SADC member countries from 2003 to 2023. From the trends of rainfall in these SADC countries shows that agricultural productivity is affected largely in these countries due to the facts in some area's rainfall seems to be high which will lead floods thus affects crops productions and some of the countries seems to have way too low rainfall throughout the years.

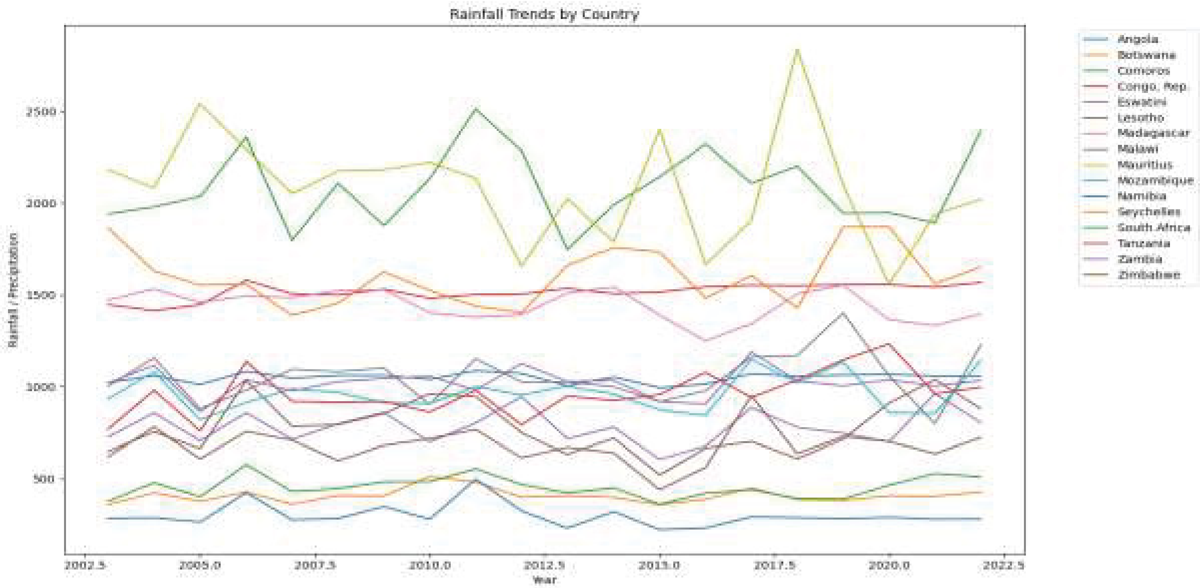

Figure 1.1 Trends in Average Annual Rainfall (mm/year) Across Selected SADC Countries, 2003–2023

Source: Author's compilation based on data obtained from the World Bank Climate Change Knowledge Portal (accessed 20 April 2026).

Furthermore, the Figure 2. below shows the level of average temperature of the chosen countries in SADC member countries during the years 2003 to 2023 for the research work. It can be observed that in the course of time between 2003 to 2023, most of the countries show an average temperature of around 28 o C, which is actually quite high as compared to other parts of the world like Europe and America. There is not the slightest decline in the level of temperature in SADC countries as the temperature is increasing, which means climate change is occurring.

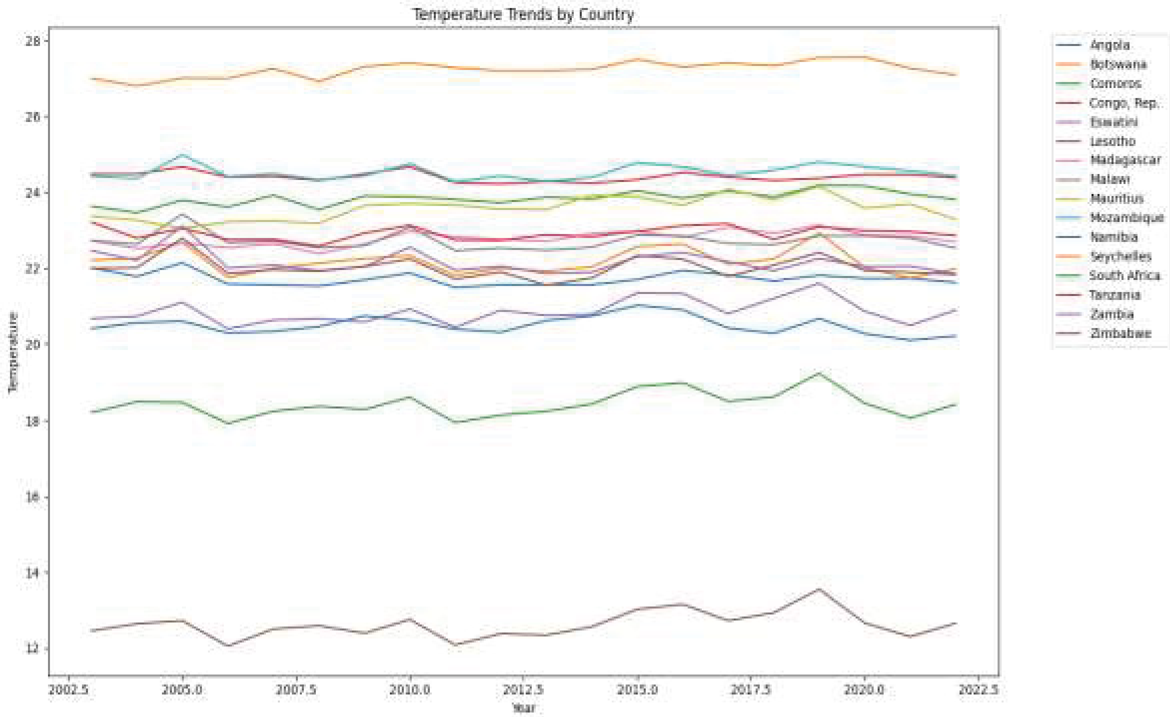

Figure 1.2 Average Annual Temperature (°C) in Selected SADC Member Countries,2003–2023

Source: Author's compilation based on data obtained from the World Bank Climate Change Knowledge Portal (accessed 20 April 2026).

Agricultural in SADC member countries trends are indications of the extent of the productivity crisis. Since the mid-2010s, many African states have experienced a rise of moderate and severe food insecurity, and the current estimates have indicated that a significant proportion of the SSA population is struggling to get adequate, safe and healthy food (FAO, 2023; J. Liu et al., 2025). In 2022, hundreds of millions of people globally endured undernourishment, and it is estimated that this number of individuals may continue being under or facing food insecurity over the next few years due to the ongoing trends and climate risks (FAO, 2023; J. Liu et al., 2025). Such processes affirm the agricultural and food systems weakness in structures and present grave challenges to SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production) implementation in SADC and other developing countries (J. Liu et al., 2025; Mavodyo, 2023).

Agricultural productivity and growth have been very different across countries, as is seen in the figure, due to differences in climate, technology, institutions and economic development. From the trends observed it can be broadly said that the countries exist in two categories. The first group is of countries where the level of agricultural production is relatively high, Seychelles, Mauritius, Zimbabwe and South Africa. The countries generally had high values of the crop production index for their crops during the study period and had high performance of their agricultural sector. Although there were some variations, they generally had higher productivity than most other countries, indicating higher agricultural capacity, availability of agricultural inputs, and relatively better supporting infrastructure and institutions.

Systemic and institutional constraints further increase the productivity losses which are climatically instigated. The SADC food systems are vulnerable to deep structural problems in relation to COVID 19 and other shocks by causing disregard to labor markets, increasing the cost of inputs, and inhibiting cross border trade and value chain. Although agricultural development in the area was stifled by insufficient use of better technologies, insufficient investment in infrastructure and substandard risk management tools long before the pandemic, which diminished adaptive capacity to climate stress (Lesolle, 2003). Despite the above suppositions that recovery efforts are trying to restructure the supply chains and rural economies, climate change is an insidious threat of productivity and food security to agricultural operations (J. Liu et al., 2025; Omotoso et al., 2023).

The second consists of countries with low to moderate agricultural productivity, such as Angola, Botswana, Comoros, Congo Republic, Eswatini, Lesotho, Madagascar, Malawi, Mozambique, Namibia, Tanzania and Zambia. The productivity of most of these countries has improved over the years, but the crop production index values are still significantly lower than for the first group of countries. There were also significant differences in certain countries in the group, reflecting more exposure to climatic variability and other production related issues. Relative to the rest of the sample, a prominent characteristic of the figure is Seychelles' very high productivity performance, in particular in the earlier decades of the study period. The overall picture shows that the agricultural productivity in countries within the SADC region increased over time but there are large variations in agricultural productivity between the countries. These differences indicate that climatic, economic, institutional and technological factors all play a part in agricultural productivity, thus suggesting an avenue for further empirical examination of the determinants of agricultural productivity in the SADC region.

Figure 3. below presents the trend of agricultural productivity, measured by the Crop Production Index, across selected SADC member countries from 2003 to 2023. The figure shows that agricultural productivity generally increased over the study period in most countries, although the growth pattern varies considerably across countries. Some countries,

such as Mozambique, Botswana, Zambia, and Malawi, experienced substantial improvements in agricultural productivity, while others exhibited moderate growth and occasional fluctuations. The figure also reveals periods of sharp increases and declines, reflecting the influence of climatic conditions, economic factors, and agricultural policies on production performance. Overall, the upward trend observed in many countries suggests gradual improvements in agricultural output; however, the considerable differences across countries highlight the heterogeneous nature of agricultural development and the varying capacity of SADC countries to respond to climate-related challenges and other productivity determinants.

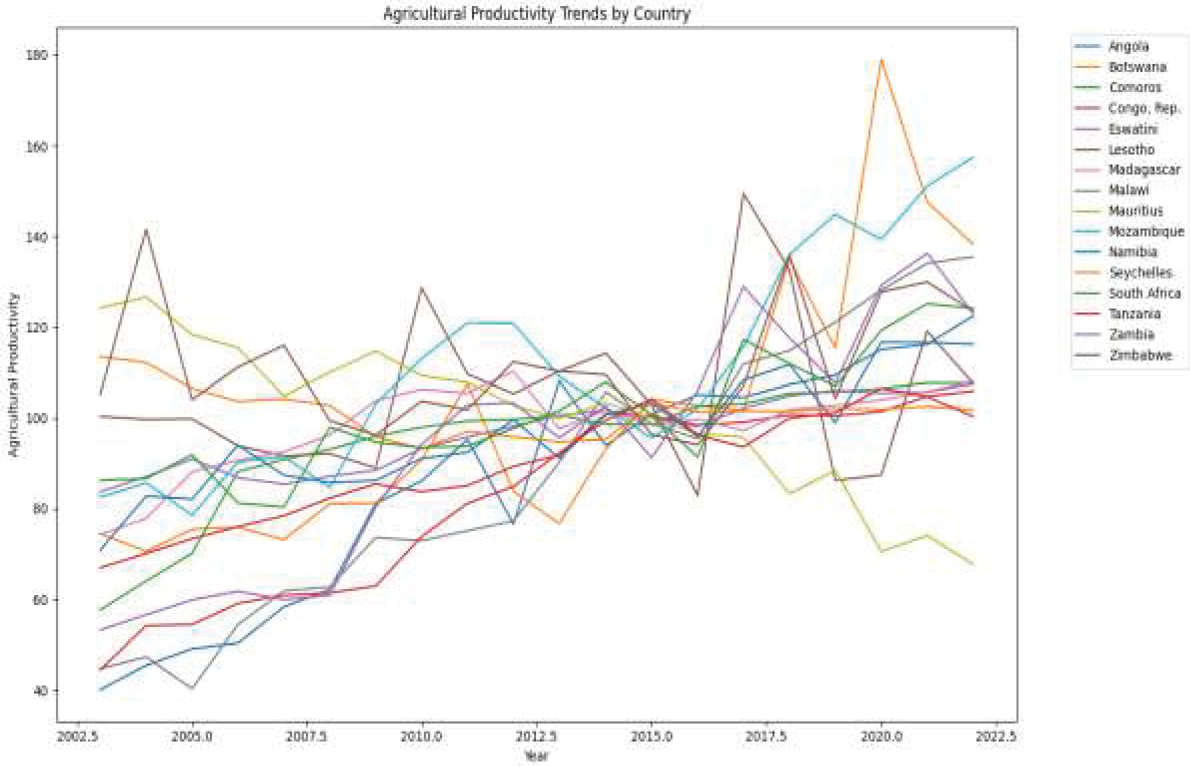

Figure 1.3 Trends in Crop Production Index in Selected SADC Member Countries, 2003–2023, Unit: Index (2014–2016 = 100)

Source: Author's compilation based on data obtained from the World Bank World Development Indicators (accessed 20 April 2026).

The trends in agricultural productivity according to the Crop Production Index (CPI) for selected SADC member countries 2003 to 2023 are shown in Figure 3. The figure indicates significant differences in the performance, growth and productivity of agriculture among countries, which are due to the variation in climatic conditions, the use of agricultural inputs, institutional quality and economic development. The countries can broadly be classified into two groups. The first group of countries are relatively high performing countries: Mozambique, Seychelles, Zimbabwe, Zambia, Malawi, South Africa, and Botswana. Agricultural productivity levels in these countries increased above 100 level in most of the study period and they had stronger growth rates. In Mozambique, productivity has grown steadily throughout the period and one of the most remarkable increases was observed. Likewise, Botswana and Zimbabwe had high productivity, but with higher variations. All of these countries have performed well and may be linked to favorable agriculture investment, intensive utilization of modern inputs and moderate adaptation to climate conditions.

The second group consists of countries with fairly low to moderate productivity, such as Angola, Comoros, Congo Republic, Eswatini, Lesotho, Madagascar, Mauritius, Namibia and Tanzania. These countries showed a little improvement in agricultural productivity as time went by but still were not as productive as the first group. However, there was evidence of some consistent positive trends in agricultural performance in several countries in this group, including Angola, Namibia and Tanzania. Some countries experienced slower growth, driven by factors including climate vulnerability, reduced investment in agriculture, reduced use of technology, and institutional factors. There was a general improvement in agricultural productivity in most SADC countries during the period of study as indicated by the figure. The variations in productivity and growth rates, however, indicate important differences in agricultural development in the region. The differences indicate that climatic conditions, institutional effectiveness, agricultural input use and overall economic conditions have a significant influence on agricultural productivity outcomes in SADC member countries.

To a significant extent, the existing body of recent empirical research continues to consider SADC a unitary block, hardly differentiating between low, lower middle and upper middle income member states in the process of quantifying climate impacts or adaptive capacity. Consequently, there is still a paucity of evidence on how different key climate variables such as temperatures rises, changes in agricultural productivity, incentive checks and CO2 emissions, optimal influences on agricultural production across SADC income groups, and the mitigating effect of institutional quality, urban population growth and the use of fertilizers have only been minimally studied (del Pozo et al., 2019; Malhi et al., 2021). This inability to analyses income sensibilities empirically weakens the quality of regional and national policy responses in that, similar adjustment policies are unlikely to fit countries that are at such a significantly different level of economic growth, institutional capacity and technological preparedness (Abdissa & Gemeda, 2025; Kantoğlu et al., 2025)

Poor allocation of fertilizer and chemical inputs may lead to more environmental degradation and increased emissions of greenhouse gases to the atmosphere, which leads to reinforcing the process of climate change and delegitimizing the long-run productivity, but proper and efficient management of fertilizer may help in sustaining the health of the soil together with increasing the yield growth and reducing the atmospheric emissions of greenhouse gases (Affoh et al., 2022; Kantoğlu et al., 2025; Lesolle, 2003). Furthermore, the dynamics of investment and governance organization, such as the foreign direct investment, trade openness and responsible investment standards, can just be converted into greater productivity in case the institutions are strong and the human capital is developed.

These processes are skewed on both ends of the income group in the SADC region. The low income member states tend to be more susceptible to changes in precipitation, temperature and CO2 emission due to weak institutions, slower adaptive capacity and diffusion of climate smart technologies and the relatively high income SADC economies are more vulnerable to systemic risks related to climate (Mavodyo, 2023). This diversity highlights the importance of examining the effects of climate change on the agriculture productivity of income groups in the SADC and develop varicosities policy reactions (Omotoso et al., 2023).

These countries showed a little improvement in agricultural productivity as time went by but still were not as productive as the first group. However, there was evidence of some consistent positive trends in agricultural performance in several countries in this group, including Angola, Namibia and Tanzania. Some countries experienced slower growth, driven by factors including climate vulnerability, reduced investment in agriculture, reduced use of technology, and institutional factors. There was a general improvement in agricultural productivity in most SADC countries during the period of study as indicated by the figure. The variations in productivity and growth rates, however, indicate important differences in agricultural development in the region. The differences indicate that climatic conditions, institutional effectiveness, agricultural input use and overall economic conditions have a significant influence on agricultural productivity outcomes in SADC member countries.

In general, climate change through shifts in precipitation, rising temperatures and growth in CO2 emissions, and institutional quality, urbanization dynamics and fertilizer use contribute to the decrease and stagnation of agricultural productivity in the SADC countries

(Jean Galbert, 2023; Omotoso et al., 2023). These forces affect food security, aggravate hunger and poverty, destabilize the livelihood of rural people, and threaten the realization of the SDGs in the region. Thus, when developing evidence-based policies to tackle climate change and ensure agricultural productivity and sustainability in SADC countries and amongst income groups, it is essential to get an empirical understanding of how climate variables contribute to the interaction with key institutional and socioeconomic drivers, to determine agricultural performance (Mavodyo, 2023). It offers the primary justification behind the present research, which is going to use empirical research as an instrument to explore how climate related variables affect agricultural productivity in the SADC economies but explicitly takes necessary institutional and socioeconomic control variables into account (Jean Galbert, 2023)

1.2 Research Problem

The South African Development Community (SADC) economies continue to be dependent on agriculture as a major economic growth driver, jobs and rural livelihoods, especially at low and lower income member countries where agriculture makes the highest contribution to GDP, employment and household income, as well as providing strategic contributions to agro processing, exports, rural development in upper middle income members (Antwi, 2023). However, with this centrality, agricultural production in most of the areas is structurally low and in others, production has declined to limit food supply, rural incomes and economy wide economic development (Semosa, 2025).

An emerging empirical evidence base is showing climate change, as one of the important structural causes of this stagnation in SADC agriculture. The agricultural systems of the region are largely rain fed and climate sensitive, and thus the production is very prone to rising temperatures, changes in rainfall regimes, frequent droughts and other types of severe weather(Malhi et al., 2021). SADC and other African experience demonstrate that productive rainfall shocks increase the agricultural output but higher temperatures and climate extremes significantly decrease agricultural yields, animal performance and farm incomes, thereby exerting a strain on access and availability of food (Adesete et al., 2023; Amouzay & El Ghini, 2025; Semosa, 2025). These effects of productivity shocks brought by climate have been manifested in increased food insecurity and malnutrition in the countries of the SADC even though the region is a relatively small contributor of global greenhouse gas emissions (Antwi, 2023.; Omotoso et al., 2023).

In a broader sense, macro and micro level analyses claim that climate change would have an adverse impact on agricultural productivity in developing countries and cause an unproductive labor and capital redistribution process with especially deleterious effects in the agricultural dependent regions (Abebaw, 2025; Jean Galbert, 2023).

Nevertheless, the negative effects of climate change in farming productivity within SADC do not act independently. Climate shocks are mediated and frequently enhanced by institutional and structural factors or weakness in terms of institutional quality, poor irrigation infrastructures, slow adoption of improved technologies, high urban population growth, and poor fertilizer application (Malhi et al., 2021). Lack of institutional capacity in most SADC countries, particularly the low- and lower-income lead to poor design and implementation of climate resilient agricultural investments and policies but on the other hand, rapid urbanization causes food demand and land use pressure (del Pozo et al., 2019). The mishandling of fertilizers and inputs, in its turn, causes environmental degradation and increase agricultural emissions, which add to the losses in the productivity at climate induced and jeopardize sustainability in the long term (Malhi et al., 2021).

Notably, the extent, processes and economic impacts of climate induced agricultural productivity decline vary decently among SADC income groups. In member states with low income and where the biggest proportion of the population is on subsistence and rain fed agriculture, climate shocks are instilled directly via crop failures and livestock death, income collapses, and acute changes in food insecurity (Carleton & Hsiang, 2016; Gornall et al., 2010). Conversely, the SADC economies in high middle income with comparatively greater adaptive capacity and more diversified economies experience climate induced water scarcity, increasing costs of production and decreasing agricultural efficiency which indirectly influence the performance of agro processing, export performance, and rural employment (Semosa, 2025). Recent studies of climate change, agriculture and inequality also suggest that climate effects and economic improvement of adaptations is uneven across locations, income groups and production regimes, and that the unevenness of climate effects and benefit of adaptation is likely to cause ecological fallacy and inappropriate policy intervention (Carleton & Hsiang, 2016; Hertel & Lobell, 2002.).

To a significant extent, the existing body of recent empirical research continues to consider SADC a unitary block, hardly differentiating between low, lower middle and upper middle income member states in the process of quantifying climate impacts or adaptive capacity. Consequently, there is still a paucity of evidence on how different key climate variables such as temperatures rises, changes in agricultural productivity, incentive checks and CO_2 emissions, optimal influences on agricultural production across SADC income groups, and the mitigating effect of institutional quality, urban population growth and the use of fertilizers have only been minimally studied (del Pozo et al., 2019; Malhi et al., 2021). This inability to analyses income sensibilities empirically weakens the quality of regional and national policy responses in that, similar adjustment policies are unlikely to fit countries that are at such a significantly different level of economic growth, institutional capacity and technological preparedness (Abdissa & Gemeda, 2025; Kantoğlu et al., 2025)

The ongoing existence of this knowledge gap has grave consequences to the realization of the United Nations Sustainable Development Goals, especially SDG 2 (Zero Hunger), SDG 13 (Climate Action), which require the creation of a climate resilient agriculture, improved food security and inclusive growth (FAO, 2023; J. Liu et al., 2025). The SADC countries can afford to adopt patchwork and nonproductive measures to address climate change in a way that does not resolve the fundamental reasons behind downturns in productivity and deficiency of food without subtle and income group-specific understanding of how climate change interacts with institutional and socioeconomic conditions and causes (Jean Galbert, 2023).

In line with this, the main research problem of the proposed study is that the agricultural productivity in the SADC nations continues to deplete due to climate change as the core reason, and it is exacerbated by the income bottlenecks within the institution and socioeconomic dimensions and the effect of which is distributed systematically across the income clusters. The given gap is aimed to be addressed in this paper, which aims at filling it by analyzing heterogeneous impacts of climate change, which is represented by the indicators of precipitation, temperature and CO2 emission, on agricultural output in SADC member states, adjusting institutional quality, urbanization, and the use of fertilizers (Semosa, 2025). Within the framework of the income group sensitive analytical approach, the proposed study will produce a well-structured, policy relevant evidence that could be applied in the design of specific, climate resilient and income appropriate agricultural policies to boost productivity, enhance food security and promote sustainable economic growth in the SADC region (Jean Galbert, 2023).

1.3 Research Questions

This study aims to answer the following questions:

1. What are the effects of key climatic variables on agricultural productivity in SADC member countries?
2. Is the impact of climate change on agricultural productivity heterogeneous across income groups?

1.4 Research objectives

The following are the objectives of the study:

1. To examine the overall effect of key climatic variables (temperature, rainfall, CO_2 emissions and other) on agricultural productivity in SADC member countries.
2. To compare how the impact of climate change on agricultural productivity from low income and high-income countries

1.5 Research hypothesis

The research hypothesis for the impact of climate change on agricultural productivity in SADC climate vulnerable countries is as follows:

- $H_{1:}$ there is significant impact of climatic variables (temperature and precipitation) on SADC countries agricultural productivity across their income groups.
- H_1: there is significant impact of government effectiveness, CO_2 emissions and urban population growth on SADC countries agricultural productivity across their income groups.

1.6 Research Gap

In accordance with the sustainability development goals. The proposed study will provide an additional contribution to the preceding findings of climate change and productivity in the agricultural sector because it will be conducted by evaluating the findings in the income groups in the member states of the SADC agency which is a broad region that has not been addressed by other researches (Emediegwu et al., 2022). Although studies performed in the past have considered the impact of climate variability in the sector of agriculture on a global (Mendelsohn et al., 1994) and, in particular, on the national and regional (Mwaura & Okoboi, 2014) scales, countries or regions are rather spoken about as a homogenous entity. In line with the Sustainable Development Goals (SDGs), this study contributes to the existing literature on climate change and agricultural productivity by examining the relationship across income groups within SADC member states. Unlike previous studies that have generally treated countries or regions as homogeneous entities, this study recognizes that differences in economic capacity, institutional quality, and adaptive resources influence countries' vulnerability to climate change. The income-group classification used in this study is based on the World Bank income classification (FY2024), which categorizes countries according to Gross National Income (GNI) per capita. This will obscure the useful variation in the adaptation potential, economy and exposure to risks of climatic dangers. Evidence of the high level of income can also be used to mark agricultural susceptibility to climatic variations as illustrated in this paper by establishing presence of low-income, lower-middle-income, and upper-middle-income SADC countries. Less-developed countries are affected more by the increase in temperature and variation of rainy seasons, but on the flip side, due to the complete dependence on the rain-based agricultural sector and the inability of such countries to use irrigation practices, such countries are most influenced and long-lasting(Emediegwu et al., 2022). Conversely, the comparatively high worth of resiliency on the more prosperous SADC economies is characterized by quite good infrastructure, the market incorporation as well as entry to the adaptation exercises. This income-group approach assists also in so clarifying the disproportional climatic drag in the SADC, and provides direct response to the literature demand of more differentiated and circumstantial examination of climatic impacts of farming (Ajao, 2012).

By comparing low-income and high-income SADC countries, this study highlights how differences in income levels shape agricultural resilience to climate variability. Low-income countries are generally more vulnerable to rising temperatures and changing rainfall patterns because of their heavy dependence on rain-fed agriculture and limited capacity to invest in irrigation, agricultural technology, and other adaptation measures. In contrast, high-income SADC countries generally possess stronger infrastructure, more developed markets, and greater financial and institutional capacity to implement climate adaptation strategies. This comparative approach provides a more context-specific understanding of the effects of climate change on agricultural productivity rather than assuming uniform impacts across all countries.

Furthermore, this study extends the literature by incorporating institutional quality and macroeconomic factors into the analysis of agricultural productivity. While many previous studies have focused primarily on climatic variables, relatively few have examined how government effectiveness, economic growth, and demographic change influence agricultural performance. By including government effectiveness, GDP growth, and urban population growth, this study provides a broader understanding of how institutional performance, economic conditions, and structural transformation interact with climate change to affect agricultural productivity. In particular, the findings demonstrate that weak governance can reduce the effectiveness of agricultural policies, distort resource allocation, and constrain investments in climate adaptation.

In addition, the research will be relevant to the climate agriculture issue as the quality of institutions and macro-structural concerns will be a part of the analysis of agricultural activities. The currently existing literature gives less emphasis on biophysical variables of climate and also less empirical data is provided regarding the processes of governance and demography (Abegaz & Kebede, 2022; Nhemachena et al., 2020). The analysis contributes the governance inefficiencies concept into the discussion by providing specifics of how the practices impact the performance of farms by having long-term effects through distorting resource allocation, limiting policy efficiency, and climate change adaptation investment one of which is corruption control in SADC lower-income countries. Besides, the inclusion of the urban population growth is linked with the bigger element of structural change as used on the agricultural sector which involves redistribution of labor, change in land utilization and restructuring of the food demand.

The conclusions point to the fact that urbanization appears to be having contradictory effects in the incomes groups, which is favoring productivity in a comparatively developed economy as it increases market size and stretches the rural production systems in the poor nations. All this results in the comprehension that the climate adaptation policies should be adjusted to the institutional change and the demographic reality (Erda et al., 2005). The research consequently offers policy implementation amicable information that the farm hardness to the level of the SADC cannot be established through climate-thorough undertakings but more, through revenue-based undertakings that would entail the general betterment of administration, regulated urbanization and structural metamorphosis all-inclusive.

1.7 Significance of the research

The proposed study adds to the existing body of knowledge by adding significant climatic variables and variables of structure and institutions such as the effectiveness of government, fertilizer use, and urban population growth. These factors are taken into account, and the analysis is able to separate climate change from other socioeconomic drivers of agricultural productivity. This offers a more complete picture of the contribution of climatic conditions, institutional quality, agricultural input use and demography to changes in agricultural performance.

This study is one of the first to break down income groups to examine the role of income in the experience of inequality. One important contribution of this study is income-group analysis. This research categorizes SADC member states into two groups – low income and high income as opposed to many other studies that lump all the countries together. This distinction is based on the different capacities of the countries to adapt, different levels of technological development, different levels of infrastructure development, different types of governance and different levels of access to financial resources. Therefore, the study offers new evidence regarding the impact of climate change on agricultural production and the differences in impact across income groups.

The study also adds methodologically as it utilizes a panel data approach with data covering 16 SADC member countries between 2003 and 2023. The analysis of the panel data enables controlling for country-specific heterogeneity and provides more reliable estimates of the relationship between climate variables and agricultural productivity. In addition, the use of model selection tests guarantees that the proper estimation methods are used in each income group.

Policy implications of the results will be quantified, giving policy makers an estimate of the magnitude of impacts of climate change on agricultural productivity, and what factors can either increase or decrease agricultural resilience. The outcomes can help governments, regional bodies, and development actors create climate-focused adaptation plans, boost institutional effectiveness, encourage climate-smart agriculture practices, optimize use of agricultural inputs. The study is used to delineate differences in climate vulnerability between income groups, which will inform the design of differentiated policy interventions, based on the different needs and capacities of countries in the SADC region.

Overall, the study contributes to the literature by incorporating climatic, institutional, demographic and structural conditions in an income-group framework that helps to better understand the effect of climatic change on agricultural productivity and yields, and produces evidence-based recommendations for sustainable agricultural development in the SADC region.

1.8 Outline of the thesis

The thesis is well structured to achieve its objectives and provides valuable insights into the factors influencing agricultural productivity in SADC countries across different income groups. Chapter Two presents a comprehensive review of the theoretical and empirical literature, identifies existing knowledge gaps, and develops the conceptual framework that guides the study. Chapter Three outlines the research methodology, including the data sources, variable definitions, model specification, and estimation techniques employed in the analysis. Chapter Four presents and discusses the empirical findings through descriptive analysis, diagnostic tests, and econometric estimations, while examining the effects of climatic and socioeconomic factors on agricultural productivity across low-income and high-income SADC countries. Chapter Five concludes the study by summarizing the key findings, discussing their policy implications for enhancing agricultural productivity and climate resilience, and providing recommendations for policymakers. The chapter also highlights the study's limitations and proposes future research directions to further advance understanding of the relationship between climate change and agricultural productivity in the SADC region.

CHAPTER II

LITERATURE REVIEW

2.1 Theoretical literature

This section outlines the theories that explain the relationship between input factors and agricultural productivity. In this study it will reflect the relationship between study variables (climatic factors such as temperature, rainfall, CO2 emissions, fertilizer consumption, urban population growth) and institutional variables such as control of corruption, government effectiveness, rule of law etc.

2.1.2 The Sustainable Livelihoods Frameworks (SLF)

The Sustainable Livelihoods Framework (SLF) broadens the analysis by focusing on the assets (capitals) that farmers use to construct their livelihoods and how these are transformed by the vulnerability context of climate trends and shocks (Mugambiwa & Rapholo, 2024; Ndlovu et al., 2020; Parker et al., 2019). Natural capital is represented by precipitation and average temperature, where depletion or variability directly constrains production (Mugambiwa & Rapholo, 2024; Ndlovu et al., 2020). Physical and financial capital are represented by fertilizer consumption, as access to fertilizer is a function of affordability and supply chain stability (Mobeen et al., 2023; Ojo et al., 2024). Studies show that financial constraints are a primary barrier to adaptation, with 80% of smallholders in similar contexts facing financial vulnerability (Ojo et al., 2024). Human and social capital are embedded within institutional quality, where effective institutions ensure property rights, reduce corruption, and facilitate extension services (Kula et al., 2013; Mnukwa et al., 2025). The SLF explains why similar climate shocks yield different productivity outcomes across SADC countries; countries where farmers possess higher livelihood capitals can transform their production strategies to maintain the crop production index despite climatic stress, whereas eroded assets lead to livelihood collapse (Mobeen et al., 2023; Schröter et al., 2005).

Previous analysis by Data Envelopment Analysis and the Malmquist productivity index carried out by Ajao (2012) implied that technological change and not efficiency change was the predominant factor in increasing productivity in Sub Saharan Africa agriculture between 1961 and 2003 and that some of the measures like control of corruption and government effectiveness was not statistically significant (Ajao, 2012). Recent evidence also somewhat defers this perspective as it demonstrates that when institutional variables are measured at sector levels, as opposed to aggregate, many parametric and bias corrected panel designs can pick up significant institutional effects that the DEA type methods can overlook (Ekeocha et al., 2023; Gelgo et al., 2023). Besides this, the research about the effects of government agricultural spending on the food security in Africa and Asia suggests that the quality of institutions predetermines the success of the spending, which means that even the same level of spending can produce significantly different outcomes in terms of productivity and food security, based on the performance of the institutions.

The most recent cross-country experiment involving Ordinary Least Squares and a Cross Sectional Autoregressive Distributed Lag (CS ARDL) model to 26 African nations reports that the direct impact of aggregate institutional quality on food supply and access is statistically insignificant, although the modifying effect of an institution on the conversion of climate shocks into agricultural outcomes is statistically significant (Alemu et al., 2024). The authors suggest that poor institutional sensitivity to climatic risks, which manifests itself in the poverty of early warning mechanisms, poor disaster management, and poor climate smartness extension, changes the factor of institutions as direct productivity promotion to mediation of adaptation and resilience (Ajao, 2012; Alemu et al., 2024). This exergies has been confirmed by more recent research on the factor productivity of African agriculture, which indicates that climate change decreases land, labor, and fertilizer productivity, and institutional and technological reactions are essential to keep the results of such shocks terrestrial and overall factor productivity brings about enduring loss of yield and total factor productivity (Alemu et al., 2024; Debertin, 1986).

Fertilizer use is also an important factor identified in the macroeconomic literature regarding cross country differences in agricultural production in Sub Saharan Africa (Erda et al., 2005). In 35 countries of Sub-Saharan Africa (2005-2020), the authors of the study Alemu et al. (2024) utilize pooled OLS and a stochastic frontier model of panel data and determine that fertilizer use explains almost all growth in the cereal yields of companies, and the proportion of fertilizer to the technical efficiency of the production of cereal crops reaches approximately 5.7% (Alemu et al., 2024; Chapoto et al., 2002.). These findings are consistent with the larger regional evaluations that indicate that the average stimulant application in Sub Saharan Africa is much lower than on a global scale and that rising the application of fertilizers, along with proper soil and water management, could lead to a substantial rise in cereal productivity and a speedy structural shift.

Fertilizer consumption reflects physical and financial livelihood capital, as low use in sub-Saharan Africa is linked to soil degradation and stagnant yields, while higher application can raise productivity and incomes if supported by credit, extension, and market access (Mobeen et al., 2023; Ojo et al., 2024). Urban population growth signals structural transformation, reducing peri-urban farmland but opening off-farm income opportunities, thus mediating how climate stress affects rural livelihoods (Chapoto et al., 2002.; Orr & Mwale, 2001). Government effectiveness shapes both adaptive capacity and institutional resilience, as it determines access to climate-related public goods and livelihood capitals, thereby moderating how precipitation, temperature, fertilizer, CO_2, and urbanization jointly influence agricultural productivity in SADC economies (Mobeen et al., 2023; Ojo et al., 2024; Schröter et al., 2005).

Integrating these theories provides a robust justification for variable selection and expected interactions in a panel data approach. Environmental Stress Theory supports the hypothesis that increased temperature and erratic precipitation will directly and negatively affect the crop production index (Fellmann, 2012.; Gornall et al., 2010; Oyelami et al., 2023). The Vulnerability Framework supports the hypothesis that high institutional quality will attenuate the negative impact of climate variables, acting as a moderating variable that enhances adaptive capacity (Kula et al., 2013; Semosa, 2025). Finally, the SLF supports the hypothesis that fertilizer consumption will positively influence productivity as a mediating variable that converts financial and physical capital into yield stability, though its effectiveness may be constrained under extreme climate stress without adequate water (Mobeen et al., 2023; Ojo et al., 2024).

The convergence of Environmental Stress Theory, Vulnerability Frameworks, and the Sustainable Livelihoods Framework offers a comprehensive theoretical basis for comparative panel data analysis. These theories collectively argue that agricultural productivity in SADC is not merely a biophysical function of weather but a socio-ecological outcome determined by the interplay of climatic exposure, adaptive capacity, and livelihood assets. This study contributes to the literature by empirically testing these theoretical interactions across the heterogeneous institutional and climatic landscapes of SADC member states.

2.2.1 Impact of climatic factors on agricultural productivity

The world empirical analysis of the effects and consequences of climate change and variability on agricultural productivity is located in Abebaw (Abebaw, 2025), but specifically Ethiopia and other areas that are susceptible to climate changes. The ultimate study aim was to investigate impact of changes in temperature, variability, and extreme weather considering its effect on crop production and adaptation behavior of farmers, which are based on econometric analyses, crop simulation models, and regional climate projections in the 2000-2024 (Abebaw, 2025; Feleke et al., 2025). In Ethiopia, where the major type of agriculture is rain-fed, shifts in temperature and changes in rainfall patterns are considered the most significant modifying factors that affect the productivity of agriculture (Abebaw, 2025; Kerebo et al., 2024; Kumsa et al., 2024). The empirical evidence created to date indicates that a combination of frequent drought and heat stress will reduce yields of maize in Ethiopia by approximately 15 percent by 2050 and yields of wheat in East Africa drought-and-heat prone areas may drop by up to 25 percent. The other estimate used in the review is that yields losses caused by the climate mean that Ethiopian agricultural GDP is going to reduce by about 5-10 percent annually. In addition, variability of rainfall not only reduces or interferes with growing season and increases the likelihood of crop failure but also worsens food insecurity in smallholder farmers with low adaptive capacity (Abebaw, 2025; Kerebo et al., 2024; Wakjira et al., 2024). This outcome can be aligned with the current empirical research of South Asia and Latin America, which demonstrates that the increased temperature and variated precipitations are expected to decrease the rice and wheat crop by approximately 10-15% (Bracho-Mujica et al., 2024).

It is concluded that drought-tolerant varieties and enhanced water management strategies are of much importance; however, due to socio-economic factors (low access to credit, technology, and services of climatic information), their success is limited (Abebaw, 2025; Feleke et al., 2025). The article is especially valuable to the researchers working with rainfall and temperature as the important variables since it helps to understand the magnitude, patterns, and financial effects of the climatic shocks on low-income rain-fed agricultural systems, which are similar under the structural aspects between Ethiopia and other economies (Abebaw, 2025; Kumsa et al., 2024)

In the article by Berhane (2018), the researchers attempt to offer an empirical evaluation of the effects of climate variability and change on agricultural productivity and food security through the effects of temperature, precipitation, and greenhouse gases emissions, being the primary predictors of the effects on crop production, water equilibrium, and food availability in rain-dependent systems. The present paper integrates the results of climate models (global and regional climate models, GCMs and RCMs) and crop models, and observation, and the analysis to establish that temperature increase has a detrimental impact on crop productivity at low latitude, whereas the effects of changes in rainfall are extremely heterogeneous, and there is no passive world pattern (Berhane, 2018; Kone et al., 2024).

Computer models of warming to 2050 suggest yield declines of around one-third in arid and semi-arid zones, and according to Berhane, (2018), it is estimated that by 2080, drylands in Africa will cover again 5-8 percent of all terrestrial area, which is already being reflected in more modern global and regional modeling.

The article raises shortcomings of coarse global climatic models at regional scales and suggests regional downscaling which would give a more faithful representation of rainfall variation and extreme events (Berhane, 2018; Kumsa et al., 2024). The paper displays results based on SRES-type emissions scenarios to demonstrate that the success of CO2 fertilization in Bier lived up to the partial recovery of yield penalties, but hinges crucially on the availability of water and nutrients and is highly uncertain (Berhane, 2018; Kone et al., 2024). This presents a solid empirical justification of why climate variability downscaled indicators are used in agricultural production studies and why using the output of climate models and farm-level data are crucial in generating outputs that are policy-relevant (Berhane, 2018; Bracho-Mujica et al., 2024).

A research study by Affoh et al. (2022)assessed how climate variability and change affected food security in 25 countries in sub-Saharan Africa. The pooled mean group (PMG) findings showed that rainfall and carbon emission positively and significantly affect the food availability in the long run except temperature which affects the food availability negatively. The research paper has observed that, climate change brings about decrease in agricultural production thus generating a rise in food insecurity, hunger, and the level of poverty in the area (Affoh et al., 2022).

On the same note, research carried out in the Sub-Saharan Africa revealed that, rising temperature and water vapor will reduce the millet yield. On the contrary, gain of wet day frequency (WDF) increases millet production of yield. (Emediegwu et al., 2022). On another occasion, Oyelami et al. (2023) discovered that, rainfall enhances food availability as compared to, temperature and inflation that reduce food availability in Africa. The authors stated that, that negative impact of temperature and inflation on food security is a loud witness that food insecurity in the area is being caused by global warning as well as the increasing food prices because it is lowering food production and buying power of citizens particularly low-income earners and net food purchasers in the region (Oyelami et al., 2023)

Physical and financial capital are represented by fertilizer consumption, as access to fertilizer is a function of affordability and supply chain stability (Mobeen et al., 2023; Ojo et al., 2024). Studies show that financial constraints are a primary barrier to adaptation, with 80% of smallholders in similar contexts facing financial vulnerability (Ojo et al., 2024). Human and social capital are embedded within institutional quality, where effective institutions ensure property rights, reduce corruption, and facilitate extension services (Kula et al., 2013; Mnukwa et al., 2025). The SLF explains why similar climate shocks yield different productivity outcomes across SADC countries; countries where farmers possess higher livelihood capitals can transform their production strategies to maintain the crop production index despite climatic stress, whereas eroded assets lead to livelihood collapse (Mobeen et al., 2023; Schröter et al., 2005).

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The overall economic performance of a country is reflected by Gross Domestic Product (GDP) growth and is therefore often used as a control in studies of agricultural productivity. The higher GDP growth will lead to higher government revenues and private investments, which can be reinvested in agriculture infrastructure, irrigation schemes, technology, research and extension. Such investments can enhance the productivity of agriculture without depending on the weather. Controlling on the GDP growth therefore enables the study to isolate the effect of climate change on agricultural productivity and to take into account differences in economic development among countries.

The foregoing theoretical and empirical literature justifies the anticipation of the study that the agricultural productivity is under downward pressure due to climatic conditions (temperature, precipitation, CO2 emission), and urban population growth. As an example, with panel data of 20 developing countries (2000-2020), Azdagaz et al. (2025) reveal that the higher temperatures and more variable precipitation have a significant negative impact on an agricultural productivity index, and (Tovilode & Moon, 2025)reveals such effects with a panel of African countries as the primary climate regressors on temperature, rainfall, and CO_2 emissions. Meanwhile, the empirical evidence suggests that these relations are mediated by the quality of institutions and utilization of inputs (such as fertilizer): Ábrahám (2025) indicated that the quality of property rights and contract enforcement were found to be the significant factor to increase the yield of cereal production, whereas Alemu et al. (2024) did reveal that the consumption of fertilizers is one of the key factors of influencing the index of productivity in relation to cereal yields in Sub-Saharan Africa.

More to the point, the study expects the positive and negative influence of climate and urbanization on agricultural productivity to be dependent on the institutional quality of the involved institution, which is assumed to be either low or high. Determined to have a statistically significant positive effect on cereal yields, Ábrahám (2025) discover that institutional indicators such as judicial independence, the protection of property rights, the enforcement of contracts, and unbiased administration of the people are significant, whereas Azdagaz et al. (2025) determine that institutional quality mediates the effect of government spending in the agricultural sector on food security and productivity in Africa and Asia. Moreover, productive capacities, the argument works adjust that institutions combine with technology, infrastructure, and human capital to define agricultural productivity, meaning that exogenous shocks on climatic and urbanization can lead to very different results when they occur in strong and weak institutional environments (Ábrahám, 2025; Semosa, 2025; Tovilode & Moon, 2025).

Lastly, the model presupposes that the approximated effect of climatic variable on farming productiveness would vary prior to and following adaptation of the quality of the institutions and fertilizers application, Azdagaz et al. (2025) and Semosa, (2025) estimate climate-productivity models including and excluding the additional controls (e.g., the controls of governments and inputs) and state that when the institutional and macroeconomic controls are included, the magnitude and the importance of the climate factors adaptively change, though the majority of the impacts are negative. On the same note, Alemu et al. (2024) demonstrate that climate proxies (CO_2 and methane emissions) have a substantial negative effect on the productivity of fertilizers and grain yields, and elimination of fertilizer use and other inputs skews the estimated correlation between climate indicators and indexes of crop productivity. Below is the conceptual framework diagram figure 5 of the study.

Erda et al. (2005) provides empirically-based evaluation of temperature change, and CO_2-fertilization on crop yield in China, with the end view of obtaining a quantitative evaluation of yield in the future under new climatic conditions. The paper uses the regional climate model PRECIS, which is a UK Hadley Centre projection, of temperature and precipitation into crop simulation models of rice, maize, and wheat, using temperature and atmospheric CO_2 as explanatory factors and precipitation as a modifying variable (Erda et al., 2005). These data have shown that climate change in the absence of CO_2 fertilization, until water and nutrient levels are depleted, might decrease crop yields by up to 37 percent of the current levels during over the 2080 year, due to heat stress and water scarcity, but higher CO_2 levels under cooler conditions could cause higher productivity, by an average of 5-15 percent. But at elevated CO_2 levels above about 450 ppm, grain quality can be compromised implying that there is a trade-off between numbers of yield and quality of grain in high-CO_2 futures (Erda et al., 2005; Kone et al., 2024).

It is concluded that the net effect of CO_2 fertilization depends on the access to irrigation, nutrient control, and the type of crops, and is very topical to conduct modern research on the subject of CO_2 emissions and agricultural production because it shows what can be gained and what severe conditions are to fulfil the gains (Erda et al., 2005; Kone et al., 2024; Wakjira et al., 2024). The article supports the idea that feelings of the CO_2 dynamics and significant relationships between temperature, rain, and CO_2 should not be considered in empirical models due to the chances of biased estimates of climate effects on crop productions (Erda et al., 2005).

2.2.2 Impact of macro-economic factors on agricultural productivity

Macroeconomic factors and institutional factors have become more and more relevant to empirical studies of agricultural productivity in Sub Saharan Africa, although their strengths and nature of impacts are still debated across procedures and settings (Ekeocha et al., 2023; Gelgo et al., 2023). According to recent research, institutional quality represents one of the most powerful predictors of agricultural value added particularly when there are significant differences among countries and across time in governance structures (Gelgo et al., 2023). In their analysis of the panel data on seven East African nations, (Gelgo et al., 2023; Tovilode & Moon, 2025), using a bias corrected Least Squares Dummy Variable estimator reveal that the effect of the government on the agricultural value added is significantly positive but the influence of voice and accountability is not significantly relevant and is even negative which suggests that the efficiency of the administrable systems and the credible execution of policies is more important to agricultural performance as compared to participatory government in the short term (Tovilode & Moon, 2025)

Evidence that is policy based implies that moderate productivity improvements have been common to fertilizer promotion in Africa due to large prices, supply bottlenecks, and poor extension services. According to, the reason behind the failure of fertilizer subsidies and programmes in distributing the fertilizers to the most suitable areas is often the issue of high production and transport costs, wrong agronomic recommendations, and a weak institutional capacity, a view supported by regional reviews on fertilizer policies and their effects on African agriculture. These limitations have also been intensified by recent global fertilizer price disruptions with some countries showing that since 2020, fertilizer supply disruptions have decreased fertilizer application and led to reduced cereal production and exacerbating food insecurity in a number of Sub-Saharan African countries (Chapoto et al, 2003.; Erda et al., 2005). Meanwhile, current efforts on yield gap closing in Sub Saharan Africa point to the need to balance increased subsistence-level application of fertilisers with site specific nutrient control and the development of effective extension services to meet not only the productivity but also the environmental sustainability objectives.

Among the macro-economic factors that drive agricultural productivity, demographic and structural factors (particularly, a high rate of urban population growth and a low rate of rural population) appear significant yet indirect (FAO, 2023; Gelgo et al., 2023). Gelgo et al. (2023), the share of rural population in East Africa is found to be related to higher agricultural value added and this implies that urbanization is related to productivity enhancing reallocation of labor, mechanization, and commercialization in agricultural output (Alemu et al., 2024; Gelgo et al., 2023). In line with this, analyses of regional foresight indicate that as urbanization occurs in Sub Saharan Africa, the portion of agricultural products in GDP decreases when non-farm activities gain and that enhanced agricultural productivity is one of the prerequisites of the structural transformation process once it is motivated to change rural poverty into a lower living standard (FAO, 2023).

The agricultural food systems and food security performances within the rural-urban spectrum also transform because of urbanization (FAO, 2023; Ouedraogo, 2006). The 2023 edition of the State of food security report by FAO indicates that agrifood systems are changing due to the growing urbanization coupled with the rise in income and changing lifestyles, which augment the rural-urban connections and heightens the role of the post farm segments in food expenditure and availability (FAO, 2023).

The existing research on the urban food systems in Sub Saharan Africa indicates that urbanization is associated with increased food demand and altered diets and the emergence of the chance to use urban and peri urban agriculture to address the food security and income of households, though with considerable limitations in land, water, and infrastructure. Concurrently, warn that a fast-paced urbanization process may cause a loss of food production and biodiversity degradation, as agricultural or natural lands are transformed into urban areas as an illustration of the necessity to control an urbanization process to protect agricultural productivity and ecosystems (Gelgo et al., 2023).

Gelgo et al. (2023) in same East African panel reveal that all GDP per capita, a smaller rural population share and increased education spending positively relate to agricultural value added, indicating how structural change and demographic transition contribute to increases in productivity (Gelgo et al., 2023). These results are agreed with in cross country evidence in low- and middle-income economies, where more robust property rights, enhanced contract enforcement, and increased agricultural research and development raise agricultural productivity in a large part; implying that more segmented institutional dimensions are pivotal in elucidating sectoral outcomes (Ekeocha et al., 2023; Tovilode & Moon, 2025). Besides, Ekeocha et al. (2023) record that the institutional quality has a profound measure on sectoral output in Sub Saharan Africa, which encompasses agriculture but the level and direction of such influence vary on different indicators of governance, which supports the cross contextual character of institutional impacts (Tovilode & Moon, 2025).

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Fertilizer use is also an important factor identified in the macroeconomic literature regarding cross country differences in agricultural production in Sub Saharan Africa (Erda et al., 2005). In 35 countries of Sub-Saharan Africa (2005-2020), the authors of the study Alemu et al. (2024) and Alemu et al. (2024) utilize pooled OLS and a stochastic frontier model of panel data and determine that fertilizer use explains almost all growth in the cereal yields of companies, and the proportion of fertilizer to the technical efficiency of the production of cereal crops reaches approximately 5.7% (Alemu et al., 2024; Chapoto et al., 2002.). These findings are consistent with the larger regional evaluations that indicate that the average stimulant application in Sub Saharan Africa is much lower than on a global scale and that rising the application of fertilizers, along with proper soil and water management, could lead to a substantial rise in cereal productivity and a speedy structural shift.

The environmental conditions and climate change, however, have a tremendous effect on the productivity of the fertilizer (Alemu et al., 2024; Chapoto et al., 2002.; Ouedraogo, 2006). Alemu et al. (2024) indicate that climate change indicators like CO2 and methane emissions have a strong negative effect on fertilizer productivity based on which a reduction in marginal returns to chemical inputs might be expected when the environment becomes worse (Alemu et al., 2024). The analysis of factor productivity in the face of climate change, in line with supplementary analysis, confirms that improved productivity of fertilizer has contributed to increase of cereal productivity in Sub Saharan Africa between 2005 and 2020, still indicates variable productivity of fertilizer as a result of inadequate investment of farm level research, critical agro ecological climate and augmented production and marketing dangers (Alemu et al., 2024; Chapoto et al, 2002.). Technical reports on fertilizers and soil health also underline that under climate change conditions, the sustainable intensification of production cannot be achieved through the increased use of fertilizers alone, but also through a better management of soil health, efficient use of nutrients and climate resilient systems of farming (European Commission Joint Research Centre, 2025).

Evidence that is policy based implies that moderate productivity improvements have been common to fertilizer promotion in Africa due to large prices, supply bottlenecks, and poor extension services. According, the reason behind the failure of fertilizer subsidies and programmes in distributing the fertilizers to the most suitable areas is often the issue of high production and transport costs, wrong agronomic recommendations, and a weak institutional capacity, a view supported by regional reviews on fertilizer policies and their effects on African agriculture. These limitations have also been intensified by recent global fertilizer price disruptions with some countries showing that since 2020, fertilizer supply disruptions have decreased fertilizer application and led to reduced cereal production and exacerbating food insecurity in a number of Sub-Saharan African countries (Chapoto et al, 2002.; Erda et al., 2005). Meanwhile, current efforts on yield gap closing in Sub Saharan Africa point to the need to balance increased subsistence-level application of fertilisers with site specific nutrient control and the development of effective extension services to meet not only the productivity but also the environmental sustainability objectives.

Among the macro-economic factors that drive agricultural productivity, demographic and structural factors (particularly, a high rate of urban population growth and a low rate of rural population) appear significant yet indirect (FAO, 2023; Gelgo et al., 2023). Gelgo et al. (2023), the share of rural population in East Africa is found to be related to higher agricultural value added and this implies that urbanization is related to productivity enhancing reallocation of labor, mechanization, and commercialization in agricultural output (Alemu et al., 2024; Gelgo et al., 2023). In line with this, analyses of regional foresight indicate that as urbanization occurs in Sub Saharan Africa, the portion of agricultural products in GDP decreases when non-farm activities gain and that enhanced agricultural productivity is one of the prerequisites of the structural transformation process once it is motivated to change rural poverty into a lower living standard (FAO, 2023).

The agricultural food systems and food security performances within the rural-urban spectrum also transform because of urbanization (FAO, 2023; Ouedraogo, 2006). The 2023 edition of the State of food security report by FAO indicates that agrifood systems are changing due to the growing urbanization coupled with the rise in income and changing lifestyles, which augment the rural-urban connections and heightens the role of the post farm segments in food expenditure and availability (FAO, 2023).

The existing research on the urban food systems in Sub Saharan Africa indicates that urbanization is associated with increased food demand and altered diets and the emergence of the chance to use urban and peri urban agriculture to address the food security and income of households, though with considerable limitations in land, water, and infrastructure. Concurrently, warn that a fast-paced urbanization process may cause a loss of food production and biodiversity degradation, as agricultural or natural lands are transformed into urban areas as an illustration of the necessity to control an urbanization process to protect agricultural productivity and ecosystems (Gelgo et al., 2023).

Collectively, the body of empirical research offers a solid, but incomplete evidence of the interaction between institutional quality, the level of fertilizer use, and urban demographic process as factors driving agricultural productivity in Sub Saharan Africa (Alemu et al., 2024; FAO, 2008; Gelgo et al., 2023). The variability in conclusions is mostly motivated by the methodological options, the level and form of institutional indicators (aggregate governance scores vs. individual dimensions like government effectiveness or property rights), and the extent to which climate and technological variables are directly incorporated in the analysis (Alemu et al., 2024; Ekeocha et al., 2023). Whilst it has been pointed out that there are studies that have focused more on the technological change and climate effects, there are also those that have underscored the enabling factor of the governance systems and structural change as well, leaving out an empirical gap on how institutional quality, fertilizer use, climate stress, and urbanization interact- a gap that can be filled by your study.

2.3 Conceptual framework

The conceptual framework considered in the given study not only considers conceptual notions but also refers to the existing empirical literature and is structured around predictor (independent) and outcome (dependent) variables. The predictor variables are a combination of factors which all contribute to agricultural productivity where temperature, precipitation, CO2 emissions, and urban population growth are populace variables as key independent variables, and institutional quality and consumption of fertilizers as the control variables. As traditional cross-country work confirms, agricultural output is predicted by crop-based index of production like cereal yield or crop production index (as per common practice of cross-country work) which is similar to recent and multi country work (Ábrahám, 2025; Azdagaz et al., 2025; Semosa, 2025; Tovilode & Moon, 2025).

The foregoing theoretical and empirical literature justifies the anticipation of the study that the agricultural productivity is under downward pressure due to climatic conditions (temperature, precipitation, CO2 emission), and urban population growth. As an example, with panel data of 20 developing countries (2000-2020), Azdagaz et al. (2025) reveal that the higher temperatures and more variable precipitation have a significant negative impact on an agricultural productivity index, and (Tovilode & Moon, 2025)reveals such effects with a panel of African countries as the primary climate regressors on temperature, rainfall, and CO2 emissions. Meanwhile, the empirical evidence suggests that these relations are mediated by the quality of institutions and utilization of inputs (such as fertilizer): Ábrahám (2025) indicated that the quality of property rights and contract enforcement were found to be the significant factor to increase the yield of cereal production, whereas Alemu et al. (2024) did reveal that the consumption of fertilizers is one of the key factors of influencing the index of productivity in relation to cereal yields in Sub-Saharan Africa.

The Gross Domestic Product (GDP) growth is added as a control variable as it is a measure of a country's economic capacity in order to support agricultural development. A higher economic growth can lead to increased investment in agricultural infrastructure, technology, irrigation, research, etc., which can increase agricultural productivity. The addition of GDP growth allows to distinguish the impact of economic growth from the impact of climate change on agricultural production.

More to the point, the study expects the positive and negative influence of climate and urbanization on agricultural productivity to be dependent on the institutional quality of the involved institution, which is assumed to be either low or high. Determined to have a statistically significant positive effect on cereal yields, Ábrahám (2025) discover that institutional indicators such as judicial independence, the protection of property rights, the enforcement of contracts, and unbiased administration of the people are significant, whereas Azdagaz et al. (2025) determine that institutional quality mediates the effect of government spending in the agricultural sector on food security and productivity in Africa and Asia. Moreover, productive capacities, the argument works adjust that institutions combine with technology, infrastructure, and human capital to define agricultural productivity, meaning that exogenous shocks on climatic and urbanization can lead to very different results when they occur in strong and weak institutional environments (Ábrahám, 2025; Semosa, 2025; Tovilode & Moon, 2025).

Lastly, the model presupposes that the approximated effect of climatic variable on farming productiveness would vary prior to and following adaptation of the quality of the institutions and fertilizers application, Azdagaz et al. (2025) and Semosa, (2025) estimate climate-productivity models including and excluding the additional controls (e.g., the controls of governments and inputs) and state that when the institutional and macroeconomic controls are included, the magnitude and the importance of the climate factors adaptively change, though the majority of the impacts are negative. On the same note, Alemu et al. (2024) demonstrate that climate proxies (CO2 and methane emissions) have a substantial negative effect on the productivity of fertilizers and grain yields, and elimination of fertilizer use and other inputs skews the estimated correlation between climate indicators and indexes of crop productivity. Below is the conceptual framework diagram figure 4 of the study.

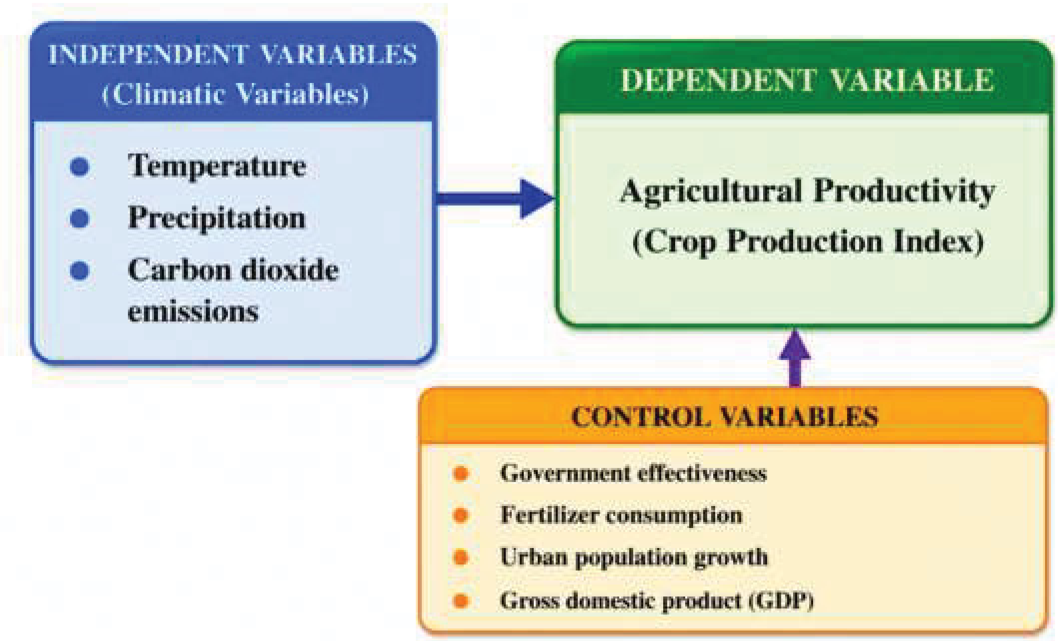

Figure 2.1 Conceptual frame work

Source: Author’s computation

CHAPTER III

RESEARCH METHODOLOGY

This chapter presents the research methodology employed in the study. It describes the study variables, data sources, and research design used to investigate the impact of climate change on agricultural productivity in SADC member countries. The chapter further outlines the measurement of both dependent and independent variables and explains the procedures used for data collection and analysis. In addition, it discusses the panel data model adopted in the study and the econometric techniques used to examine the effects of climatic factors, namely precipitation, average temperature, and carbon dioxide (CO_2) emissions, together with other selected variables, on agricultural productivity across different income groups within the SADC region.

3.0. Research type and Approach

The given study can be identified as quantitative research because it had used a systematically organized method of collecting and analyzing quantitative data to find out trends and make a conclusion. Another quantitative method that was undertaken by the study is a panel data study. The choice of this approach is explained by the fact that the study was conducted to determine the various determinants of Agricultural productivity in the countries that are members of SADC and the study questions and hypothesis were answered with the help of statistical analysis. Descriptive and inferential statistics have been employed in order to meet the study objective. Inferential statistics are used to make inferences whereas descriptive case outlines the characteristics of the data

Table 3.1 Description of the selected variables

Variables	Unit of Measurement	Source	Expected sign
Dependent Variable			
Agricultural productivity	The Crop Production Index (CPI) represents an agricultural output measure that derived its base period	World Bank	

(Crop production index)	values from 2014 to 2016 with a value of 100. (Index)		
Independent variables (Climatic variables)			
Precipitation	Ratio scale (in millimeters)	World Bank (Climate Knowledge Portal)	+
Average temperature	Degree Celsius (0C)	World Bank (Climate Knowledge Portal)	-
Carbon dioxide emissions	Percentage	World Bank	-
Control variables			
Fertilizer consumption	Percentage of fertilizer production used in agriculture, showing inputs in agricultural input. % (ratio)	World Bank	+
Government effectiveness	Measures range from -2.5 (for weak government effectiveness) to +2.5 (for strong government effectiveness).	World Bank	+

Gross Domestic Product	(Annual %)	World Bank	+
Urban Population growth	(Annual %)	World Bank	-

Crop production index shows agricultural production for each year relative to the base period 2014-2016. It includes all crops except fodder crops. Regional and income group aggregates for the FAO's production indexes are calculated from the underlying values in international dollars, normalized to the base period 2014-2016. (Semosa, 2025). The agricultural production index is prepared by the Food and Agriculture Organization of the United Nations (FAO). The FAO indices of agricultural production show the relative level of the aggregate volume of agricultural production for each year in comparison with the base period 2014-2016.

They are based on the sum of price-weighted quantities of different agricultural commodities produced after deductions of quantities used as seed and feed weighted in a similar manner. To obtain the index, the aggregate for a given year is divided by the average aggregate for the base period 2014-2016. Since the FAO indices are based on the concept of agriculture as a single enterprise, amounts of seed and feed are subtracted from the production data to avoid double counting, once in the production data and once with the crops or livestock produced from them. Deductions for seed (in the case of eggs, for hatching) and for livestock and poultry feed apply to both domestically produced and imported commodities. They cover only primary agricultural products destined to animal feed (e.g. maize, potatoes, milk, etc.). (Semosa, 2025) Processed and semi-processed feed items such as bran, oilcakes, meals and molasses have been completely excluded from the calculations at all stages.

3.1. Study Area and Scope of the Research and Country Coverage

The research seeks to investigate the climatic factors on agricultural productivity in SADC member countries. Secondary data were utilized in the study which took place in the period between 2003 and 2023 and used World development indicators (WDI) of World Bank and World Bank Climate Knowledge Portal. The paper took this time because of the access to data. Southern African Development Community has Sixteen climatic vulnerable countries but however, Angola, Botswana, South Africa, Tanzania, and Zimbabwe among others were chosen as the sample countries. In addition, our variables of interest are rainfall, temperature and carbon dioxide emission and are representative of elements of climate change whereas the macro-economic variables like urban population growth, and institutional quality and fertilizer consumption are the control variables. Dependent variables to be used in the study is agricultural productivity (crop production index).

This research investigates the comparative impact of climate change on agricultural productivity across Southern African Development Community (SADC) member countries using a panel data approach. It examines the impacts of precipitation, temperature, government effectiveness, urban population growth, and fertilizer consumption on the crop production index to identify key influencing factors. The subject of this study is the elements affecting agricultural productivity, while the research object is the crop production index in SADC countries.

The study employs secondary panel data for the period 2003 to 2023 across SADC member states. Data for the crop production index (representing agricultural productivity), precipitation, temperature, government effectiveness, urban population growth, and fertilizer consumption were sourced from the World Bank Development Indicators database and national statistical offices of SADC countries. The dependent variable, crop production index, measures overall agricultural output volume relative to a base period (2014–2016 = 100), capturing changes in crop yields and productivity. This variable aligns with prior studies on climate impacts in Africa.

3.2 Data analysis Techniques

STATA will be selected as the main analysis tool because it offers robust facilities for data management and modern econometric analysis of cross-section and panel data (Cameron & Trivedi, 2005; Gujarati & Porter, 2009; Wooldridge, 2021). Descriptive and inferential statistics were employed. Descriptive statistics were first used to summarize and explore the characteristics of the panel data across different strata cross-sectional units such as regions, districts, or production groups observed over time using measures such as the mean, minimum, and maximum for agricultural productivity, precipitation, temperature, urban population growth, carbon dioxide emissions, institutional quality, and fertilizer consumption (Gujarati & Porter, 2009; Wooldridge, 2021). This step helps to reveal the variation within and between strata and to identify potential outliers or data issues before moving to formal econometric modelling (Cameron & Trivedi, 2005).

For inferential analysis, the study employed panel-data regression models to examine the determinants of agricultural productivity across the specified strata (Cameron & Trivedi, 2005; Gujarati & Porter, 2009; Wooldridge, 2021). Panel methods are particularly useful because they allow for control of unobserved heterogeneity that varies across cross-sectional units but is time-invariant, thereby reducing omitted-variable bias compared with pure cross-section or time-series approaches (Cameron & Trivedi, 2005; Wooldridge, 2021). In particular, the study estimated pooled Ordinary Least Squares (OLS), fixed-effects, and random-effects models to account for stratum-specific effects and obtain consistent and efficient parameter estimates, following standard panel-data practice where model choice is guided by specification tests such as the Hausman test (Cameron & Trivedi, 2005; Gujarati & Porter, 2009; Wooldridge, 2021).

3.2.1 Model specifications

This study used one set of models and this is shown below:

Model: $CPI = f\ (rf, temp, \mathrm{CO2}, \mathrm{pop}, \mathrm{fer\_co}, \mathrm{gvt\_ef}, \mathrm{gdp}) \ldots eq\ 1$

$\mathrm{CPIit}=\beta 0+\beta 1\mathrm{rfit}+\beta 2\mathrm{tempit}+\beta 3\mathrm{CO2it}+\beta 4\mathrm{popit}+\beta 5\mathrm{fer\_coit}+\beta 6\mathrm{gvt\_efit}+\beta 7\mathrm{gdpit}+\varepsilon\mathrm{it} \ldots eq\ 2$

In model 1 above, *CPI* means crop production index which is the proxy for agricultural productivity and is used as the dependent variable, for country i in year t. β_0 serves as the constant term, whereas, β_1 to β_6 represent the coefficients of the independent variables of the selected countries at time t, and ε_{it} is the error term. In this model, where *rf, temp, CO2, pop, fer_co, govt_ef, gdp represent* rainfall average temperature, urban population growth, carbon dioxide emission, fertilizer consumption, government effectiveness and gross domestic product respectively.

3.2.2 pre-estimation

The pre-estimation test gives descriptive statistics of the variables of interest in the study. It is useful for determining the standard deviation, mean, maximum, and minimums of the data values. Importantly, this process is very important in our study because it allows us to understand the behavior of the data set by testing normality and the absence of mistakes.

3.3 Estimation techniques

The study estimated the model by using pooled OLS, fixed effect, and random effect on both low-income group and high-income group on these estimation methods.

3.3.0 Pooled OLS model

One of the estimation techniques used in analyzing panel data is the pooled ordinary least square method. The model will be able to determine which line best fits the data through an identification of the relation that exists within the data points. (Ceesay et al., 2024), But the flaw in this approach lies in the fact that it considers the heterogeneity of cross-sectional data but ignores the time-specificity of panel data which means the unobservable heterogeneity of countries here (Mahrous, 2019), which is the countries in this case and cannot adjust to the time specific in panel data(Ceesay et al., 2024). The pooled OLS estimation operates like multiple linear regression. Below are the equations of the pooled OLS model:

CPIit=β0+β1rfit+β2tempit+β3CO2it+β4popit+β5fer_coit+β6gvt_efit+β7gdpit+εit…. eq 3

3.3.1 Fixed Effects model

Fixed effect model is the type of estimator for panel data analysis where the variables used are time-demeaned. Furthermore, fixed effect model differs from pooled OLS in that it considers the heterogeneous nature of countries. (Mahrous, 2019) It can also be useful where the unobserved individual effects are correlated with the explanatory variables. Nevertheless, this method cannot still be used if the unobserved individual effects are uncorrelated with the explanatory variables(Ceesay et al., 2024). Below are fixed effect model equations for the study.

CPIit=β0+β1rfit+β2tempit+β3CO2it+β4popit+β5fer_coit+β6gvt_efit+β7gdpit+εit…. eq 4

Where: α_i controls the country effect in the panel and δ_t is the year dummy.

3.3.2 Random Effects model

The random effect model also includes consideration for unobserved heterogeneity between the countries in the panel data set (Mahrous, 2019). However, while compared to FE, random effects can be used when the unobserved individual effect is not related to the independent variable(s), (Ceesay et al., 2024). Below are the random effect model equations:

$CPIit=\beta0+\beta1rfit+\beta2tempit+\beta3CO2it+\beta4popit+\beta5fer\_coit+\beta6gvt\_efit+\beta7gdpit+\varepsilon it$ …. *eq* 5

3.3.3 The Breusch Pagan Lagrange Multiplier and Hausman tests for optimal baseline model selection

Consequently, in line with the traditional approaches of estimating panel data regression, we adopted the Breusch-Pagan Lagrange Multiplier (B.P. LM) and Hausman tests for selecting the optimal baseline model among Pooled OLS, Random Effect, and Fixed Effects Models. The B.P. LM test is applied in distinguishing between the Pooled OLS and Random Effects Models. However, the Hausman test is applied in distinguishing between the Random Effects Model and the Fixed Effects Model, considering the assumptions associated with panel data regressions. H0: supports the Random Effect as the Optimal Baseline Model, while H1: supports the Fixed Effect as the Optimal Baseline Model.

3.3.4 Diagnostics post estimation test

In panel data model (Pooled OLS, Fixed Effect and Random Effect Model), there may be problem of heteroscedasticity and serial correlation. As a consequence, the optimal baseline model has been tested for heteroscedasticity and serial correlation. In this regard, heteroscedasticity and serial correlation in the model cause the issue of biasness, thereby violating the classical assumptions. With a view to solving these issues, the estimation method based on optimal baseline model was used in the study. This estimation method was robust and solved the issue of heteroscedasticity and serial correlation.

CHAPTER IV

RESULTS AND DISCUSSION

In this chapter, we present the findings and discussions of the research. This chapter will be organized as follows. We will start with the pre-estimation findings called descriptive statistics. Then we will go for the selection of the optimal baseline model. The optimal baseline model can be selected either by using a pooled OLS, random effect, or fixed effect. Then we will present the findings of our study. But since we have only one model in our study, the findings will be presented one at a time. For example, in this study, we will present and discuss the findings from model 1 that focuses on the effect of climate change on Crop production index.

4.1 Descriptive Statistics

Table below presents the descriptive statistics for the variables used in the analysis, based on 160 observations. The results show that the average Crop Production Index is 96.80, with a standard deviation of 20.10. The minimum value is 41.20, while the maximum is 176.50. This indicates that agricultural productivity differs considerably across the countries and years included in the study.

Urban Population has a mean value of 2.98 and a standard deviation of 1.52, suggesting moderate variation in the rate of urban population growth. The values range from -2.40 to 5.50, showing that while some countries experienced a decline in urban population growth, others recorded substantial increases.

Rainfall has an average of 1,069.30 mm, with values ranging from 225.10 mm to 2,830.40 mm. The relatively large standard deviation of 538.60 indicates significant differences in rainfall patterns across the sample. Similarly, Average Temperature has a mean of 21.95°C, a standard deviation of 3.08, and ranges from 12.10°C to 27.40°C, reflecting variation in climatic conditions.

Fertilizer Consumption records an average of 56.40 kilograms per hectare, with a high standard deviation of 114.80. The wide range, from -2.20 to 1,530.00, suggests substantial differences in fertilizer use among the countries.

Governance Effectiveness has an average score of 0.51, with values ranging from -1.80 to 1.12, showing that governance quality differs across countries. Finally, Gross Domestic Product (GDP) Growth averages 3.25%, with a standard deviation of 4.85. GDP growth ranges from -11.30% to 14.80%, indicating that some countries experienced economic contraction while others recorded strong economic growth during the study period.

Overall, the descriptive statistics reveal noticeable variation in agricultural productivity, climate conditions, governance, and economic performance across the sample. These differences provide sufficient variability for examining how climate change and other factors influence agricultural productivity.

Table 4.1 Descriptive Statistics Results on low-income countries

Variable	**Observations**	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
Crop Production Index	160	96.80	20.10	41.20	176.50
Urban Population	160	2.98	1.52	-2.40	5.50
Rainfall	160	1,069.30	538.60	225.10	2,830.40
Average Temperature	160	21.95	3.08	12.10	27.40
Fertilizer Consumption	160	56.40	114.80	2.20	1,530.00
Carbon Dioxide Emission	160	3.68	11.65	0.02	60.80
Governance Effectiveness	160	0.51	0.72	-1.80	1.12
Gross Domestic Product (GDP Growth, %)	160	3.25	4.85	11.30	14.80

Source: Author’s compilation; results obtained from Stata software

Table 4.2 Descriptive Statistics Results on high income countries

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
Crop Production Index	160	97.68	20.78	40.15	179.04
Urban Population	160	3.04	1.58	-2.60	5.57
Rainfall	160	1,079.66	547.91	222.65	2,837.69
Average Temperature	160	22.09	3.11	12.05	27.56
Fertilizer Consumption	160	57.70	117.60	2.26	1,545.00
Carbon Dioxide Emission	160	3.83	11.99	0.014	61.10
Governance Effectiveness	160	0.48	0.75	1.81	1.15
Gross Domestic Product (GDP Growth, %)	160	3.31	4.92	11.30	14.80

Source: Author's compilation; results obtained from Stata software

From the table above presents the descriptive statistics for the variables used in the analysis based on 160 observations. The results show that the average Crop Production Index is 97.68, with a standard deviation of 20.78. The minimum value is 40.15, while the maximum is 179.04. This suggests that agricultural productivity varies considerably across the countries and years included in the study.

Urban Population has a mean value of 3.04 and a standard deviation of 1.58. The values range from -2.60 to 5.57, indicating that some countries experienced a decline in urban population growth while others recorded relatively high growth rates.

Rainfall has an average of 1,079.66 mm, with a standard deviation of 547.91 mm. Rainfall ranges from 222.65 mm to 2,837.69 mm, showing substantial differences in precipitation levels across the sample. Similarly, Average Temperature has a mean of 22.09°C and a standard deviation of 3.11°C, with values ranging from 12.05°C to 27.56°C. This indicates moderate variation in temperature among the countries.

Fertilizer Consumption records an average of 57.70 kilograms per hectare, with a relatively high standard deviation of 117.60. The values range from -2.26 to 1,545.00, suggesting considerable differences in fertilizer use across the countries.

Governance Effectiveness has an average score of -0.48 and a standard deviation of 0.75. The values range from -1.81 to 1.15, implying that governance quality differs substantially among the countries in the sample. Gross Domestic Product (GDP) Growth has an average of 3.31%, with a standard deviation of 4.92. The minimum value of -11.30% and maximum value of 14.80% indicate that while some countries experienced economic contraction, others achieved strong economic growth during the study period.

Overall, the descriptive statistics reveal considerable variation in agricultural productivity, climate conditions, fertilizer use, governance quality, and economic performance across the sample. This variation provides a suitable basis for examining the relationship between climate change and agricultural productivity

4.2 Overall sample estimation from SADC member countries

As seen in Table 3, the precipitation has positive statistically significant relationship with agricultural productivity as the Fixed Effects coefficient is 0.014. This suggests the productivity of agriculture is raised by about 0.014 units for every 1mm of annual precipitation change, with all else being equal. On the other hand, for every 100 mm of precipitation, there is an increase in agricultural productivity by approximately 1.4 units. The positive association implies that sufficient rain will lead to good soil moisture, more water for a pasture crop and better plant growth. Precipitation is crucial for improving crop yield, agricultural production and agricultural output, particularly in most SADC countries where agriculture is predominantly rain-fed. This result corroborates the study carried out by Emediegwu et al., (2022) which showed that agricultural production in Sub-Saharan Africa is positively related to precipitation.

The Coefficient value of average temperature is -8.122 which is negative and statistically significant, suggesting that agricultural productivity decreases by an average of 8.122 units for every degree in average temperature, other factors being constant. A negative coefficient indicates that the rise in temperature negatively influences agricultural production by causing evapotranspiration, lowering soil moisture levels, causing heat stress to crops, and reducing water availability. Warming may lead to lower production, shorter growing seasons and greater production risks, especially in areas where crops are sensitive to climate. The higher absolute value of the coefficient indicates the high economic impacts of temperature increase; lower productivity in agriculture can lead to lower income from farming, food insecurity and higher food price pressure. This is similar to the results found by Zhao et al., (2017) who reported that greater temperatures have a significant impact on the agricultural output in African economies.

The coefficient for CO_2 is positive and statistically significant with a value of 1.981, which means that a unit increase in CO_2 emissions leads to an increase in agricultural productivity of about 1.981 units, ceteris paribus. The positive relationship between carbon dioxide (CO_2) emissions and agricultural productivity may be attributed to both the CO_2 fertilization effect and the broader economic development processes associated with higher emissions. Elevated CO_2 concentrations can enhance photosynthesis, improve water-use efficiency, and stimulate crop growth, thereby increasing agricultural yields (Broberg et al., 2019; Taylor & Schlenker, 2021). In addition, higher CO_2 emissions are often associated with greater levels of industrialization, mechanization, technological advancement, and investment in agricultural infrastructure, all of which can contribute to improved productivity. Consequently, the positive coefficient observed in this study may reflect not only the direct biological benefits of increased CO_2 concentrations but also the indirect effects of economic development on agricultural production.

This suggests the productivity of agriculture is raised by about 0.014 units for every 1mm of annual precipitation change, with all else being equal. On the other hand, for every 100 mm of precipitation, there is an increase in agricultural productivity by approximately 1.4 units. The positive association implies that sufficient rain will lead to good soil moisture, more water for a pasture crop and better plant growth. Precipitation is crucial for improving crop yield, agricultural production and agricultural output, particularly in most SADC countries where agriculture is predominantly rain-fed. This result corroborates the study carried out by Emediegwu et al., (2022) which showed that agricultural production in Sub-Saharan Africa is positively related to precipitation.

Countries with higher emissions have often more advanced technologies and infrastructure, transport networks, energy access, irrigated areas and agricultural technologies, which increase production efficiency. In addition, higher concentrations of CO_2 in the atmosphere could inhibit growth and photosynthesis under poor conditions. Hence, the positive sign could reflect the impact of economic modernization as well as the temporary fertilizer impact of CO_2 on food production. This is confirmed by the results of Nelson et al., (2013), who noted that moderate CO_2 concentrations could boost crop productivity, but this effect could become less pronounced as climate-related damage grows with time.

In the case of government effectiveness, the coefficient is negative and highly significant, meaning a one-unit increase in the government's effectiveness will lower the agricultural productivity by about 24.968 units, ceteris paribus. This is counterintuitive, but could be a glimpse of the structural shift that many SADC economies are going through. Good governance is often followed by economic diversification; that is, investments, public expenditure and labor resources are gradually diverted from agriculture to industrial and service sectors that provide greater returns and economic growth. This means that in the face of better overall governance, the agricultural sector could be given relatively less attention. Also, reforms in the institutions and governance systems can take time to be reflected in the level of productivity in agriculture. This can lead to the negative coefficient being a reflection of transitional economic adjustments and sectoral shifts, but not a direct negative impact of government effectiveness on agricultural productivity.

The findings indicate that government effectiveness is a negative and statistically significant variable with agricultural productivity both in the Pooled OLS and the Fixed Effects models. In particular, the Fixed Effects model suggests that holding other variables constant, an increase of one unit in government effectiveness leads to a decrease of 24.968 units in the Crop Production Index. This is in contrast to theory expectations that good governance will lead to better policy implementation; public service delivery; stronger institutions and support to agricultural development, which in turn is expected to increase agricultural productivity.

One reason for this could be that there is no guarantee that a better overall performance of government will lead to increased investment or policy support for agriculture. In some SADC countries, non-agricultural activities (industry and services) may have been the focus of attention and public investments as part of an overall economic transformation, alongside governance reforms. This means that the agricultural sector is likely to end up with a relatively smaller share of the resources, even if overall governance is better, and thus relatively less enhanced agricultural productivity.

The coefficient of growth in urban population is negative and statistically significant (-2.827), which means that for every unit increase in the growth in urban population, agricultural productivity decreases by about 2.827 units of the agricultural productivity, while other factors remain constant. This negative relationship suggests that urbanization can lead to a decrease in agricultural labor due to migration to urban areas, and also put a strain on agricultural land. The productive farmlands are converted into houses, shops, and industrial units, which are built in urban areas leading to the decline of the agriculture area which is also the productive area. Furthermore, the migration of younger and more productive laborers to the urban areas may lead to a shortage of labor within the rural areas which can impact agricultural production. Such impacts are especially high in the countries with low mechanization rates and agriculture being labor-intensive.

Fertilizer consumption however has a positive statistically significant coefficient of 0.024 which means that for every unit increase in the fertilizer consumption in the farms, agricultural productivity would increase by about 0.024 unit of production, while other factors remain constant. The positive coefficient shows the importance of the fertilizer in making the soil fertile, supplying essential nutrients and boosting crop yields. More fertilizer permits farmers to produce more from the same amount of farmland and enhance productivity. The discovery implies that the use of productivity enhancing agricultural inputs are still crucial to boost agricultural production, food security and rural incomes in the SADC countries. This is not the first result to suggest that fertilizer consumption is a key contributor to agricultural productivity improvement in developing countries, as witnessed in many studies.

Gross Domestic Product (GDP) has a positive relationship with the Crop Production Index across all three estimation models. In the Pooled OLS model, the coefficient of 0.421 is positive but statistically insignificant, indicating that GDP growth does not have a significant effect on agricultural productivity under this specification. However, in the Random Effects model, GDP has a positive and statistically significant coefficient of 0.568, suggesting that a one-percentage-point increase in GDP growth is associated with an increase of approximately 0.568 points in the Crop Production Index, holding other factors constant. Similarly, the Fixed Effects model shows a positive and statistically significant coefficient of 0.913, indicating an even stronger effect of GDP growth on agricultural productivity after controlling for unobserved country-specific characteristics.

The positive and significant relationship in the Random Effects and Fixed Effects models suggests that higher economic growth contributes to improved agricultural productivity. This may be because economic growth increases investment in agricultural infrastructure, technology, irrigation systems, research and development, and access to agricultural inputs, all of which can enhance crop production. Furthermore, stronger economic performance can improve government capacity to support the agricultural sector through better policies, extension services, and rural development programs. Overall, the findings imply that economic growth plays an important role in promoting agricultural productivity, although its effect becomes more evident after accounting for country-specific factors.

The results indicated that both climatic and structural economic factors are important to agricultural productivity in SADC countries. Rising temperatures, urban population growth and government effectiveness are negatively related to agricultural productivity, though higher precipitation, CO_2 emissions and fertilizer use are positively related. The findings suggest that policy measures and more intensive application of productivity-enhancing inputs can boost agricultural production and expansion, while climate-related threats and the continued structural shift in the economy can limit the agricultural productivity potential. The results highlight the need for climate adaptation actions, investments in agricultural technology, better use of inputs and policies to keep the agricultural sector competitive in the context of overall economic development and urbanization.

The foregoing theoretical and empirical literature justifies the anticipation of the study that the agricultural productivity is under downward pressure due to climatic conditions (temperature, precipitation, CO2 emission), and urban population growth. As an example, with panel data of 20 developing countries (2000-2020), Azdagaz et al. (2025) reveal that the higher temperatures and more variable precipitation have a significant negative impact on an agricultural productivity index, and (Tovilode & Moon, 2025)reveals such effects with a panel of African countries as the primary climate regressors on temperature, rainfall, and CO2 emissions. Meanwhile, the empirical evidence suggests that these relations are mediated by the quality of institutions and utilization of inputs (such as fertilizer): Ábrahám (2025) indicated that the quality of property rights and contract enforcement were found to be the significant factor to increase the yield of cereal production, whereas Alemu et al. (2024) did reveal that the consumption of fertilizers is one of the key factors of influencing the index of productivity in relation to cereal yields in Sub-Saharan Africa.

More to the point, the study expects the positive and negative influence of climate and urbanization on agricultural productivity to be dependent on the institutional quality of the involved institution, which is assumed to be either low or high. Determined to have a statistically significant positive effect on cereal yields, Ábrahám (2025) discover that institutional indicators such as judicial independence, the protection of property rights, the enforcement of contracts, and unbiased administration of the people are significant, whereas Azdagaz et al. (2025) determine that institutional quality mediates the effect of government spending in the agricultural sector on food security and productivity in Africa and Asia. Moreover, productive capacities, the argument works adjust that institutions combine with technology, infrastructure, and human capital to define agricultural productivity, meaning that exogenous shocks on climatic and urbanization can lead to very different results when they occur in strong and weak institutional environments (Ábrahám, 2025; Semosa, 2025; Tovilode & Moon, 2025).

Lastly, the model presupposes that the approximated effect of climatic variable on farming productiveness would vary prior to and following adaptation of the quality of the institutions and fertilizers application, Azdagaz et al. (2025) and Semosa, (2025) estimate climate-productivity models including and excluding the additional controls (e.g., the controls of governments and inputs) and state that when the institutional and macroeconomic controls are included, the magnitude and the importance of the climate factors adaptively change, though the majority of the impacts are negative. On the same note, Alemu et al. (2024) demonstrate that climate proxies (CO2 and methane emissions) have a substantial negative effect on the productivity of fertilizers and grain yields, and elimination of fertilizer use and other inputs skews the estimated correlation between climate indicators and indexes of crop productivity. Below is the conceptual framework diagram figure 4 of the study.

The relatively low R^2 values obtained from the pooled OLS, fixed effects, and random effects models should be interpreted with caution and do not necessarily indicate weak model performance. Agricultural productivity is influenced by a wide range of economic, institutional, technological, and environmental factors, many of which are difficult to measure and incorporate into a single empirical model. As a result, it is not uncommon for studies in this area to report moderate or relatively low R^2 values.

Table 1.3 Overall sample estimations for both models

Model: The impact of climate change on Agricultural productivity on SADC member countries as a whole			
Dependent variable: Crop Production Index			
	Pooled OLS	RE Model	FE Model
Variables	Coefficients	Coefficients	Coefficients
Precipitation	-0.004* (0.002)	0.001 (0.004)	0.014*` (0.008)
Average temperature	-0.818* (0.434)	-1.254 (0.829)	-8.122* (4.418)
Carbon dioxide emissions	-0.068***(0.106)	0.081 (0.205)	1.981** (0.904)
Gross Domestic Product	0.421 (0.267)	0.568*** (0.314)	0.913** (0.904)
Governance effectiveness	-5.000** (2.097)	-7.916* (3.267)	-24.968*** (6.453)
Urban population growth	-3.534** (0.913)	-3.416** (1.252)	-2.827* (1.564)
Fertilizer consumption	0.027** (0.013)	0.028* (0.013)	0.024* (0.014)
Cons	127.141***(9.909)	128.487***(18.564)	247.998**(99.185)
R square	0.071	0.051	0.102
Country	16		
Observation	320		
BP-LM test = (0.0000)			

Hausman test = (0.0000)			

Source: Author's computation; results obtained from Stata software

4.2.1 The Systematic selection of the optimal panel baseline model suitable for analyzing models for both income group and high-income group.

The choice of the best model for the baseline analysis will conform to the conventional panel data model estimation techniques. This is done through the estimation of pooled OLS, random effects, and fixed effects models, followed by selecting the appropriate model through the B-P LM and Hausman tests for each model analyzed in the study. The empirical results from table 4 below show that, in the case of the model of the study on low-income categories in SADC Countries, the B-P LM test is statistically significant at 1%, hence the B-P LM test favors either the random effect model or fixed effects model. Having confirmed this, the next step is to estimate the fixed effect and random effects and finally apply the Hausman test. Also from the above table, the outcome of the Hausman Test shows that the probability value is 0.0000, and this is statistically significant at 1%. Thus, this means that the alternative hypothesis should be accepted, indicating that the fixed effect model is the best baseline model. In addition, the outcomes of the B-P LM Test for the model of high-income groups show that the random effect model is best compared to the pooled OLS. As such, since the B-P LM probability value is 1.00 for high-income countries, then this means that there is no unobserved heterogeneity between the high-income group of countries.

Table 4.4 Result of the Systematic Selection of the Optimal Panel Baseline Model Suitable for low-income group and high-income group: Result of the Systematic Selection of the Optimal Panel Baseline Model Suitable for low-income group and high-income group

	Model for low-income group	Model for high income group
Name of test	Significance level	Significance level
BP- LM test	chi2 = 89.50 (0.0000)	chi2 = 0.00 (1.0000)
Hausman test	chi2 = 22.66 (0.0009)	

Note: The probability values are in parenthesis and BP-LM (Breusch Pagan Lagrange Multiplier).

Source: Author's computation; results obtained from Stata software

The Hausman specification test was conducted to determine the most appropriate panel data estimation technique for the low-income group. The test evaluates whether the Random Effects (RE) model is consistent and efficient by examining the presence of correlation between the unobserved country-specific effects and the explanatory variables. The null hypothesis states that the Random Effects estimator is consistent and efficient, implying that there is no correlation between the country-specific effects and the regressors, while the alternative hypothesis states that the Fixed Effects (FE) estimator is consistent and preferred because such correlation exists.

The test results yielded a chi-square statistic of 22.66 with a corresponding probability value of 0.0009, which is less than the 5 percent significance level. Consequently, the null hypothesis is rejected, indicating the existence of a systematic correlation between the unobserved country-specific effects and the explanatory variables. This suggests that the Random Effects estimator is inconsistent and would produce biased estimates. Therefore, the Fixed Effects model is considered the most appropriate estimation technique for the low-income group, as it effectively controls for unobserved country-specific characteristics that may influence agricultural productivity.

For the high-income group, the model selection process indicates a different outcome. The estimated variance of the country-specific random effects is zero (Var(u) = 0), with an associated probability value of 1.000. This result implies that there is no significant unobserved heterogeneity across the high-income countries included in the sample. In other words, country-specific effects do not contribute meaningfully to explaining variations in agricultural productivity beyond the explanatory variables already included in the model. As a result, neither the Fixed Effects nor the Random Effects estimator provides additional explanatory power. Therefore, the Pooled Ordinary Least Squares (Pooled OLS) model is considered the most appropriate estimation technique for the high-income group because it provides efficient and unbiased estimates without the need to account for country-specific effects.

4.3 The impact of climate change on agricultural productivity on low-income countries group

The aim of this study was to look at how the impact of climate change on agricultural productivity changes with selected macroeconomic factors among the low-income countries in the Southern African Development Community (SADC). After the Hausman specification test, the Fixed Effects model was chosen as the best estimation method and results were interpreted as such. The results are summarized in Table 5 and compared to the pooled OLS and Random Effects estimation.

The significance test results show that the precipitation has a positive and statistically significant influence on the productivity of agriculture. The value of the coefficient of 0.017 indicates that for every unit change in the annual precipitation by 1 mm the crop production index changes by about 0.017 units while other variables remain constant. The p-value is found to be less than 10 per cent, thus the null hypothesis is rejected, and it is concluded that there is evidence to support that precipitation has a significant effect on agriculture productivity in low-income countries of the SADC. The positive relationship indicates that rainfall is still an important input to agriculture as the majority of countries in the region are highly reliant on rain-fed agriculture systems. Good rainfall ensures that the soil moisture is sufficient to facilitate crop growth, improve livestock production and in turn boost agricultural outputs. Thus, better rainfall can help to increase crop productivity, incomes of farmers, reduction of poverty, and improvement in the rural livelihoods. Despite the positive effect of rainfall, some countries in SADC have short and non-predictable rainy seasons that last for only 3 to 4 months, thereby reducing food production and making them more vulnerable to decline in productivity.

This result is similar to other empirical studies that have previously stressed that rainfall plays an important role in agricultural production in Sub-Saharan Africa. Previous studies have shown that rainfall variability and water availability have a profound effect on the yield of crops, both by (Glover, 1957; Nenwala et al., 2025; Peprah, 2014) proved that better water management leads to higher agricultural yields in semi-arid areas in Africa. These studies are consistent with the present results in confirming that rainfall continues to be one of the most important factors shaping the performance of agriculture in economies highly dependent on climate sensitive agriculture.

Average temperature, on the other hand, has a negative and statistically significant effect on agricultural productivity. The coefficient of -8.89 means that for a unit rise in the average temperature, the production index of the crop decreases by about 8.89 unit, when other factors remain the same. The coefficient is statistically significant, indicating that temperature plays an important role in the agricultural performance in low-income countries in the SADC. The negative association suggests that the greater the temperature, the more evapotranspiration would increase, the lower soil moisture, the higher heat stress on crops and livestock, and the lower agricultural production. The region of SADC has tropical and semi-arid climatic conditions, and a further rise in temperature could further compound water scarce and agricultural productivity. This reduced productivity can then lead to food security issues, reduced agricultural incomes and overall economic growth.

This result aligns with Schauberger et al., (2017) who reported that maize and soybean yields decreased rapidly with temperatures above 30 °C. Likewise, Zhao et al., (2017) found that higher temperatures have negative impacts on the productivity of the world's main crops. Extreme heat also adversely affects farm-level productivity in Nigeria as demonstrated by (Kumar & Khanna, 2019; Mayorga et al., 2023) have provided evidence that the effect of higher temperatures on agriculture is negative, and leads to production instability especially in developing nations. Hence, the findings are consistent with the idea that increased temperatures are a real challenge to the productivity of agriculture and economic development in the SADC region.

The results further reveal that carbon dioxide (CO_2) emissions have a positive and statistically significant impact on agricultural productivity. Coefficient 19.10 indicates that at the same level of other independent variable(s), a rise of 1 unit in carbon dioxide emissions leads to a corresponding rise of 19.10 units in the crop production index. The study finds that carbon dioxide emissions have a significant impact on agricultural productivity as the coefficient is statistically significant at the 1 percent level. The positive relationship can be attributed to the carbon fertilization effect, which refers to the increased photosynthesis, water-use efficiency and crop growth due to rising concentrations of atmospheric CO_2. In addition, economic modernization, industrial development, mechanization, and the development of infrastructure are usually correlated with higher CO_2 emissions, and these factors can indirectly benefit agricultural productivity.

The same result was found by Broberg et al., (2019) who reported that wheat yield was seen to rise by around 26 percent due to elevated CO_2 concentrations. In the same way, Vanuytrecht et al., (2012)found that increased concentrations of CO_2 led to increased crop biomass and agricultural productivity, and (Bai et al., 2024; Z. Liu & Lu, 2024) showed that higher CO_2 levels led to improved plant growth and agricultural production. The results indicate that CO_2 emissions can yield short-term productivity gains, but over the long-term these may be counterbalanced by climate-related challenges like droughts, floods and extreme temperatures.

There is a negative and statistically significant relationship between government effectiveness and agricultural productivity. The coefficient of -25.04 suggests that a one-unit rise in government effectiveness will lead to an around 25.04 unit drop in the crop production index, with the other factors in the model being constant. This seems quite counterintuitive, but it could be indicative of the structural change taking place in many low-income SADC economies. Better governance is generally accompanied by economic diversification, industrialization and urbanization, and this can lead to a reallocation of resources, labor and investments from agriculture to industry and services. Moreover, institutional changes can take a long time to take effect, before they can show up in agricultural improvements.

This finding is the same as M. Lio & Liu, (2008)who reported that some dimensions of governance could have a negative impact on agricultural productivity if institutional reforms are not properly implemented. Likewise, (Lamm, 1980; Lio & Liu, 2008) found that the negative effects of government action can also lead to lower agricultural performance because of policy inefficiencies, market distortions, and lessened production incentives. Thus, this negative coefficient might be related to problems in policy implementation or structural economic changes, not necessarily to a negative effect of governance improvements on agriculture.

The coefficient of the urban population growth is positive at 5.94, which means that if the urban population growth increases by 1%, agricultural productivity increases by 5.94%, with an increase in agricultural productivity being expressed in terms of percentage. The coefficient, however, is not statistically significant, suggesting that there is inadequate evidence to conclude that urbanization has a significant impact on agricultural productivity in low-income SADC countries. On the other hand, urbanization can lead to larger markets for agriculture products, better infrastructure, and easier access to new technologies, but the positive effects of these changes are not yet strong enough to be measured in terms of agricultural productivity.

However, the positive coefficient is overall in line with research emphasizing the positive impacts of urbanization on agricultural development. Oueslati et al., (2019) revealed that population concentration can boost agricultural productivity by facilitating market access for agricultural products, and Widya et al., (2019)indicated that the urban agglomeration can contribute to the agricultural productivity growth. Likewise, Kyalo Willy et al., (2019) discovered that rising population can induce agricultural intensification and better land use management. Yet, as the coefficient is not statistically significant, the potential benefits should be taken with a pinch of salt in the context of low-income SADC countries.

Lastly, records of fertilizer use have positive and statistically significant effect on agricultural productivity. With the coefficient of 1.01, a one unit raise in the level of the fertilizer input raises the crop production index by about one point, holding all other factors constant. The positive relationship underlines the significance of fertilizer as an input to increase agricultural productivity. Fertilizers help to augment soil fertility, reduce soil nutrient deficiencies, promote crop growth, and boost crop production. However, with many parts of sub-Saharan Africa affected by nutrient-deficient soils, the use of fertilizer may be a key factor in enhancing food security and agricultural productivity.

The result is in line with Martey et al., (2019)who reported that the use of fertilizers had significantly enhanced agricultural productivity and farm income in Ghana. Likewise, Ogeto & Ali, (2020)showed that fertilizer application has a positive effect on maize production in African countries, and Paudel, (2025)found that low use of fertilizers negatively impacts crop yields in Mali. While Paudel, (2025)pointed out the environmental impacts of over-fertilization, the research also confirmed its role in ensuring the productivity of agriculture. Hence, the results validate fertilizer as one of the key contributors to the agricultural productivity growth in low-income countries in the SADC region.

Gross Domestic Product (GDP) has a positive relationship with the Crop Production Index across all three estimation models. In the Pooled OLS model, the coefficient of 0.842 is positive but statistically insignificant, indicating that GDP growth does not have a significant effect on agricultural productivity under this specification. In the Random Effects model, GDP has a positive and statistically significant coefficient of 1.267, suggesting that a one-percentage-point increase in GDP growth is associated with an increase of approximately 1.267 points in the Crop Production Index, holding other factors constant. In the Fixed Effects model, the coefficient of 1.891 is also positive but statistically insignificant, indicating that although GDP growth is associated with higher agricultural productivity, the effect is not strong enough to be considered statistically different from zero after controlling for country-specific characteristics.

The positive coefficients across all three models suggest that economic growth is generally associated with improvements in agricultural productivity. Higher GDP growth may increase investment in agricultural infrastructure, modern farming technologies, irrigation systems, and access to improved inputs such as fertilizers and high-quality seeds. In addition, stronger economic performance can enhance government spending on agricultural research, extension services, and rural development, which can contribute to increased crop production. However, the lack of statistical significance in the Pooled OLS and Fixed Effects models suggests that the positive effect of GDP growth is not consistent across all model specifications and may depend on differences in country characteristics or other factors affecting agricultural productivity.

The overall performance of the model is satisfactory. The R-squared value of 0.50 means that 50 percent of the variation in agricultural productivity can be explained by the climate, macroeconomic variables used in the model, and the other 50 percent can be explained by factors that are not in the analysis. Besides, the F statistic–814.70, and associated probability value of 0.0000, indicate that the model is jointly significant and has a good fit to the data. The results thus indicate that climate and selected macroeconomic variables, among the low-income countries of the SADC region, are significant indicators of the agricultural productivity

When comparing the three models, Fixed Effects (FE), Pooled OLS and Random Effects (RE), it seems the Fixed Effects model is the most suitable estimation method for this study. The FE and RE models allow for unobserved heterogeneity among the low-income countries in the SADC region while the Pooled OLS model treats countries as homogenous and ignores country specific characteristics. The Hausman specification test, however, showed that the country effect is correlated with the explanatory variables, in violation of the assumptions made by the RE model, which is therefore a better and more consistent estimator. Moreover, the FE model achieved the highest explanatory value ($R^2 = 0.50$) than the Pooled OLS model ($R^2 = 0.1967$) and the RE model ($R^2 = 0.4813$), which implies that the FE model explains better the variations in agricultural productivity across low-income SADC countries.

Overall, the results of the Fixed Effects model are in broad agreement with the empirical literature as well as the economic context of low-income SADC countries. The results indicate that climate and productive factors have significant impact on agricultural production. Rising temperatures and urbanization have a negative effect on the potential for agricultural growth, but there is a positive effect from higher precipitation and fertilizer application. The positive impact of CO_2 emissions and the negative impact of government effectiveness, which is unexpected, may be related to the structural and developmental characteristics of the low-income SADC countries. The results are significant, highlighting the need to implement strategies for climate adaptation, sustainable use of resources, more efficient utilization of agricultural inputs and better policy implementation for long-term agricultural productivity, food security and economic development in the region.

Table 4.5 Results of the Optimal Baseline Model on low-income group

Model 1: The impact of climate change on Agricultural productivity on low-income group			
Dependent variable: Crop Production Index			
	Pooled OLS	RE Model	FE Model
Variables	Coefficients	Coefficients	Coefficients
Precipitation	-0.005 (0.010)	0.022** (0.010)	0.017* (0.008)
Average temperature	8.203 (8.011)	4.690 (6.917)	-8.891** (3.551)
Carbon dioxide emissions	9.567** (3.112)	17.542*** (4.430)	19.103*** (5.047)
Gross Domestic Product	0.842 (0.721)	1.267** (0.838)	1.891 (0.972)
Governance effectiveness	-22.770 (12.831)	-21.221*** (7.612)	-25.040** (0.003)
Urban population growth	0.075 (4.347)	4.305 (4.850)	5.944 (5.250)
Fertilizer consumption	0.328 (0.276)	0.828*** (0.212)	1.019** (0.205)
Cons	124.705(195.380)	-106.494 (171.019)	200.543*(90.463)
R square	0.196	0.481	0.502
Country	8		
Observation	160		
BP-LM test = (0.0000) Hausman test = (0.0009)			

Please note that (**) and *** denote statistical significance at P < 0.1, 0.05, and 0.01 respectively.

Source: Author's computation; results obtained from Stata software

4.3.2 The impact of climate change on agricultural productivity on high-income countries group

This study aims to look at the effect of climate change on high-income SADC agricultural productivity as show in table 6 in a country-specific context, with selected macroeconomic variables as controls. After performing Hausman specification test, the Pooled OLS model was found to be the most suitable baseline estimator. As such, the Pooled OLS results are discussed and compared to the Fixed Effects and Random Effects results, where appropriate.

The findings show that there is a negative, though not statistically significant correlation between precipitation and agricultural output. The estimated coefficient indicates that rainfall increases by 1mm are likely to lead to a drop in the crop production index by about 0.003 units, other factors being equal. The coefficient is not statistically significant, so there is not enough evidence to say that there is a meaningful relationship between rainfall and agricultural productivity in high-income SADC countries. This could be due to the fact that high income countries tend to have more effective irrigation systems, water management and climate adaptation technologies, and hence less reliance on natural rainfall patterns for agricultural production. As a result, the variability in rainfall may not have significant effects on the agricultural production. The results are similar to those reported by Kang et al., (2009) who observed that rain variability and overabundance in any type of rainfall can have negative consequence on the yields of crops by disturbing the growing conditions and agricultural efficiency. The outcome indicates that the quality, timing and distribution of the rain rather than its quantity, may be more significant for agricultural productivity.

The average temperatures have a negative and statistically significant effect on agricultural productivity. The coefficient means that the productivity of agriculture declines at the rate of about 11.38 units per 1-degree Celsius rise in temperature, other factors being equal. The discovery suggests that higher temperatures have a negative impact on agriculture due to greater evapotranspiration, lower soil moisture, heat stress, and less yield. While high-income SADC nations are better equipped to adapt to temperature increases than low-income nations, this increased temperature remains a challenge to agricultural systems. The findings are similar to those found by (Aragón et al., 2019; Kumar & Khanna, 2019; Mayorga et al., 2023; Schauberger et al., 2017; Zhao et al., 2017), who found that agricultural productivity and yields decrease with rising temperatures and extreme heat events. The discovery thus brings to light that temperature continues to be one of the most important climate-related challenges to agricultural productivity even in relatively more advanced economies of the SADC.

Population growth in urban areas has a negative but not significant coefficient. The estimated result indicates that agricultural productivity could be lowered by around 3.23 units due to the increased rate of urbanization, but the result is not significantly different from zero. One possible explanation is that the increased speed of urbanization of urban areas facilitates migration from the rural areas, which in turn leads to a decrease in the number of laborers in the agricultural sector and an increase in the competition for available agricultural land due to urban growth. The lack of statistical significance, however, suggests that population growth in urban areas might not be a significant constraint on agricultural productivity in higher income SADC countries. This could be due to the fact that technological development, mechanization and better agricultural techniques offset the lack of labor caused by urbanization Rondhi et al., (2024), and (Andrews & Chetrick, 1988), have reported similar results of loss of agricultural efficiency in the context of urban expansion, which can be caused by the conversion of land and reallocation of labor.

These findings show that there is a negative, though not statistically significant correlation between precipitation and agricultural output. The estimated coefficient indicates that rainfall increases by 1mm are likely to lead to a drop in the crop production index by about 0.003 units, other factors being equal. The coefficient is not statistically significant, so there is not enough evidence to say that there is a meaningful relationship between rainfall and agricultural productivity in high-income SADC countries. This could be due to the fact that high income countries tend to have more effective irrigation systems, water management and climate adaptation technologies, and hence less reliance on natural rainfall patterns for agricultural production. As a result, the variability in rainfall may not have significant effects on the agricultural production. The results are similar to those reported by Kang et al., (2009) who observed that rain variability and overabundance in any type of rainfall can have negative consequence on the yields of crops by disturbing the growing conditions and agricultural efficiency. The outcome indicates that the quality, timing and distribution of the rain rather than its quantity, may be more significant for agricultural productivity.

There is also a negative, but statistically not significant, relationship between carbon dioxide emissions and agricultural productivity. The results of the analysis show that the impact of changes in carbon dioxide emissions is not significant for agricultural productivity among the countries in the sample from high income SADC countries. The CO_2 fertilization effect could stimulate plant growth with rising CO_2 levels, but this effect can be counterbalanced by negative effects of climate change, such as droughts, extreme weather events or increased temperatures. The net effect is therefore statistically non-significant. This result is contradicted by other studies by Kang et al., 2009; Millar et al., 2011), who reported that elevated CO2 levels can enhance photosynthesis and crop productivity. The insignificant result found in the present study indicates that positive and negative effects of carbon dioxide emissions might cancel each other in high income economies of the SADC.

Government effectiveness is associated with a positive and not statistically significant relationship. The positive sign indicates that better governance, institutional quality, policies and public service delivery could help increase agricultural productivity. The functions of good governance, such as better provision of infrastructure, extension services, market development, and agricultural sector investment can contribute to the development of agriculture. The results lack significance in the statistical sense but indicate that the government's influence on agricultural productivity is not strong enough during the study period. However, the direction of the coefficient is the same as previous studies. Lio & Liu, (2008)showed that the countries that have stronger governance tend to have better agriculture productivity, and (Lio & Liu, 2008; Petrov, 2025). reported that effective governance system leads to improving the efficiency of agriculture by implementing good policy and allocating resources.

A statistically insignificant positive effect can be seen for fertilizer use on agricultural output. The estimated coefficient indicates that, ceteris paribus, a one-unit increase in fertilizer use corresponds to a 0.113 unit increase in the crop production index. The positive relationship is a result of the vital contribution of fertilisers towards the improvement of soil fertility, nutrient availability and crop yields. Unfortunately, the lack of significance statistical results suggests that fertilizer use is not enough to achieve significant productivity increases. The effectiveness of fertilizer use can be affected by the quality of fertilizer, fertilizer application efficiency, soil properties, availability of irrigation, and other agricultural technologies. This is in line with the findings of (Chapoto et al., 2002; Endale, 2011; Rehman et al., 2019; Sharafi et al., 2025)who revealed that fertilizer application has a positive contribution to agricultural productivity and production yields.

Gross Domestic Product (GDP) exhibits a positive relationship with the Crop Production Index across all three estimation models. In the Pooled OLS model, the coefficient of 0.684

is positive but statistically insignificant, indicating that GDP growth does not have a significant effect on agricultural productivity under this estimation method. Similarly, the Random Effects model reports a positive coefficient of 0.412, which is also statistically insignificant, suggesting that GDP growth does not have a significant influence on crop production when country-specific random effects are considered.

In the Fixed Effects model, however, GDP has a positive and statistically significant coefficient of 0.684, indicating that a one-percentage-point increase in GDP growth is associated with an increase of approximately 0.684 points in the Crop Production Index, holding other variables constant. This finding suggests that economic growth contributes to higher agricultural productivity after controlling for unobserved country-specific characteristics.

The positive relationship observed across all models implies that stronger economic performance can support agricultural development through increased investment in agricultural infrastructure, improved farming technologies, irrigation facilities, agricultural research, and access to modern production inputs. Higher economic growth may also strengthen government capacity to finance agricultural policies and rural development programs that enhance crop production. Overall, the results indicate that GDP growth has a positive effect on agricultural productivity, although this effect is statistically significant only in the Fixed Effects model, highlighting the importance of accounting for country-specific factors when examining the relationship between economic growth and agricultural productivity.

The findings indicate that, across all high-income SADC countries, temperature is the only factor that has a statistically significant effect on agricultural productivity. The negative impact of temperature underscores the increasing exposure of agriculture to climate change, even in relatively highly developed countries and societies with high adaptive capacity. In most cases the indicators show the expected trends, but these are not statistically significant when comparing precipitation, urbanization, carbon dioxide emissions, government effectiveness or the use of fertilisers. The results indicate that high income SADC countries might be more resilient to some risks associated to climate change because of their technological innovation, infrastructure and institutional capacity. However, the region is still vulnerable to agricultural productivity and food security because of the increase in temperatures.

The results mostly confirm the Sustainable Livelihoods Framework. The negative impact of temperature corroborates both theories because it shows that poor weather affects the output of agricultural factors, and also adversely affects livelihoods. The positive coefficients of the government effectiveness and fertilizer consumption are also consistent with theoretical predictions of positive association between inputs, institutions, and livelihood assets, and agricultural performance. The relatively minor impact of rainfall and CO2 emissions, however, indicate that high income SADC nations may have mechanisms which lessen reliance on natural climate. On the whole, it can be concluded that the overall productivity in high-income SADC countries is influenced by the interaction between climate, productive resources, institutional quality and adaptive capacity.

The results from the FE, Pooled OLS and RE models show that the estimated relationships are largely similar across the 3 specifications, with some variation in the size and direction of some of the coefficients. The Pooled OLS model as well as the Random Effects model shows a negative relationship between the variables - precipitation and agricultural productivity; however, in the Fixed Effects model, the coefficient is positive, indicating that rainfall has a positive impact on agricultural productivity after taking into account the characteristics of the country. There is a negative relationship between average temperature and agricultural productivity in all models, albeit only statistically significant in the baseline Pooled OLS model.

Despite the varying magnitude of the impact of temperature changes on agricultural production, the general trend is negative, which means that a change in temperature has a detrimental impact on agricultural outcomes. Likewise, in all three models, urban population growth has a negative coefficient, and is not statistically significant, meaning that urbanization might lead to a decrease in agricultural labor supply and a further pressure on agricultural land, but the overall impact of urbanization on agricultural productivity is not sufficiently large in the sample studied. The results further showed that the relationship between carbon dioxide emissions and the other specifications of the model was negative in Pooled OLS and Random Effects model, but positive in the Fixed Effects model. The variation indicates that some countries might be more affected by carbon dioxide emissions than others, depending on their adaptation capacity, technological progress and farming systems.

The results also show that the fertilizer use had a consistent positive relationship with agricultural productivity in all specifications of the model, which confirms the significant impact of agricultural inputs on enhancing soil fertility, crop growth and agricultural production. Similarly, the government effectiveness generally has a positive but statistically non-significant association with agricultural productivity in the Pooled OLS and Random

Effects models while the Fixed Effects model shows negative coefficient. The disparity could be due to governance transformation processes, implementation barriers, or the lag in realizing agricultural outcomes from governance improvements. Overall, the comparison of the three estimation methods shows that the direction of most of the coefficients are fairly consistent across the models. The dominant and constant negative influence of temperature and urban population growth and the positive influence of fertilizer use, are indicative of the strength of these relationships. There are, however, differences in the precipitation, carbon dioxide emissions and the government effectiveness across the countries, all of which suggest that country-specific factors remain significant in determining agricultural productivity in high income SADC countries.

Table 4.6 Results of the Optimal Baseline Model on high-income group

Model 2: The impact of climate change on agricultural productivity on high income group			
Dependent variable: Crop production index			
	Pooled OLS	RE Model	FE Model
Variables	Coefficients	Coefficients	Coefficients
Precipitation	0.001 (0.281)	-0.003 (0.004)	0.001 (0.007)
Average temperature	-6.763 (4.406)	-1.381*** (0.360)	-6.763 (4.406)
Carbon dioxide emissions	0.337*** (0.281)	-0.112 (0.093)	0.337 (0.281)
Gross Domestic Product	0.684 (0.541)	0.412 (0.296)	0.684*** (0.541)
Governance effectiveness	-21.183 (12.506)	0.234 (4.576)	-21.183 (12.506)
Urban population growth	-5.406 (5.067)	-3.230 (2.670)	-5.406 (5.067)
Fertilizer consumption	0.045 (0.021)	0.023 (0.018)	0.113 (0.021)
Constant	246.668***	137.514***	246.668**
R square	0.119	0.795	0.797
Country	8		
Observation	160		
BP-LM test chi2 = 2 (0.0000)			

Note: * (**) *** indicate statistically significant with P value < 10%, 5% and 1% respectively. The standard errors are in parenthesis, OLS (Ordinary Least Square), RE (Random Effect), FE (Fixed Effect), and BP-LM (Breusch Pagan Lagrange Multiplier).

Source: Author's computation; results obtained from Stata software

CHAPTER FIVE

CONCLUSION, POLICY IMPLICATION, AND FUTURE RESEARCH DIRECTION

The findings and conclusions of the research presented in this book are described in this chapter. There are three components to this concluding chapter. First, the summary of findings of the study, then the recommendations for policies that need to be taken, and finally future research suggestions.

5.1 Conclusion of the study

Climate change and zero hunger are still a global problem and both issues are discussed by global leaders, international organizations, policy makers and academicians and are part of the 17 UNSDGs 2030. Agriculture zero hunger is achieved is weather dependent as a result of this; it is the sector that is heavily affected from the adverse effect of climate change (Andrews & Chetrick, 1988). The relation between climate change and agricultural productivity as discussed in previous studies remain some of the issues that are not explored in SADC context. SADC is among the most vulnerable sub-regions to the impact of climate change mainly due to its dependence on rainfed agriculture for livelihood (Abebaw, 2025). Consequently, this study looks at the effect of climate change on agricultural productivity as follows: Firstly, the effect of climate change on agricultural productivity on low-income groups in the SADC, and secondly the effect of climate change on agricultural productivity on high income groups in the climate vulnerable countries in SADC (Vanuytrecht et al., 2012).

This study adds to the growing number of research examining the impact of the climate variables and selected macroeconomic factors on agricultural productivity in low-income and high-income countries in the Southern African Development Community (SADC). The study aligns well with the aims of the United Nations Sustainable Development Goals (SDGs), specifically SDG 2 (Zero Hunger) which aims to end hunger by ensuring sustainable agriculture and development, SDG 13 (Climate Action) which calls for urgent action to combat climate change and its adverse effects, and SDG 1 (No Poverty), as agriculture plays a crucial role in providing livelihoods and economic development in the region (Alene & Coulibaly, 2009).

The empirical results show that despite income and adaptive capacity differences, climate change still plays an important role in the productivity outcomes of agriculture in SADC countries. For low-income SADC countries, the study determined the positive effects of precipitation and fertilizer use on agricultural productivity and the negative effects of average temperature and government effectiveness (Rehman et al., 2019). In contrast, there was a positive and significant correlation between CO_2 emissions and agricultural productivity, indicating a short-term carbon fertilization effect. In the countries of the Southern African Development Community (SADC), however, temperature was the only climate factor that was consistently significant and had a negative impact on agricultural productivity in high income SADC countries. Other factors such as precipitation, fertilizer use, carbon dioxide emissions, government effectiveness, and urban population growth were not significant statistically and indicate that these economies have greater adaptive capacity, technological progress, and institutional strength(Petrov, 2025).

The results indicate that the effects of climate change on agriculture are not the same in all countries in SADC. Rainfall-dependent agricultural systems continue to be critical in low-income countries, subjecting them to high climatic vulnerability. Precipitation has positive impacts on agriculture production when levels are adequate, as this contributes to good soil moisture and water availability, and negative impacts when temperatures are raised as a result of higher evapotranspiration from soil and plants, heat stress and lower soil moisture (Kumar & Khanna, 2019). In contrast, high-income countries seem to be more prepared to manage rainfall variability via irrigation, better infrastructure, technological innovations, and better resource management. However, the negative impact of temperature on all income groups suggests that increasing temperatures are one of the major long-term challenges facing agricultural sustainability in the study area(Schauberger et al., 2017).

The fertilizers used in low-income countries are also having a positive impact, showing that productive inputs are essential to soil nutrient deficiencies and improved crop production. The study underscores the importance of policies that enhance access to affordable and efficient agricultural inputs. Likewise, the beneficial effect of CO_2 emissions in LICCs might be a short-term effect of the emissions' stimulation of growth and water use efficiency (Broberg et al., 2019). These benefits, however, should be taken with a grain of salt because the longer-term impacts of climate change such as droughts, floods and extreme weather events are likely to outweigh these short-term benefits over time.

One of the surprising takeaways from this study is the negative correlation between government effectiveness and income level in low-income countries. The outcome does not imply that governance is a bad influence on agricultural productivity but rather may be an indication of the structural transformation that is continuing in the farming sector, with resources being gradually released from agriculture and reallocated to other sectors, such as industry and services (Lio & Liu, 2008). It can also point to implementation problems, inefficiencies in policies or time delays in institutional change and agricultural results. Thus, the identification of this finding is significant, not only for the need to enhance governance quality, but also to secure the implementation of agricultural policy and focus it on productivity improvements. The positive effects of fertilizer use and precipitation, alongside the negative effect of temperature, confirm that changes in production inputs and environmental conditions directly influence agricultural output. The study also supports the Sustainable Livelihoods Framework, which emphasizes the importance of natural, physical, and institutional assets in shaping livelihood outcomes. Climate variability, particularly temperature increases, was found to undermine agricultural productivity and consequently threaten livelihood security, while productive inputs and adaptive capacities enhance resilience and productivity (Kang et al., 2009).

From an economic perspective, the findings carry important implications for the SADC region. Agriculture remains a major source of employment, income generation, food security, and export earnings, particularly in low-income member states. Declining agricultural productivity resulting from rising temperatures may exacerbate poverty, food insecurity, unemployment, and economic vulnerability. Therefore, investments in climate adaptation strategies such as irrigation infrastructure, climate-smart agriculture, drought-resistant crop varieties, sustainable land management, agricultural research, and extension services are essential for maintaining productivity and ensuring long-term economic growth (Alene & Coulibaly, 2009).

Overall, the study concludes that climate change significantly affects agricultural productivity in SADC countries, with the magnitude and direction of impacts varying according to national income levels and adaptive capacity. While low-income countries remain highly exposed to rainfall variability and temperature increases, high-income countries demonstrate greater resilience to some climate-related risks. However, rising temperatures continue to pose a substantial threat across all countries regardless of income status. The findings underscore the need for coordinated regional policies that strengthen climate adaptation, promote sustainable agricultural practices, improve resource management, and enhance institutional effectiveness. Such measures are essential for achieving sustainable agricultural development, reducing poverty, and supporting inclusive economic growth throughout the SADC region.

5.2 Policy Recommendations

The negative effect of climate change on agricultural productivity has policy implications for SADC region. The region has low level of food security, with 85.511 on average crop production index. Thus, climate change will continue to threaten food security in the region in the future. In addition, the vagaries of climate change will drive down the productivity of agricultural sector including farming for crop production. Following the results of our study, we give the following set of policy directions for decision making at national and regional level for action by governments, policy makers and other stakeholders. Below are the policies:

Reduce carbon dioxide emission/ Strengthen the policies of environmental sustainability and emission reduction

Although Africa at large contribution to global carbon emission is negligible, SADC region is significantly dependent on the use of fossil fuels for various activities including energy supply for electricity, cooking, transportation and others. The release of this emission causes depletion in the atmosphere resulting in extreme weather conditions, therefore impacting farming activities and reducing the ability to produce crops. Therefore, the sub-region should strive to lower carbon emission by adopting energy transition, tax holiday for carbon emission reduced enterprises and carbon market. This will immensely contribute in reducing carbon emission which will help to boost crop production, thereby improving food security and wellbeing in the sub-region.

The results of the carbon dioxide emissions reveal a need for a balance between environmental and agricultural policies across the SADC region. While some positive effects on crop growth may occur in the short-term due to fertilization effects, it is important for governments to push efforts harder to reduce GHG emissions and environmental degradation, thereby reducing long-term damages to agricultural productivity due to climate change. This can be done by investing in renewable energy, sustainable farming systems, afforestation programmes, and environmentally friendly farming technologies that boost productivity and environmental sustainability.

1. Promote smart agriculture: SADC region needs to adopt smart agriculture that is climate resilient. This type of agriculture is not affected by climate change since it is drought and low precipitation resilient. Furthermore, countries should ensure that farmers practice climate smart agriculture. One of such practices is to encourage farmers to make use of natural resources in order to engage in farming activities. Instead of using unsustainable agricultural methods, including the use of non-

renewables sources of energy and non-organic fertilizers like nitrogen which contributes to carbon emission and deteriorates the environment, thus reducing food production. Therefore, it is essential that natural resources should be made available to farmers through renewable energy. This will not only create an eco-friendly environment but will also ensure sustainable improvement in agricultural productivity, thus reducing poverty and hunger which will contribute towards sustainable development.

Based on the findings that rainfall positively influences agricultural productivity, governments in the SADC region should increase investment in irrigation systems, water harvesting technologies, dams, and climate-resilient water management infrastructure to reduce excessive dependence on rainfed agriculture. Since the region experiences irregular and limited rainfall patterns, improving access to sustainable water resources will help farmers maintain stable crop production throughout the year and reduce the vulnerability of agricultural activities to rainfall variability and drought conditions.

Given that rising temperatures negatively and significantly affect agricultural productivity, policymakers should strengthen climate adaptation and mitigation strategies aimed at reducing the adverse effects of global warming on the agricultural sector. Governments should promote the adoption of heat-resistant and drought-tolerant crop varieties, improve climate-smart agricultural practices, and strengthen agricultural research institutions to develop technologies that can withstand extreme weather conditions. In addition, expanding climate information services and early warning systems will help farmers better prepare for temperature shocks and climate-related risks.

2. Promote Government Effectiveness within the Sub-region: Promoting government effectiveness is essential for enhancing agricultural productivity and achieving sustainable development within the sub-region. The findings of this study suggest that effective governance plays a critical role in supporting agricultural growth through the formulation and implementation of sound agricultural policies, efficient delivery of public services, investment in rural infrastructure, and effective allocation of resources. Strong institutions can facilitate farmers' access to agricultural inputs, extension services, technology, and markets, thereby improving productivity and food availability. In contrast, weak government effectiveness may result in poor policy implementation, inefficient service delivery, and inadequate support for the agricultural sector, which can constrain productivity

growth. Therefore, governments should prioritize strengthening institutional capacity, improving policy execution, enhancing transparency and accountability, and investing in agricultural support systems to create an enabling environment for agricultural development, food security, poverty reduction, and sustainable economic growth across the sub-region.

3. Balanced Rural–Urban Development and Agricultural Land Protection: In response to the mixed effects of urban population growth on agricultural productivity, SADC governments should implement policies that promote balanced rural and urban development. Policymakers should create economic opportunities and improve infrastructure in rural areas to reduce excessive rural–urban migration and labor shortages in agriculture. Furthermore, governments should encourage agricultural commercialization, strengthen rural–urban market linkages, and protect productive agricultural land from uncontrolled urban expansion in order to maintain agricultural efficiency and production capacity.
4. Improving Governance Effectiveness and Institutional Quality: Since government effectiveness was found to influence agricultural productivity, governments in the SADC region should strengthen institutional quality, policy implementation, accountability, and political stability in order to improve agricultural sector performance. Effective governance can enhance public investment in agriculture, improve extension services, strengthen market institutions, and create a conducive environment for both local and foreign investment in agricultural production. Additionally, reducing corruption and improving regulatory quality will help increase farmers' confidence and encourage greater participation in agricultural activities
5. Enhancing Access to Fertilizers and Modern Agricultural Inputs: Based on the positive contribution of fertilizer consumption to agricultural productivity, governments should increase access to affordable agricultural inputs through subsidies, credit facilities, and improved distribution systems, especially for smallholder farmers. Policymakers should also promote the efficient and sustainable use of fertilizers through farmer education programs, soil testing initiatives, and extension services to prevent environmental degradation while improving soil fertility and crop yields. Increased investment in agricultural inputs and modern farming technologies will contribute significantly to improving agricultural productivity and supporting economic development in the SADC region.

5.3 Future Research Direction

This study offers valuable insights into the effect of climate change and some of the factors on agricultural productivity in the SADC region, but there are some areas that need to be further explored. Future research should expand the scope of the analysis to include other climate change-related indicators like drought frequency and severity, flooding events, soil degradation, humidity, and other extreme weather events, to gain a deeper understanding of climate change effects on agricultural productivity. Second, agricultural productivity could be disaggregated into different agricultural subsectors, such as major agricultural crops and livestock production, to find out which agricultural activities are most vulnerable to climate change. Third, the use of more sophisticated econometric models, such as dynamic panel data, threshold models, and nonlinear estimation techniques, could be used in future research to examine both short-term and long-term effects to see if there are nonlinear relationships. Fourth, research needs to explore the role and importance of adaptation and resilience factors such as technological innovation, irrigation systems, agricultural finance, agricultural extension services, and climate-smart agriculture in addressing negative impacts of climate change. Last but not least, a country-specific and comparative analysis across SADC countries can add greater understanding of the effects of institutions on productivity and climate resilience, and inform more targeted and effective policy interventions.

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APPENDICES

Appendix 1. Definition of selected variables of the study

Variables	Definition
Dependent Variables	
Crop production index proxy for agricultural productivity	Crop production index which measures the agricultural productivity includes crop variety and quantity that is produced in a particular country. Crop production index shows agricultural production for each year relative to the base period 2014-2016. It includes all crops except fodder crops.
Independent variables (Climatic variables and Control variables)	
Rainfall proxied by Precipitation	Rainfall refers to the supply of water in the form of rain from the atmosphere to the surface of the earth. Water released from clouds in the form of rain, freezing rain, sleet, snow, or hail. It is the primary connection in the water cycle that provides for the delivery of atmospheric water to the Earth.
Average temperature	Temperature refers to the degree of hotness or coldness of a place given at a particular period of time. Temperature varies globally and is a key factor that influence crop production. The expected temperature in degrees, valid for the indicated hour. Global temperature is an average of air temperature recordings from weather stations on land and sea as well as some satellite measurements.

Carbon dioxide emissions	A measure of annual emissions of carbon dioxide (CO_2), one of the six Kyoto greenhouse gases (GHG), from industrial processes including IPCC 2006 codes 2.A.1 Cement production, 2.A.2 Lime production, 2.A.3 Glass Production, 2.A.4 and NH_3). The measure is standardized to carbon dioxide equivalent values using the Global Warming Potential (GWP) factors of IPCC's 5th Assessment Report (AR5).
Governance effectiveness	Government Effectiveness captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. Estimate gives the country's score on the aggregate indicator, in units of a standard normal distribution, i.e. ranging from approximately -2.5 to 2.5.
Urban population growth	Annual urban population growth rate for year t is the exponential rate of growth of midyear urban population from year t-1 to t, expressed as a percentage. Urban population refers to people living in urban areas as defined by national statistical offices. It is calculated using World Bank total population estimates and urban ratios from the United Nations World Urbanization Prospects.
Fertilizer consumption	Fertilizer consumption measures the quantity of plant nutrients and is calculated as production plus imports minus exports. Fertilizer products cover nitrogenous, potash, and phosphate fertilizers (including ground rock phosphate).