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CLIMATE VARIABILITY IMPACT ON AGRICULTURE PRODUCTION: EMPIRICAL EVIDENCE FROM SADC REGION.

BY

GRANT MUNASHE MAZENGERA

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SUPERVISOR : MR KAIRIZA

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Approval Form

The undersigned certify that they have supervised, read and gave recommendation to Bindura University of Science Education for Acceptance of the research entitled:

CLIMATE VARIABILITY IMPACT ON AGRICULTURE PRODUCTION: EMPIRICAL EVIDENCE FROM SADC REGION.

Submitted by **GRANT MUNASHE MAZENGERA**

Signature of Student.. Date..04../..10../.24.

Signature of Supervisor.. Date..04../..10../..24..

Signature of Chairperson.. Date..04./..10../..24...

Release Form

NAME OF AUTHOR: **GRANT MUNASHE MAZENGERA**

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PERMANENT ADDRESS: **93A TWENTY DALES HATFIELD HARARE**

Dedication

I dedicate this dissertation to my precious sister Gracious and her husband Leonard Bangira, my brother Given, my friends and to my lovely parents Anna and George Mazengera.

Abstract

This dissertation investigates the effects of climate change on agricultural output within the SADC region. Utilizing annual panel data from 14 member states (2004-2022) and incorporating factors like rainfall, temperature, labor, government expenditure, and inflation, a Random Effects Model (REM) analysis is employed.

The research reveals a positive and statistically significant relationship between precipitation and agricultural productivity, with an optimal level identified at 14.75 mm of rainfall. Conversely, temperature exhibits an insignificant negative effect.

These findings highlight the urgency of addressing climate change's agricultural impacts in the SADC region. Projections indicate a potential 20% reduction in growing seasons by mid-century, leading to a 40% decline in cereal yields and decreased livestock fodder availability.

To bolster agricultural resilience, the dissertation recommends several strategies:

- Implementing climate-resilient agricultural practices
- Developing robust climate information systems
- Strengthening research capacity and institutional frameworks
- Enacting climate-sensitive agricultural policies
- Fostering regional and international cooperation
- Expanding extension services to reach more farmers
- Enhancing data collection and monitoring systems

These recommendations provide valuable insights for policymakers, researchers, and stakeholders in the SADC region. By implementing these strategies, the long-term sustainability and resilience of the agricultural sector in the face of climate change can be secured.

Acknowledgement

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LIST OF ACRONYMS

CO_2	**CARBON DIOXIDE**
GDP	**GROSS DOMESTIC PRODUCT**
FEM	**FIXED EFFECTS MODEL**
IPCC	**INTERGOVERMENTAL PANEL ON CLIMATE CHANGE**
MAPP	**MULTI-COUNTRS AGRICULTURAL PRODUCTIVITY PROGRAMME**
SADC	**SOUTHERN AFRICAN DEVELOPMENT COMMUNITY**
SSA	**SUB-SAHARAN AFRICA**
REM	**RANDOM EFFECTS MODEL**
WB	**WORLD BANK**

CHAPTER ONE

INTRODUCTION

1.0 Introduction

Agricultural sector, despite being a relatively small portion of the global economy, is critically important when considering the overall economic impacts of climate change due to its dependence on specific temperature and precipitation levels (Barton & Leke, 2020). A multitude of factors influence and drive agriculture, including market fluctuations, government policies (subsidies, tariffs, etc.), management practices, technology access, and biophysical characteristics like water availability and soil quality (Niang et al., 2014). This inherent link to natural resources makes agriculture vulnerable to the uncertainties of environmental shifts, especially sudden changes in weather patterns like natural disasters (Leal Filho et al., 2015).

There's a particular concern about climate change's impact on poverty in Sub-Saharan Africa (SSA) due to the strong link between agriculture and livelihoods in the region. The expectation is that negative effects on agriculture will significantly worsen rural poverty (World Bank 2008). This is especially true for developing countries where a large portion of the rural population relies on agriculture for their survival (Mbow, C., et al., 2014; Fischer, 1996; Adams *et al*., 1999; International Food Policy Research Institute, (IFPRI), 2009; Seneviratne, S. I., et al., 2012). Limited technology and resources make it difficult for developing countries to adapt their agricultural sectors to worsening environmental conditions, potentially causing significant economic losses. (Crosson, 1997). Studies suggest these losses might reach approximately 10% of countries gross domestic product. (Hernes et al., 1995; IPCC, 2001, 2014)

However, some researchers argue against a purely negative view of climate change's agricultural effects. They propose that the increased carbon dioxide concentrations associated with climate change could benefit agriculture by enhancing photosynthesis, leading to a potential advantage (Rosensweig & Hillel, 1995; Ringius et al., 1996;

Hulme, 1996; IPCC, 1996; Reilly et al., 1996; Darwin, 2001). This creates uncertainty about the true impact of fluctuations on agriculture in the Southern African Development Community (SADC) region. While some believe it will improve crop yields, others foresee detrimental consequences.

The SADC region is anticipated to be particularly vulnerable due to moisture deficits. Changes in rainfall patterns are already altering the areas suitable for specific crops (SADC 2014). This situation is further complicated by the region's dependence on rain-fed agriculture, which can lead to complete crop failure during droughts. For instance, only 6.6% of cultivated land in the SADC has irrigation capabilities, which is a small fraction of the region's potential (Nhemachana et al., 2010). Water demand has tripled since the 1950s, while freshwater availability has declined. Arid and semi-arid regions are particularly vulnerable to climate change impacts on food production, with studies highlighting potential land degradation and decreased agricultural productivity (Turral et al., 2011).

Environmental shifts dramatically endanger the world’s ability to feed its population by disrupting agricultural production. (Mora et al., 2013). Rising temperatures are expected to decrease yields of key crops while fostering the spread of weeds and pests. Shifts in precipitation patterns will likely lead to more frequent short-term crop failures and long-term declines in overall production. Although some regions might see advantages for particular crops due to climate change, most experts agree it will ultimately harm agriculture overall. Several empirical studies (Nelson et al., 2009; Alvaro et al., 2009; Mohammed-Lawal & Atte, 2006; King, 2004) emphasize the urgency of addressing climate change before its consequences become catastrophic, highlighting its potential to be a more significant threat than global terrorism. It's important to note that these studies were conducted at the country level and may not directly reflect the situation in Africa.

1.1 Background

The 2014 Intergovernmental Panel on Climate Change (IPCC) report painted a concerning picture of our planet, suggesting Earth's rising temperatures resemble illness (Cook et al., 2016). The report warns that we are nearing a tipping point, where even slight increases in temperature could trigger dramatic environmental shifts. Safeguarding our planet has become a critical issue for governments around the world (Zamfir, 2014). Deteriorating environmental quality has sparked widespread concern and a surge in efforts to understand the root causes of climate change-induced environmental degradation, particularly its impact on agricultural production (Dinda, 2004).

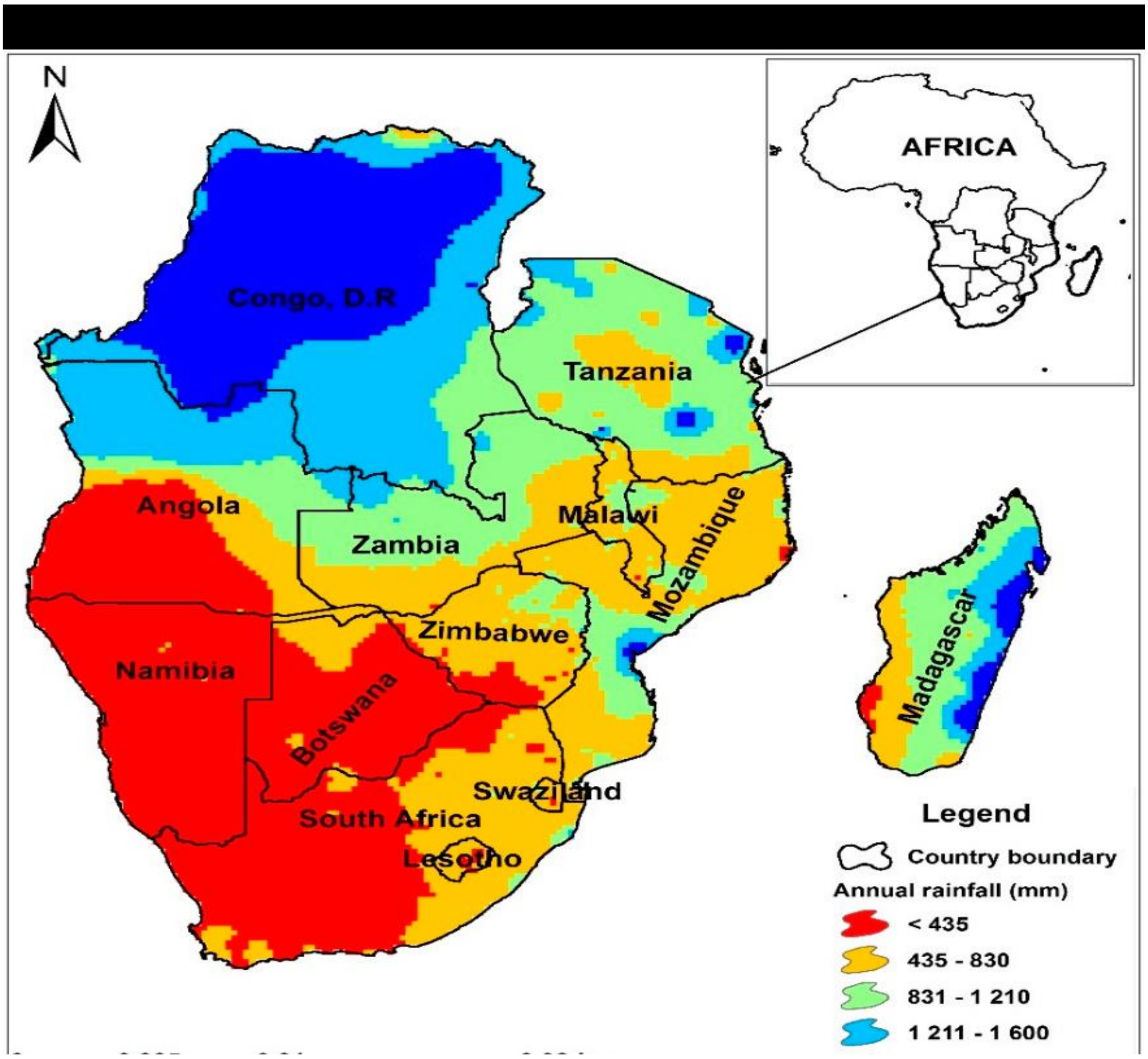
Recognizing the importance of regional integration for economic growth and a unified Africa (Capaso, 1998), the Southern African Development Community (SADC) was established in 1992 (SADC, 2011). This 16-nations bloc aims to foster economic development, eradicate poverty, and facilitate the free movement of goods, services, capital, and labour within the region. However, the sub-region faces a significant climatic challenge. SADC countries have historically grappled with recurring droughts, documented throughout the 20th century (SADC, 2008). More recently, the sub-region has observed a concerning warming trend and an increase in heat waves (SADC-CSC, 2018). These climatic shifts pose a serious threat to the SADC's economic and developmental goals.

1.1.1 The state of SADC’s Climate.

The Southern African Development Community (SADC), a 16-member economic bloc encompassing countries like Angola and Botswana (SADC, 2011), grapples with severe water scarcity. With only a meager 6.11% of its vast 986 million hectares cultivated and a significant portion (75%) classified as arid, just a quarter of the region enjoys the benefits of a humid climate (Migdley et al., 2011). This inherent dryness is further exacerbated by highly erratic rainfall patterns, with annual precipitation fluctuating wildly between 100 and 2,000 millimeters (Migdley et al., 2011).Climate change casts an even darker shadow on the region's water woes. SADC countries are witnessing an increase in the frequency of hot days, accompanied by a decline in extremely cold days (Migdley *et al.*, 2011). Rainfall patterns, already unpredictable, are exhibiting increased variability between years. Some regions experience periods of excessive wetness, while others face intensified droughts. This trend is particularly alarming given the SADC's existing climate variability, characterized by a long-term decline in rainfall since 1950 (IPCC Africa, 2014). Additionally, most of Southern Africa is experiencing rising annual mean, maximum, and minimum temperatures, with the most significant warming occurring in the past two decades (IPCC Africa, 2014). These trends collectively highlight the vulnerability of the SADC region to climate change and its potential to disrupt agricultural production and water security.

Millions of families across the Southern African Development Community (SADC) depends on small-scale agriculture as their main source of sustenance, despite significant challenges (Tarr, 2003). This vulnerability stems from the region's dependence on agriculture and the highly uneven distribution of annual rainfall, as illustrated in Figure 1. Many areas within SADC are susceptible to droughts due to this erratic precipitation.

Figure 1 Location map of SADC countries showing average annual rainfall distribution pattern



Source: Nhamo *et al.*, 2019

In addition rising temperatures, alongside the well-documented shifts in precipitation patterns, pose a significant threat to the SADC region (Hummel, 2015). Most countries within the community have already begun experiencing the negative impacts of this warming trend.

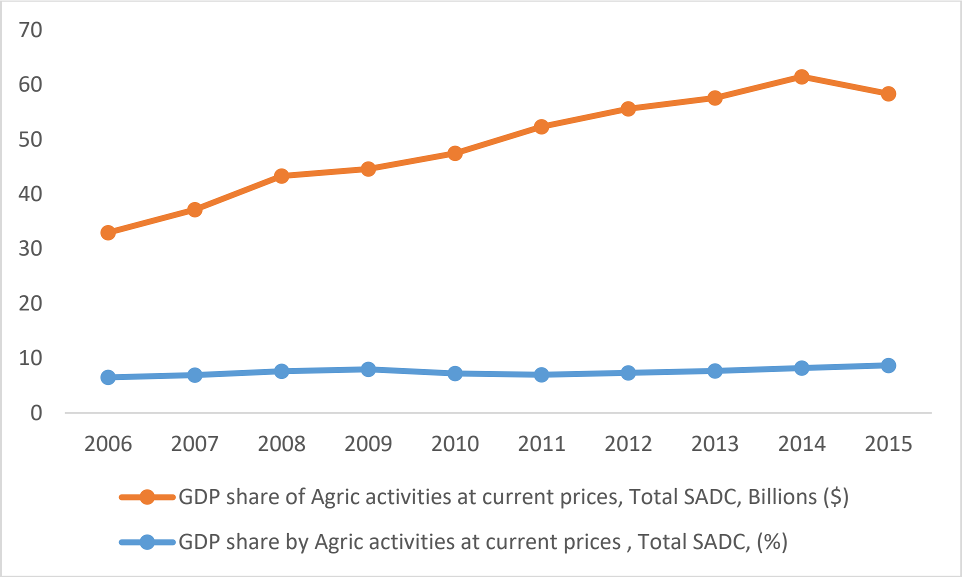
The SADC Climate Change Policy Paper by Lesolle (2013) compiles data showing rising temperatures across the region. Instrumental observations indicates particular increase in minimum temperatures. For instance, Namibia experienced warming at a rate of 0.023oC per year between 1950 and 2000 (Government of Namibia, 2002). Botswana observed a similar trend, with warming at a rate of 0.017oC per year during the same period. This overall upward trend in temperature is corroborated by reports like the IPCC Fourth Assessment Report (IPCC 2007), which highlights an increase in the frequency of above-normal temperature years.

1.1.2 SADC's Agricultural Productivity

The Intergovernmental Panel on Climate Change (IPCC) warns on significant threats to food security in Southern Africa due to climate change. Their reports predict a decline in agricultural Gross Domestic Product (AgGDP) by 2% to 7% by 2100 (Niang et al., 2007). This decrease coincides with a projected population boom, rising from 0.9 billion in 2005 to 2 billion by 2050. Even with current increases in crop production, these combined factors suggest agriculture will struggle to keep pace with food demands without adaptation strategies (Niang et al., 2007). Maize, a staple cereal in the region, is expected to be particularly affected, with production reductions ranging from 12% to 40% by 2050 (Calzadilla et al., 2013). The IPCC further anticipates a 27-32% decline in maize, sorghum, millet, and groundnut production by 2050 under a scenario of a 2°C temperature rise above pre-industrial levels (Calzadilla et al., 2013). Previous research also indicates a 20% crop and livestock season shrink in Southern Africa by mid-century, possibly cutting yield by 40% and reducing livestock food (Niang et al., 2007; Calzadilla et al., 2013). These studies underscore the urgency of implementing mitigation measures to prevent severe consequences for Southern African agriculture.

Figure 2 reveals a steady rise in the total value (in billions of US dollars) that agriculture contributes to the SADC region's GDP, the proportional contribution of agriculture to GDP has remained relatively flat over the past decade. This flat line, although preferable to a decline, suggests the agricultural sector is not keeping pace with the overall economic growth of the region.

Figure 2: Agricultural productivity share of GDP in the SADC region



Source: Own illustration using data from SADC Statistical yearbook year 2015

1.1.3 Policies affecting agriculture in SADC region

Declaration on Agriculture & Food Security (2004)

Recognizing the importance of agriculture and food security to regional well-being, the (SADC) prioritizes these issues in its Declaration on Agriculture and Food Security. Through this declaration, SADC member states pledge to bolster agriculture as a means of enhancing food access for the region's population. The agreement outlines short, medium, and long-term goals to improve agricultural development and food security in Southern Africa. Short-term plans target immediate food security improvements by ensuring smallholder access to agricultural inputs, optimizing fertilizer use, and increasing production of drought-resistant crops and fast-maturing livestock. In the medium to long term, the focus shifts to maintaining sustainable practices through environmental protection, disaster preparedness, and research into modern agricultural technologies. The declaration tasks the SADC Integrated Committee of Ministers with implementing the accompanying Plan of Action and reviewing progress biennially.

SADC Multi-country Agricultural Productivity Programme (MAPP), April 2008

Spanning 15 years and divided into three 5-year phases, the SADC MAPP program tackles agricultural development in the SADC region. Its core objective is to improve the generation and spread of agricultural technologies that cater to the needs of smallholder farmers and markets. By fostering stronger connections between agricultural institutions, the program aims to propel smallholder productivity. This, in turn, will lead to the creation of more accessible and market-oriented agricultural technologies, ultimately driving agricultural growth and boosting incomes, particularly for those living in rural areas.

Charter Establishing the Centre for Coordination of Agricultural Research and Development (CCARDESA) (2010)

The Member States of the Southern African Development Community on the 5th November 2010 signed a charter establishing the Centre for Coordination of Agricultural Research and Development for Southern Africa. Acknowledging that the capacity of the SADC region scientific community to undertake and manage research and development (R&D), and related training activities has increased considerably and cooperation in Agricultural Research and Development would enhance efficiency in alleviating common problems, Member States agreed to the development the centre. The Charter provides Member States with a framework for the establishment and operationalisation of a Sub-regional Organisation that will coordinate agricultural research and development (R&D) in the SADC region. It outlines the specific objectives and functions of the centre as well as its relationship with the SADC Secretariat.(SADC 2010)

1.1.4 Policies concerning climate change in the SADC region

A comprehensive understanding of moisture trends, encompassing both soil moisture and rainfall patterns, is paramount for forecasting future crop production under a changing climate. Established research demonstrates that climate variability and change will significantly impact current and future agricultural systems and food security [Godfray et al., 2010]. These alterations are projected to substantially modify environmental conditions due to shifts in seasonal patterns. In Southern Africa, for example, climate variability and change, in conjunction with other factors, are adversely affecting the agricultural sector and the region's capacity to meet the rising food demands of its growing population [Godfray et al., 2010]. Water deficits are a principal challenge, driven by a confluence of factors including increased demand from competing sectors and a rise in the frequency and intensity of droughts. Efforts to manage these mounting stresses on food and water security are further hindered by a multitude of challenges, such as increasing temperatures, altered rainfall patterns, rising sea levels, and land and water degradation. It is within this complex context that various SADC policies are being established to bolster agricultural resilience in the region.

Within the international framework addressing climate change and its agricultural consequences, two agreements stand out for their specific contributions. The Ramsar Convention, dedicated to the conservation of wetlands of international importance, has proactively addressed the evolving challenge of climate change. A dedicated resolution within the convention outlines strategies for adaptation and mitigation measures specifically tailored to wetland ecosystems. Similarly, the Convention on Biological Diversity (CBD) has played a crucial role. Through a substantial body of decisions and technical papers, the CBD has meticulously documented the critical connections between biodiversity and mitigating the effects of climate change. This emphasis on biodiversity conservation underscores its potential as a cornerstone strategy for building resilience within agricultural systems facing a changing climate.

1.2 Problem statement

Achieving sustainable development hinges on prioritizing environmental sustainability, particularly within the agricultural sector. The environment itself constitutes a global public good, susceptible to a free-rider problem: individual countries, acting in their own economic interest, may prioritize increased production and associated pollution, neglecting the external environmental costs borne by the international community. Climate change, a consequence of such actions, poses a serious and urgent threat, potentially triggering a global decline in agricultural output (Zenghelis, 2006). Despite a shared interest in environmental preservation, international negotiations are often complicated by conflicting economic considerations. Countries may advocate for policies that allow them to raise production levels, even if such actions lead to increased emissions. This fundamental tension between national economic interests and the global environmental good necessitates innovative solutions and international cooperation to ensure long-term agricultural sustainability.

In the (SADC) region, agriculture has long been the backbone of livelihoods, serving as a primary source of income and food security for a substantial portion of the population [Moreki & Tsopito, 2013]. However, the escalating threat of climate change poses a significant challenge for all nations, particularly those heavily reliant on agriculture. While regional collaboration within SADC offers potential synergies, it does not shield individual member states from the adverse effects of climate change on agricultural output. These impacts are likely to disproportionately burden the poor, potentially leading to a decline in employment opportunities and wages, especially for unskilled laborers. This study aims to bridge a gap in the existing literature by examining the specific impact of climate change on agricultural production within SADC. Despite the potential benefits of collaboration, the available research suggests that regional membership alone is insufficient to guarantee immunity from climate change's detrimental effects.

1.3 Study objectives

The study aims to explore how climate variability impact agricultural production in the SADC countries.

The specific objectives are:

- to assess the impact of climate variability on agricultural production in SADC region, and

- to simulate future effects of climate change on agricultural production.

1.3.1 Research questions

The research questions that arise are:

- What is the impact of climate variability on agricultural production in SADC region?
- How much does agricultural production change in the future given certain amounts of climate variants in the study?

1.4 Research Hypothesis

Null hypothesis: Climate variability has an impact on agricultural production in SADC region.

1.5 Significant of the study

Across Africa, unprecedented climate shifts are unfolding, threatening a humanitarian crisis and jeopardizing national development goals. Urgent action is needed to curb human activities driving climate change. While Africa itself bears minimal responsibility for this global phenomenon, it stands at the forefront of vulnerability, facing increasingly frequent and extreme weather events like droughts and floods. This vulnerability is compounded by widespread poverty and a lack of robust adaptation strategies within the region. The need to integrate climate change considerations into policy and planning frameworks is undeniable. This responsibility falls not just on nations directly impacted by climate change, but also on those contributing to its causes. In Southern Africa, for instance, climate change is expected to exacerbate existing dry conditions, while any rainfall is likely to occur in intense bursts, leading to increased erosion and flood damage. Despite these stark predictions, they often fail to translate into concrete policy action within Southern African countries.

Climate change presents the most formidable challenge to sustainable development yet encountered by the international community. Its transnational character necessitates solutions that extend beyond national or regional spheres, requiring a robust global response. The emphasis on mitigation strategies, exemplified by international agreements like the Kyoto Protocol, serves as a testament to this shared responsibility. However, a critical knowledge gap persists regarding the specific impacts of climate change on agricultural productivity within intergovernmental trade and development organizations like SADC. Understanding these effects is crucial for ensuring the overall well-being of member states.

Chapter two reviews literature on the impact of climate variability on agricultural production while chapter three provides a detailed outline of the methodology used in the study. Estimation, presentations and interpretations are done in chapter four, while chapter five gives a summary, conclusion and policy recommendations as well as areas of further study.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter reviews the relevant literature on the impact of climate variability on agricultural production. It is divided into two sections, with the first section reviewing the theoretical literature on climate change with agricultural production, and the last section will review relevant studies which is the empirical literature that has been carried out on the two variables.

2.1 Theoretical literature

Within economic theory, a fixed factor of production that restricts industry entry commands an equilibrium rental price commensurate with its productivity. Applied to agriculture, land represents such a fixed factor. If a farmer's annual net revenue from a specific plot establishes the maximum rental price they are willing to incur. When farming profits remain positive after factoring in rent, competition will drive rental rates upwards until these excess profits are eliminated. Furthermore, land quality plays a significant role. Farmers demonstrate a heightened willingness to pay rent for parcels boasting superior productive capacity, translating to increased potential profits. In a state of equilibrium, the rental value of exceptionally fertile land will demonstrably reflect the exact increase in net revenue it generates. Deviations from this equilibrium incentivize adjustments in land usage by farmers, ultimately driving the rental price up or down until it accurately captures the land's true value.

2.1.1 Mechanism for climate impact on agricultural production

According to Hulme (1996), climate change disrupts African agriculture through four key mechanisms. First, changes in temperature and rainfall patterns are expected to harm crops. Second, fluctuating atmospheric carbon dioxide levels can have mixed effects on plant growth. Third, more frequent and intense droughts and floods are predicted to devastate crops, soils, and agricultural output. Finally, climate change can indirectly impact African agriculture by altering populations of insects, weeds, diseases, and livestock, and by affecting water availability as discussed below.

2.1.1.1 Changes in temperature and precipitation

Climate change, characterized by rising temperatures and altered precipitation patterns, is projected to have a substantial impact on the global map of agricultural ecosystems. The resulting changes in soil moisture content, growing season length, with overall crop production potential will vary significantly across geographic regions. At mid-latitudes and high-latitudes, warmer temperatures may lead to extended growing seasons, with the potential to expand crop production poleward and benefit countries in these areas. However, the potential benefits of a longer growing season might be tempered by inherent limitations in soil fertility at higher latitudes. The true extent of this constraint remains unclear, as numerous other factors, including precipitation levels, fertilizer use, and irrigation availability, will also exert a significant influence on agricultural outcomes. Conversely, lower-latitude regions are expected to experience negative consequences from rising temperatures, particularly in areas where ambient temperatures are already close to or exceed optimal levels for crop growth. Furthermore, changes in both temperature and precipitation will place strain on irrigation resources. Reduced precipitation may lead to intensified exploitation of aquifers for agricultural purposes, placing additional pressure on competition for already stressed surface and groundwater resources used for non-agricultural needs such as industry and municipalities. The anticipated rise in potential evapotranspiration is likely to exacerbate drought stress, particularly in semi-arid tropical and subtropical regions.

2.1.1.2 Carbon dioxide

Rising CO2 levels in the atmosphere, predicted to reach significant heights by 2050, could have a positive impact on agriculture. This is because higher CO2 increases the rate of photosynthesis in plants, especially those with the C3 pathway (like wheat, rice, and soybeans). This essentially means plants can grow more efficiently. While the effect is smaller, C4 plants (like corn and sorghum) also benefit. Studies suggest that crop yields could improve by 10-30% due to CO2 fertilization. Another perk is improved water use efficiency, allowing plants to get by with less water. However, this positive outlook comes with a caveat. Increased CO2 might also lead to more problematic pests and weeds, potentially offsetting some of the gains.

2.1.1.3 Water availability

Water availability, especially runoff, is a key factor affecting how climate change will impact many places, particularly Africa. Research suggests that rainfall and growing season length are key to climate change's impact on agriculture (Hulme, 1996; Fischer, 1996; Strzepek and Smith, 1995; Sivakumar, 1992). However, as mentioned earlier there are significant limitations to our ability to accurately predict rainfall trends. Additionally, there is less confidence about precipitation patterns in other parts of the world compared to other climate changes. The absence detailed rainfall forecasting models at both regional and sub-regional levels makes it difficult for researchers to draw definitive answers about the impact on agriculture.

2.1.1.4 Occurrence of extreme events

Climate variability and extreme weather events like droughts, floods, and temperature fluctuations can cause significant agricultural losses (Rosenzweig & Hillel, 1995). Increased drought frequency puts pressure on water resources due to factors like increased plant transpiration and water allocation demands. Conversely, regions experiencing increased rainfall intensity face issues like soil erosion, leaching of agricultural chemicals, and nutrient runoff from livestock waste into water bodies. While predicting the exact nature of these changes across different agro-climatic zones remains challenging, studies suggest that the cost of adapting to rapid climate shifts will be higher (Adams et al., 1999). El Niño/Southern Oscillation (ENSO) is a climate phenomenon receiving significant attention due to its substantial impact on temperature and precipitation patterns. Regions like Southern Africa are particularly vulnerable to these ENSO-driven variations.

2.1.2 Production Function Theory

A production function acts as a blueprint for a firm, outlining how adjustments to inputs like labour or materials translate to changes in output, the final good or service produced. It also serves as a guidepost, indicating the maximum level of output achievable with a set amount of resources.

The production function is expressed as:

Q = f (K, L, etc.)

The output (Q) of a firm depends on the inputs of capital (K) and labor (L) (Quiggin and Horowitz,1999). We assume here that the firm employs only two factors of production which is labour and capital. Specifically to this study, augmentation of capital is subdivided into man-made capital which is agricultural equipment and natural capital which is precipitation and temperature which can only be determined by nature unlike man-made capital which are available and determined by humans.

2.1.3 Ricardian Technique

An empirical approach for studying the sensitivity of agriculture production. It was named after David Ricardo's (1772-1823) observation that value of land or land rents reflects the net productivity of farm land and estimates the impact of climate variables and also the impact of other variables on farm revenues (Mendelsohn et al.,1994). The Ricardian technique assumes that a farmer will, when confronted with a change in climate, immediately behave in ways similar to a farmer long accustomed to farming in such conditions. If the Ricardian approach predicts significant losses of productivity even with full and immediate adaptation then the reality will be worse. Fixed capital may become maladapted because of climate change Quiggin & Horowitz (1999). The Ricardian technique assumes that trade in agricultural produce is sufficient to equalize the returns on differentiated factors of production in all locations. But impediments to the movement of goods might prevent prices for land of identical quality being equalized, particularly for land in different countries.

2.1.4 Water, Energy and Food security Nexus (WEF Nexus)

The Food and Agriculture Organization (FAO) emphasizes a interconnected nature of water, energy and food security, forming a complex nexus. Actions taken in one sector can ripple through and impact the others. All three are fundamental for human well-being, poverty reduction, and achieving sustainable development goals. While water is the most abundant resource among the three, it's also finite, primarily derived from precipitation and temperature patterns. Ironically, it's also the most exploited. Water plays a critical role in various sectors, including forestry, fisheries, and the entire agricultural production chain. It's also used to generate and transmit various forms of energy. Agriculture, in fact, is the biggest consumer of freshwater globally, accounting for a staggering 70% of total withdrawals, but over a quarter of the world's energy consumption goes towards agriculture, food production, distribution and even food waste management.

2.2 Empirical literature

Mendelsohn et al. (1994) pioneered research on climate change's impact on agriculture using US data. They built two models: a crop-land model and a crop revenue model. The first gave more weight to counties with larger crop areas, while the second prioritized counties with higher agricultural revenue. They simulated a climate scenario with a 2.8°C temperature increase and 8% precipitation increase. Interestingly, the models produced contrasting results. The crop-land model predicted land value decline, while the crop revenue model projected an increase. This discrepancy stemmed from the different weighting schemes and crop models used. Mendelsohn argued that market value reflects a specific land parcel's production capacity, implying that spatial variations in climate directly affect land productivity. Their study successfully captured the relationship between climate and agricultural productivity using a regression analysis. However, this current research will employ panel data regression models to examine how climate variables influence agricultural output over time.

Gornell et al. (2010) conducted a comprehensive review of potential climate change impacts on global agriculture. Their analysis incorporated projected meteorological and hydrological changes from a climate model. The study highlighted the complexities arising from regional agriculture's dependence on distant rainfall patterns, snowmelt, and glaciers. Additionally, indirect effects like sea-level rise, storms, and disease outbreaks were not quantified. A particularly significant source of uncertainty lies in how the direct effects of increased CO2 on plant physiology might interact with climate change to influence overall productivity. The authors concluded that reliably quantifying the aggregate impacts of climate change on global agriculture remains a challenge. This uncertainty, coupled with limitations in capturing the nuances of extreme weather events in global assessments, motivated the decision to focus on the smaller, more specific case of the SADC region. This focus is particularly relevant given the historical prevalence of extreme weather events in Sub-Saharan Africa (SSA), where most SADC countries are located.

Researchers like Porter & Semenov (2005) and Battisti & Naylor (2009) have found a link between rising climate instability and fluctuating agricultural yields in Europe since the mid-1980s. Their studies using ANOVA analysis suggest that countries like Spain and Italy are particularly vulnerable to these variations. They also warn that even crops in temperate regions could be harmed by extreme heat without proper adaptation strategies. While these earlier studies provided valuable insights, they didn't specifically address integrated regions like SADC. This current research aims to fill that gap by focusing on the impact of climate change on agricultural productivity in the SADC region.

Prior research has established a strong link between climate change and agricultural vulnerability in Africa. Maddison (2006) employed a Ricardian approach, analyzing perceived land values from farmer surveys in eleven African countries. This approach revealed heightened susceptibility to climate shifts in warmer regions, highlighting the critical role of water availability. Water supply, heavily influenced by temperature and precipitation, is demonstrably sensitive to climate fluctuations. Similarly, Kurukulasuriya and Mendelsohn (2006) utilized farm-level data from eleven African countries to conduct a Ricardian cross-sectional analysis. Their work explored the relationship between climate variables and net crop revenue, revealing that both decreased precipitation and increased temperatures lead to declining net revenues. Furthermore, their predictions of warmer and drier conditions align with the dominant dryland character of the SADC region, suggesting a particularly negative impact on agricultural productivity within this integrated bloc. These studies collectively provide a robust foundation for understanding the interconnectedness between climate change and agricultural productivity in Africa.

Building on existing research, this study will employ a different approach. Basak (2009) utilized the DSSAT simulation model to evaluate consequences of forthcoming climate shift on Bangladeshi agriculture. Their findings indicated significant yield reductions of up to 28.7% with a 4°C rise in maximum temperatures. Notably, the study highlighted a more detrimental effect from increasing maximum temperatures compared to decreasing minimum temperatures. In contrast to this forward-looking approach, our investigation will leverage historical climate data for the SADC region. By simulating variations in climatic variables, both increases and decreases, we aim to illuminate the potential changes SADC agriculture can expect to encounter.

A study by Usman et al. (2011) investigated the effects of climate change on agriculture in Pakistan's arid regions. Their research employed a two-pronged approach: a Ricardian analysis utilizing data from a structured farmer survey in the Rawalpindi division, and time series analysis of climate data from meteorological stations. Focusing on wheat production, the study identified a significant negative correlation between net farm revenue and rising temperatures, while increased rainfall showed a positive association with revenue. However, the negative impact of temperature increase outweighed the positive effect of rainfall. Notably, a 1% rise in temperature translated to a yearly loss of Rs. 4180 in net revenue. The study underscores the need for a paradigm shift in the region's agricultural practices, including the adoption of innovative irrigation techniques, novel crop cultivation methods, and adapted cropping patterns.

Blanc's (2011) extensive study explored the multifaceted impacts of climate change on agricultural production in Sub-Saharan Africa. The research employed a two-pronged approach to assess both crop yield and farmer behavior. The first analysis examined the influence of various weather elements on crop yields. It revealed that temperature, precipitation, evapotranspiration, floods, and droughts all exerted significant effects, with these factors having a stronger impact in regions with less suitable agricultural conditions. Interestingly, the study also found a positive correlation between CO_2 concentration and crop productivity, particularly for plant-based crops. The second analysis focused on how climate change influences farmer decision-making. The findings indicated that farmers' decisions regarding crop allocation were more responsive to factors like export prices for crops and livestock, along with variability in precipitation and temperature. Notably, both increased variability in temperature and precipitation led to a decrease in land designated for crops. This suggests that as climate risks intensify, farmers may opt to engage in alternative activities or diversify their crops, highlighting the link between climate change and farmer adaptation strategies.

Several prior studies, including Downing (1992) who examined food security in Zimbabwe, Kenya, and Senegal, have explored the effects of climate variability on African agriculture. These investigations employed diverse methodologies and emphasized the importance of a nuanced understanding of vulnerability. According to Rosenzweig et al.,*(*1995) the downing's work incorporated data on various non-climatic factors like socioeconomics, trade, institutions, and geography to assess "current vulnerability, risk of present and future climatic variations and responses to reduce present vulnerability and improve resiliency to future risks." Similarly, Rosenzweig et al. (1995) and Desanker (2002) built upon Downing's foundation by focusing on the vulnerability of African countries to climate-induced declines in agricultural production. This current study expands the scope of this research by encompassing all 16 countries within the SADC region, with a specific focus on how climate change affects agricultural output across this integrated bloc.

Prior research by Downing (1992) established a valuable framework for assessing climate change's impact on food security in African nations. This foundational study, encompassing Zimbabwe, Kenya, and Senegal, employed a multifaceted approach that incorporated various non-climatic factors. Specifically, Downing examined the socioeconomic landscape, trade dynamics, institutional structures, and geographic contexts to create a comprehensive picture of "current vulnerability, risk of present and future climatic variations and responses to reduce present vulnerability and improve resiliency to future risks." Building upon this groundwork, Rosenzweig et al. (1995) and Desanker (2002) further explored the susceptibility of African countries to climate-induced reductions in agricultural productivity, emphasizing the concept of vulnerability. The present study adopts a similar investigative approach, albeit on a broader scale. Encompassing all 16 member states of the Southern African Development Community (SADC), this research endeavors to elucidate the specific effects of climate change on agricultural output within this integrated regional bloc.

Studies in Nigeria Sowunmi & Akinola (2010) and Egypt Onyeji & Fischer (1994) highlight water as crucial for agricultural production. Sowunmi & Akinola used statistical methods (ANOVA & CV) to analyze the link between climate variability and agricultural parameters across diverse Nigerian zones (1980-2002). Their findings suggest adequate water enables year-round production with minimal temperature impact. Onyeji & Fischer explored potential changes in agricultural output under climate change scenarios in Egypt, considering broader economic consequences through global trade effects.

Sowunmi & Akinola's (2010) findings may suggest a straightforward link between climate change and declining agricultural production. However, Huong et al. (2018) offer a more nuanced perspective using a quadratic Ricardian model and Error Correction Model. Their research suggests an inverted U-shaped relationship between climate variables and agricultural output. This implies that agricultural productivity might actually increase up to a certain level of factors like CO2, but then begin to decline once a threshold is surpassed. This highlights the potential for a non-linear relationship between climate change and agricultural production, where both extremes (too much or too little of certain climate variables) can be detrimental. This finding aligns well with scientific understanding, as exceeding or falling below optimal levels for factors like temperature and CO2 can negatively impact crop yields.

2.3 Conclusion

A recurring theme throughout this research is the complex interplay between climate change vulnerability and various local factors in agriculture. These factors encompass biological conditions like soil composition, crop selection, farmer awareness of climate shifts, and existing agricultural management practices (whether focused on maximizing output, revenue, etc.). Essentially, climate change introduces an additional layer of uncertainty for farmers to grapple with. It translates into heightened production risks, increased likelihood of extreme weather events, disruptions to field operation schedules, and challenges in planning investments for new technologies.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter outlines the methodological framework of the study. It will detail the chosen research design, the population under investigation, and the specific sample utilized. We will also explore the empirical model, providing definitions and justifications for the variables involved. Finally, the section will conclude by discussing the data sources and the estimation procedure used in the analysis.

3.1 Research Design

This research investigates how climate change affects agricultural output across SADC countries. Employing a quantitative approach, the study utilizes annual panel data spanning the years 2000 to 2018. Data accessibility played a key role in selecting this source, as it was readily available from the statistical agencies of SADC member states. Panel data was chosen over other options due to its particular strengths and applicability to this specific investigation. It has the advantage of incorporating both spatial and temporal variations in variables, compared to cross-sectional and time-series data, panel data offers a richer information set with reduced collinearity, greater variability and more degrees of freedom for a given sample size. Most importantly, it addresses the issue of heterogeneity among countries in the analysis. However, it's important to acknowledge that panel data inherits some limitations from both cross-sectional and time-series data.

3.1.1 Study Population and Sample

The study population includes 14 countries that constitute the SADC region. These countries include Angola, Botswana, Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe for the period 2000 to 2022. The exclusion of the other two countries is due to the fact that they recently join SADC hence all data was not there, but still, 14 out of 16 countries is still a good sample.

3.1.2 Data Sources

This research leverages data from two key sources: the World Bank (WB) and the national research and meteorological service centers of the SADC member states. This comprehensive approach incorporates both international datasets and information specific to each SADC country, fostering a more nuanced understanding of the research topic.

3.2 Model Specification

This study comprehensively evaluates the influence of climate change on agricultural output within SADC countries, this study adopts a hybrid methodological approach. It leverages the strengths of both the Ricardian Approach and the Cobb-Douglas production function. The Ricardian Approach, well-suited for investigations into long-term climate change impacts on agriculture, estimates these effects by examining how climatic variables influence farm revenue or land value. From this approach, the study incorporates precipitation (P) and temperature (T) as key variables capturing climate change (Mendelsohn et al., 1994). To achieve a more nuanced understanding, the study integrates the Cobb-Douglas production function, which models output (Y) as a function of labour (L) and capital (K). This framework is further strengthened by incorporating control variables: government expenditure (G) serving as a proxy for capital investment, and inflation (INFL). The resulting model for this investigation can be functionally expressed as:

$$Y = Y\ (P, T, L, G, INFL) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (1)$$

The econometric equation for the model is specified as:

$$Y_{it} = \alpha_0 + \alpha_1 P_{it} + \alpha_2 T_{it} + \alpha_3 L_{it} + \alpha_4 G_{it} + \alpha_5 INFL_{it} + \alpha_6 P_{it}^2 + \alpha_7 T_{it}^2 + \epsilon_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where α_0 is the intercept, $\alpha_1$to α_7 are coefficients of independent variables and ϵ_{it} is the error term to account for unexplained change on agricultural production by climate change measures and the control variables.

3.3 Definition and Justification of Variables

Agricultural Production (Y_{it})

Ayinde et al., (2021) define agricultural productivity as the agriculture value added per worker, which measures the output of the agricultural sector minus the value of intermediate inputs. It encompasses value addition from forestry, hunting, fishing, crop cultivation and livestock production. This variable serves as the dependent variable in the model.

Precipitation (P_{it})

This study incorporates total annual rainfall within each SADC country as a variable reflecting climate change's influence on agricultural output. This variable, precipitation (indexed by rainfall data), aligns with the Ricardian Approach. According to existing research (Kumar & Sharma, 2023), theory suggests a positive correlation between rainfall and agricultural productivity – in other words, areas with higher rainfall are expected to see greater agricultural output.

Temperature (T_{it})

This research also considers temperature as a key indicator of climate change's influence on agriculture, following the Ricardian Approach. Rosenzweig and Hillel (2015), suggest potential benefits for higher-latitude regions from temperature increases due to longer growing seasons and expanded arable land, these gains might be limited by less fertile soils. Conversely, Edame et al. (2021) and Chan (2022) point towards potential drawbacks in lower-latitude regions, where already warm temperatures could be pushed beyond optimal levels for crop growth, leading to negative impacts. Therefore, the relationship between temperature and agricultural output is expected to be complex, with advantages and disadvantages contigent on the specific event.

Labour (L_{it})

This study uses total population growth rate as an indirect measure of the agricultural labour force. The aim is to investigate the potential for an adverse connection between growing population and agricultural productivity. Enu and Attah-Obeng (2023) suggested that population increases can put pressure on the available agricultural land, potentially leading to a decline in productivity per worker.

Government Expenditure (G_{it})

To assess the role of government support in agriculture, this study incorporates government expenditure as a variable. Established theories (Benin et al., 2019) suggest a positive correlation between government investment in the agricultural sector and overall agricultural output. This can be attributed to various forms of government support, such as input subsidies, extension services, infrastructure development, and research initiatives, which can all contribute to boosting agricultural productivity (Selvaraj, 1993).

Inflation ($INFL_{it}$)

This study incorporates inflation, measured by the consumer price index (Oyinbo et al., 2022), to understand its complex relationship with agricultural productivity. On one hand, rising prices for agricultural outputs (what farmers sell) could incentivize increased production, potentially leading to a positive correlation. However, Olatunji et al. (2022) suggest a possible negative effect when considering inflation's impact on input prices (what farmers buy). Inflationary pressures on things like seeds, fertilizer, and machinery could dampen productivity gains. Therefore, the anticipated effect of inflation on agricultural output is likely to be intricate, potentially exhibiting both positive and negative influences.

Table 2: Variables and Expected Relationship

Dependent Variable	Independent Variables	Relationship
Agricultural Production (Y_{it})	Precipitation (P_{it})	Positive/Negative
	Temperature (T_{it})	Positive/Negative
	Labour (L_{it})	Negative

	Government Expenditure (G_{it})	Positive
	Inflation ($INFL_{it}$)	Positive/Negative

3.4 Estimation Procedure

While Pooled Ordinary Least Squares (POLS) is a common approach in data analysis, it falls short when dealing with panel data. This method fails to account for the unique characteristics of individual units (countries) over time. This shortcoming leads to biased estimates because the error term and independent variables become intertwined. To address this limitation and leverage the strengths of panel data, researchers turn to Fixed Effects Models (FEM) and Random Effects Models (REM). Interestingly, Ordinary Least Squares can still be useful in panel data analysis under specific conditions. If the country-specific effects are unrelated to the independent variables, OLS can provide unbiased and consistent estimates. However, these conditions are often not met in real-world scenarios, making FEM and REM more preferable choices for analyzing panel data.

3.4.1 Fixed Effects Model (FEM)

This study utilizes the Fixed Effects Model (FEM) to account for the unique characteristics of each SADC member country. FEM acknowledges heterogeneity, meaning individual countries can have different starting points (intercepts) in terms of agricultural productivity. These intercepts are "fixed" across time periods for each country, implying their baseline productivity remains constant throughout the study period. Assuming that $ov\ (X_{it}, v_i) \neq 0$, Mathematically, the FEM can be represented as:

$$Y_{it} = \beta_{1i} + \beta_2 X_{2it} + \beta_3 X_{3it} + \varepsilon_{it}$$

Where $\varepsilon_{it} = v_i + \mu_{it}$

In panel regression models i and t represents the crossectional identifier and time identifier respectively. v_i is treated as the unknown parameter to be estimated and the combined crosssectional and time series error component (μ_{it}). Y_{it} is the explained, dependent or the regrassand variable and β_{1i} are cross section (SADC countries) specific intercepts which are time invariant and β_2 and β_3 are the slope coefficients of the explanatory or independent variables X_{2it} and X_{3it} which do not vary across cross sections. According to Johnston and Dinardo (1997), state that consistent estimates of these parameters are difficult to obtain in typical panel data cases where T is small and N is large. Even though we cannot estimate v_i consistently, we can consistently estimate the remaining parameters β_i. FEM address the omitted-variables problem by reducing the variance that affects Random Effects Model or Ordinary Least Squares (OLS) estimator (Johnston and Dinardo, 1997; Gujarati, 2003 and Brooks, 2008).

3.4.2 Random Effects Model (REM)

The Fixed Effects Model (FEM), while straightforward to implement, can become statistically demanding (expensive in terms of degrees of freedom) when dealing with numerous cross-sectional units (countries) as highlighted by Gujarati (2004). Given our study's focus on 14 SADC countries over 16 years, the Random Effects Model (REM), also known as the Error Components Model (ECM), presents a more suitable approach. We can express the REM mathematically as:

$$Y_{it} = \beta_{1i} + \beta_2 X_{2it} + \beta_3 X_{3it} + \varepsilon_{it}$$

Where $\varepsilon_{it} = v_i + \mu_{it}$

Instead of treating β_{1i} as fixed , we assume that is a random variable with mean value of β_1 (no subscript i here) and the intercept value of the individual country can be expressed as:

$\beta_{1i} = \beta_1 + \varepsilon_i$ i = 1, 2, ………,N

According to Gujarati (2009) the following assumptions are made on Random Effects Model:

$v_t \sim N(0, \delta_v^2)$, $u_{it} \sim N(0, \delta_u^2)$, $E(v_i, u_{it}) = 0$, $E(v_i, v_j) = 0$: $(i \neq j)$ and $E(u_{it}, u_{is}) = E(u_{it}, u_{jt}) = E(u_{it}, u_{js}) = 0 : (i \neq j; t \neq s)$

In this model, the errors don't influence each other over time or between countries. This avoids a common issue called autocorrelation, ensuring reliable results. It suggest that $E(\varepsilon_{it}) = 0$ and this ensures consistent error variance (homoscedasticity) as illustrated by the following equation: $var(\varepsilon_{it}) = \delta_v^2 + \delta_u^2$. The General Least Squares method combines the weighted averages of within-group and between-group estimators, allowing for the extraction of information from both sources of variation.

3.4.3 Fixed Effects Model or Random Effects Model

Choosing between the Fixed Effects Model (FEM) and Random Effects Model (REM) requires careful consideration. Although both can be unbiased under specific conditions (Johnston & DiNardo, 1997), FEM is often preferred. REM assumes all relevant time-invariant factors are included, which can be unrealistic. FEM avoids this issue, making it more robust against omitted variable bias, a potential flaw in REM.

Johnston and Dinardo (1997) stated that many researchers favors the FEM over REM because they have a reasonable belief that it is not true for the fixed effects to be uncorrelated with the regressors of interest. Therefore the fundamental assumption underlying the FEM is (Xit,) ≠ 0 while REM assumes that (Xit,) = 0. The FEM solves the omitted-variables problem by throwing away some of the variance that contaminates either the REM or the Ordinary Least Squares (OLS) estimator (Johnston and Dinardo, 1997; Gujarati, 2003 and Brooks, 2008). However, according to Davidson and MacKinnon (1999), if T is small and N is large, and the assumptions underlying REM hold, the FEM is relatively not efficient as compared to the REM.

Choosing between (FEM) and (REM) hinges critical considerations regarding the underlying data structure, as outlined by Johnston and Dinardo (1997). When many time periods (T) is substantial similar to the number of cross-sectional units (N), both models yield statistically indistinguishable parameter estimates. In such scenarios, the choice becomes one of computational efficiency, with FEM often favored due to its relative simplicity. However, the decision becomes more nuanced when T is limited and N is large, a situation frequently encountered in panel data studies like ours (14 countries over 16 years). The estimates derived from FEM and REM can diverge considerably. FEM is the preferred approach if we have reason to believe the SADC countries were not selected randomly for the sample. Conversely, REM is more appropriate if we can assume random selection of countries. It's important to acknowledge a potential limitation associated with FEM. Estimating separate intercepts for each country (N dummy variables) uses a greater number of degrees of freedom compared to REM, particularly when dealing with a large number of countries (N). This can have implications for the overall power of the statistical tests

3.4.5 Hausman Test

Hausman Test (Gujarati, 2009) helps decide between fixed effects and random effects model by comparing their results. It checks if the simpler random effects model is reliable. A Chi-square (χ2) statistic helps make the decision. The formal test is as follows:

$H = (\alpha\hat{}FE - \alpha\hat{}RE)'[var(\alpha\hat{}FE) - var(\alpha\hat{}RE)]{-1}(\alpha\hat{}FE - \alpha\hat{}RE) \sim \chi K\ 2$

where K denotes the dimension of the slope vector α

Thus $H0$: $Cov(X_{it}, v_i) = 0$

$H1$: $Cov(X_{it}, v_i) \neq 0$

Rejection of the null hypothesis in a Hausman test signifies that the Random Effects Model (REM) is not an appropriate choice for our investigation. Consequently, the Fixed Effects Model (FEM) emerges as the preferred estimator. However, it's crucial to acknowledge that FEM estimates are conditional upon the error terms specific to our sample. While the Hausman test provides valuable insights, navigating the complexities of fixed effects, measurement errors, and dynamic selection problems within panel data analysis remains a challenge, as highlighted by Johnston and DiNardo (1997). This underscores the notion that panel data, although a significant advancement over purely cross-sectional data, is not without its limitations and cannot completely eliminate all econometric issues.

3.4.4 Panel Unit Root Test

This investigation employed the Levin-Lin-Chu (2002) unit root test to assess the stationarity of the data. The test is particularly suited for balanced panel datasets, where each cross-sectional unit (SADC country in this context) possesses the same number of observations across the study period. Additionally, the Levin-Lin-Chu test assumes a common autoregressive parameter across all panels. The null hypothesis of the test posits that all panel units exhibit unit root characteristics, signifying non-stationarity. Conversely, rejection of the null hypothesis at the 5% significance level (p-value < 0.05) leads to the conclusion that the data series are stationary. In essence, stationarity implies that the data does not exhibit persistent trends or seasonal fluctuations over time, ensuring the validity of statistical inferences drawn from the analysis.

3.5 Conclusion

This chapter meticulously outlines the methodological framework employed to investigate the impact of climate change on agricultural production within SADC countries over the period 2000 to 2022. It delves into the specific research design adopted, the rationale behind the sample selection, and the detailed specification of the model chosen for analysis. Additionally, the chapter provides a comprehensive justification and definition of all variables incorporated into the study.

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND DISCUSSION OF RESULTS

4.0 Introduction

To provide a comprehensive overview of the behavior of the variables involved in assessing the impact of climate change on agricultural productivity in SADC, summary statistics were calculated, as illustrated in Table 1. The descriptive statistics encompass three key measures: overall, within, and between. Within variation captures changes over time or within individual entities (time-varying), while between variation pertains to differences across entities (cross-sectional). Overall variation reflects the combined effect of time and individual units. The analysis utilized data from 14 SADC countries (n=14) spanning the period from 2004 to 2022 (T=19), resulting in a total of 266 observations (N=266). The data exhibits strong balance. This summary provides a comprehensive insight into the data structure, aiding in the understanding of the research objectives (Milliken and Johnson, 1984).

Since panel data comprises both cross-sectional and time-series components, variables id and t represent the cross-sectional units and time periods, respectively. The maximum value of variable i is 14, corresponding to the 14 SADC countries included in the study, while the maximum value of t is 19, representing the 19 time periods from 2004 to 2022.

Table 1 shows summary of explanatory variables excluding rainfall

Variable		Mean	Std. Dev.	Min	Max	Observations
i	Overall	7.5	4.038728	1	14	N = 266
	between		4.1833	1	14	n = 14
	Within		0	7.5	7.5	T = 19
t	overall	10	5.48755	1	19	N = 266
	between		0	10	10	n = 14

	within		5.48755	1	19	T = 19
Agriculture production	overall	12.33607	9.535314	1.82838	38.81841	N = 264
	between		9.657386	2.346027	30.88635	n = 14
	within		2.30325	4.262276	20.68255	T = 18.8571
Temperature	overall	21.75726	2.743229	12.78601	26.32564	N = 266
	between		2.809667	13.6514	25.03783	n = 14
	within		.4090114	20.52122	23.61698	T = 19
Rain	overall	76.39612	36.8608	17.12733	180.5993	N = 266
	between		36.58016	24.01025	149.1653	n = 14
	within		10.55938	35.81258	136.9569	T = 19
Labour	overall	41.81717	27.81365	1.217777	82.521	N = 266
	between		28.55945	1.393588	76.14247	n = 14
	Within		3.655031	31.4638	51.79096	T = 19
Government expenditure	Overall	15.61378	7.939411	-3.59325	35.33276	N = 264
	Between		7.495524	3.341434	33.3398	n = 14
	Within		3.225279	1.846204	30.74375	T = 18.8571
Inflation	Overall	112.6624	1503.256	-9.616154	24411.03	N = 264
	Between		418.4427	2.475834	1576.908	n = 14
	Within		1453.106	-1466.656	22946.78	T bar = 18.8571

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Temperature on average have the overall value of 21.76 degrees. This entails that on average SADC countries experience hot temperatures. Temperature is more volatile across the sampled SADC countries than within the countries as shown by larger between variations and lower within variation.

Overall percentage of employed people in agriculture in SADC is 41.8% on average which then implies that most of the countries in SADC depend of agriculture as a source of employed despite the fact that employment in agriculture is seasonal. Furthermore, there are other macroeconomic variables that affect agriculture value namely government expenditure through subsidies and inflation rate. On average the government expenditure in SADC is 15.6% of the level of Gross Domestic Product. However, overall inflation rate for SADC is a three digit number 112.67% which is hyperinflation and it might be an inflated figure from Zimbabwe`s hyper inflationary period.

Table 2: Summary of the dependent variable

Variable		**Mean**	**Std. Dev.**	**Min**	**Max**	**Observations**
Agriculture production	overall	12.33607	9.535314	1.82838	38.81841	N = 264
	between		9.657386	2.346027	30.88635	n = 14
	within		2.30325	4.262276	20.68255	T = 18.8571

The average value of agriculture output as a percentage of gross domestic product is 12.36 % with total variability of 9.53%. The lowest and highest values are 1.82% and 38.82% respectively. This means that most of the countries in the SADC are agro based since almost 40% of the employed people are in the agriculture sector. Value of agriculture is more volatile across SADC countries than within the countries as shown by larger between variation of 9.65 and a within variation of 2.60.

Table 3: Contains descriptive statistics of the main independent variable rainfall

Variable		Mean	Std. Dev.	Min	Max	Observations
rain	overall	76.39612	36.8608	17.12733	180.5993	N = 266
	between		36.58016	24.01025	149.1653	n = 14
	within		10.55938	35.81258	136.9569	T = 19

Climate variables which are temperature and rainfall (precipitation) on average they have the overall value of 21.76 degrees and 76.4 mm, respectively. This entails that on average SADC countries experience hot temperatures and low levels of rainfall. Temperature and rainfall are more volatile across the sampled SADC countries than within the countries as shown by larger between variations and lower within variation.

4.1 Correlation Analysis

In order to uncover the relationship between variables both independent and dependent variables, the study conduction a correlation matrix. This section investigates the links between the variables. Through the use of correlation matrix in Table 3, the study can test for multicollinearity and compute correlation between variables. From Table 4, all independent variables that is: temp, tempsq, rain, rainsq, inflation except inflation have a positive relationship with the dependent variable namely value of agriculture. Multicollinearity test which is a measure of linear dependence between independent variables can be measured by pairwise correlation coefficients. If the coefficients are more than 0.8 it implies the existence of multicollinearity.

Table 4: Hausman Specification test

	(b)	(B)	(b-B)	sqrt(diag(V_b-V_B)
	fixed	random	Difference	S.E.
tem	-1.498725	-.3971011	-1.101624	.8890396
tempsq	.0392078	.0155941	.0236137	.0187859
rain	.0763992	.0860308	-.0096316	.0087254
rainsq	-.0002506	-.0002915	.0000409	.0000344
lab	.1753403	.1670536	.0082867	.0131239
gexp	-.1336265	-.1331429	-.0004836	.0084696
infl	.0002697	.0002693	3.63e-07	.0000107

b = consistent under Ho and Ha; obtained from xtreg

B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test: Ho: difference in coefficients not systematic

chi (χ2) *(5) = (b-B)'[(V_b-V_B)^(-1)](b-B)*

= 2.46

Prob> chi (χ2) = *0.7824*

The Chi Squared for the Hausman test is 2.46 and the corresponding probability value is 0.7824. Thus, we may fail to reject the null hypothesis that there is no systematic difference between FEM and REM coefficients at 5 % level of significance. Thus, we fail to reject the null hypothesis that the difference in the coefficients is not systematic at 5% significance level, implying that the Random Effects Model (REM) is appropriate and is to be preferred to the Fixed Effects Model (FEM).

Table 5: Random Effects Model

Following the specifications by Hausman test, the study uses Random Effects Model. This implies that all the conclusions and interpretations will follow the explanations of REM as alluded to in the methodology section. Table 5 shows that the constant is positive and statistically insignificant. The model exhibits strong variations with within variance of 23%, between variance of 19.4% and 20% overall variation of the whole model.

4.2 Impact of temperature on agriculture production

The coefficient of temperature and its squared value are statistically insignificant, temperature has a negative relationship with agriculture production value. It implies that a unit increase in temperature will result to 0.39% decline in the percentage of that is contributed by agriculture to GDP. Also the square temperature is insignificant with a positive relationship. The results are in tandem with the findings of Munoir (2014) and Sowunmi and Akinola (2010).

4.3 The impact of rainfall or precipitation on agriculture production

The coefficient of rainfall statistically significant at 5% level of the significance.

$$\frac{\partial agric}{\partial rain}=0.00860308—0.0002915*2rain = 0,$$

$$\rightarrow 0.000583 rain = 0.00860308$$

$$\rightarrow rain^{*}=14.75$$

This means that as long as rain is below 14.75, it will promote agriculture growth in SADC. The results corroborates with the findings of Oyinbo et al., (2012).

Table 5: Random Effects Model

agric	Coef.	Std. Err.	z	P>z	[95% Conf.	Interval]

tem	-.3971011	2.389237	-0.17	0.868	-5.079919	4.285717
tempsq	.0155941	.0560577	0.28	0.781	-.094277	.1254653
rain	.0860308	.0356562	2.41	0.016	.016146	.1559156
rainsq	-.0002915	.0001835	-1.59	0.112	-.0006511	.0000682
lab	.1670536	.034312	4.87	0.000	.0998034	.2343039
Gexp	-.1331429	.0446996	-2.98	0.003	-.2207525	-.0455333
Infl	.0002693	.0000917	2.94	0.003	.0000896	.0004491
cons	4.168853	26.43502	0.16	0.875	-47.64284	55.98055

R-sq: Obs per group:

within = 0.2323 min = 17

between = 0.1944 avg = 18.7

overall = 0.2029 max = 19

4.4 The Influence of Labour on Agricultural Production

Aligned with production theory and the predictions of this research, it was discovered that labour has a significant and positive effect on agricultural production. Labour is statistically significant at the 1% level, with a coefficient of 0.167%. This suggests that a one percent increase in labour leads to a 0.167% increase in agricultural production. However, this also indicates diminishing returns to scale, given that labour is one of the inputs in agricultural production.

4.5 The Impact of Government Expenditure on Agricultural Production

Contrary to expectations, government expenditure, which contributes to inputs such as subsidies, was found to have a negative relationship with agricultural production. Government expenditure is statistically significant at the 5 percent level. A one percent increase in government expenditure on agriculture leads to a 0.13 percent decrease in the contribution of agriculture to GDP. This slight decline may be attributed to inefficiencies resulting from subsidies.

4.6 The Effect of Inflation on Agricultural Production

The study revealed that inflation positively impacts agricultural production, as indicated by a coefficient of 0.0002693. Inflation is statistically significant at the 1 percent level of significance. This suggests that a one percent increase in inflation results in a 0.0002693 percent increase in agricultural contribution to GDP.

CHAPTER FIVE

SUMMARY, CONCLUSION AND POLICY RECOMMENDATIONS

5.0 Introduction

This chapter is divided into two sections. The first section presents a summary of the findings of the study. The second section provides policy recommendations based on the empirical results and identified areas for further research.

5.1 Summary of the findings and conclusion

This study has examined the impact of climate change on agricultural productivity in the SADC countries. The main objective of the study was to assess the extent to which climate change affects agricultural production in the SADC region. It also aimed to simulate into the future, the impacts of climate change on agricultural production in the future as projections. The motivation of the study is the fact that climate change and its variability may have led to adverse effects in the prioritized global agricultural sector. The continued increase in the frequency of dry spells, uneven distribution of rainfall and increasing temperatures may have contributed to the low agricultural production in the SSA region hence there bringing up the need to assess the impact of these variabilities in the SADC region trade partners. The analysis was conducted over a sample of 14 selected countries for the period 2000-2018. Correlation and multicollinearity tests were done and through the use of the Hausman Specification test, it was determined that the Random Effects Model (REM) was the most appropriate.

This study is different from a lot of other studies that have been conducted before in several ways, the first difference being that it takes into account the whole SADC region as trading partners, thereby taking into account the effects of climate change on their agricultural production as a group, which has not been done many times before in the African region. Secondly, the use of panel data which also incorporates the element of time series in a climate study helps in identifying the effects of temporal variations of climate variables on agricultural production, as climate variations effects across space could be different from those over time. Lastly, in addition to climate variables which are rainfall variability and temperature variability, economic variables were also included in order to capture the effects of extreme events on agricultural production.

First the study finds a strong link between Hulme (1996)'s Water availability mechanism and agricultural productivity as highlighted in Chapter 2 subsection 2.1.1.3; and the Occurrence of extreme events mechanism and agricultural production in subsection 2.1.1.4. This means that water availability is of great importance in seeing agricultural production increase in the SADC region and that extreme weather events such as floods and cyclones are not good for agricultural productivity as evidenced by the statistically significant rainsquared variable because too much of one thing is never good. It is however against the aprior expectations that temperature was found to be statistically significant probably because the variance in the independent variable was very little hence the notion that it does not affect agricultural production. Given the stated above, the study conclude however that climate change has an impact on agricultural production.

Secondly however, government expenditure was found to have a negative relationship which is also different from the expected relationship between it and agricultural productivity. Labour on the contrary, was found to be positively linked to agricultural production. This was not expected to be case as labour tends to have diminishing returns ceteris paribus. Lastly, inflation had a positive relationship with the depended variable as the price level is always seen as an indication to producers so that they produce more in order to benefit from the high or higher prices.

5.2 Policy Implications and Recommendations

Climate change presents a significant threat to the SADC region as it is expected to increase the frequency and intensity of climatic events. Predicted higher temperatures, altered rainfall patterns, and an overall decrease in rainfall will have serious consequences for the region. The ability to forecast weather can help governments and communities prepare for, and reduce these potential negative impacts, of adverse weather events. The region needs to develop flexible adaption strategies and frameworks framed around scenario planning that would culminate in a resilient agricultural system by increasing knowledge exchange and shared best practices on detecting pets and diseases, as well as weather forecasting and drought monitoring. Therefore, SADC member states should collaborate to find ways to adapt to, and mitigate, the effects of climate change in the region. The evident and adverse climate change impacts on the agriculture sector in southern Africa that include reduced crop yields and new strains of pests and diseases on both crops and livestock, require evidence based adaptations policy frameworks that leads to the resiliency of the agricultural system.

Although these can be implemented at national and local levels, they are more effective at regional level as dealing with the challenges at regional levels reduces the risk of recurrence. Implementing these initiatives at regional could be very positive for a region that is moving towards integration or have already integrated. Agriculture development and adaptation to climate change should consider cross-sectoral approach of the water-energy-food (WEF) nexus, which systematically provides evidence to policy and decision-making. The advantage of the WEF nexus is that it is flexible and can be linked to scenario planning methods such as Shared Socioeconomic Pathways (SSPs).

The SADC community should also invest in having more labour so as to increase agricultural production in the region, this being observed from the results in the study. Having more labour as a means to production is not enough but investment should be done in semi and skilled workers which will increase yields all across the region and that would benefit the whole everyone in the integration not only from sales that would accrue from exporting the agricultural produce but to ensure that the region has enough food for the growing population.

SADC nations at national level ought to see to it that they reduce or do away with channeling expenditure towards agricultural production as this may reduce productivity if producers are given subsidies. Instead subsidies should be given to the consumers so they can be able to demand more of the products hence increase productivity.

5.3 Suggestion for Further Research

Agriculture and climate change are deeply intertwined. The effects of global warming on food supply are dire, whilst world population is increasing. It's time to change the way agriculture affects the environment, and vice versa. This research could be further developed by testing the causal relationship between climate change and agricultural productivity whether is bidirectional or it goes from one to the other variable. The study also could not include all 16 SADC members hence in future, more data should be collected for a wholesome study.

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APPENDIX

APPENDIX 1: SUMMARY OF EXPLANATORY VARIABLES EXCLUDING RAINFALL

Table 1 shows summary of explanatory variables excluding rainfall

Variable		Mean	Std. Dev.	Min	Max	Observations
i	Overall	7.5	4.038728	1	14	N = 266
	between		4.1833	1	14	n = 14
	Within		0	7.5	7.5	T = 19
t	overall	10	5.48755	1	19	N = 266
	between		0	10	10	n = 14
	within		5.48755	1	19	T = 19
Agriculture production	overall	12.33607	9.535314	1.82838	38.81841	N = 264
	between		9.657386	2.346027	30.88635	n = 14
	within		2.30325	4.262276	20.68255	T = 18.8571
Temperature	overall	21.75726	2.743229	12.78601	26.32564	N = 266
	between		2.809667	13.6514	25.03783	n = 14
	within		.4090114	20.52122	23.61698	T = 19
Rain	overall	76.39612	36.8608	17.12733	180.5993	N = 266
	between		36.58016	24.01025	149.1653	n = 14
	within		10.55938	35.81258	136.9569	T = 19
Labour	overall	41.81717	27.81365	1.217777	82.521	N = 266
	between		28.55945	1.393588	76.14247	n = 14
	Within		3.655031	31.4638	51.79096	T = 19
Government expenditure	Overall	15.61378	7.939411	-3.59325	35.33276	N = 264
	Between		7.495524	3.341434	33.3398	n = 14
	Within		3.225279	1.846204	30.74375	T = 18.8571
Inflation	Overall	112.6624	1503.256	-9.616154	24411.03	N = 264
	Between		418.4427	2.475834	1576.908	n = 14
	Within		1453.106	-1466.656	22946.78	T bar = 18.8571

Appendix 2 : SUMMARY OF THE DEPENDENT VARIABLE

Table 2: Summary of the dependent variable

Variable		Mean	Std. Dev.	Min	Max	Observations
Agriculture production	overall	12.33607	9.535314	1.82838	38.81841	N = 264
	between		9.657386	2.346027	30.88635	n = 14
	within		2.30325	4.262276	20.68255	T = 18.8571

Appendix 3: DESCRIPTIVE STATISTICS OF THE MAIN INDEPENDENT VARIABLE RAINFALL

Table 3: Contains descriptive statistics of the main independent variable rainfall

Variable		Mean	Std. Dev.	Min	Max	Observations
rain	overall	76.39612	36.8608	17.12733	180.5993	N = 266
	between		36.58016	24.01025	149.1653	n = 14
	within		10.55938	35.81258	136.9569	T = 19

APPENDIX 4 : HAUSMAN SPECIFICATION TEST

Table 4: Hausman Specification test

	(b)	(B)	(b-B)	sqrt(diag(V_b-V_B)
	fixed	random	Difference	S.E.
tem	-1.498725	-.3971011	-1.101624	.8890396
tempsq	.0392078	.0155941	.0236137	.0187859
rain	.0763992	.0860308	-.0096316	.0087254
rainsq	-.0002506	-.0002915	.0000409	.0000344
lab	.1753403	.1670536	.0082867	.0131239
gexp	-.1336265	-.1331429	-.0004836	.0084696
infl	.0002697	.0002693	3.63e-07	.0000107

APPENDIX 5: RANDOM EFFECTS MODEL

Table 5: Random Effects Model

agric	Coef.	Std. Err.	z	P>z	[95% Conf.	Interval]
tem	-.3971011	2.389237	-0.17	0.868	-5.079919	4.285717
tempsq	.0155941	.0560577	0.28	0.781	-.094277	.1254653
rain	.0860308	.0356562	2.41	0.016	.016146	.1559156
rainsq	-.0002915	.0001835	-1.59	0.112	-.0006511	.0000682
lab	.1670536	.034312	4.87	0.000	.0998034	.2343039
Gexp	-.1331429	.0446996	-2.98	0.003	-.2207525	-.0455333
Infl	.0002693	.0000917	2.94	0.003	.0000896	.0004491
cons	4.168853	26.43502	0.16	0.875	-47.64284	55.98055

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