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Thesis Title: Determination of vulnerability of food systems to price and climatic shocks in SACU countries: Case of Namibia, Botswana and South Africa

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SUMMARY

After thesis examination, I confirm that the student has addressed the examiners' comments to my satisfaction. I, therefore, approve submission of the following;

- 2 electronic copies (MS Word & PDF) e-mailed to the programme coordinator

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NAMIBIA UNIVERSITY OF SCIENCE AND TECHNOLOGY

Determination of vulnerability of food systems to price and climatic shocks in SACU countries: Case of Namibia, Botswana and South Africa

God'spower Musarurwa

Thesis submitted in partial fulfilment of the requirements for the degree of Master of Agribusiness Management at the Namibia University of Science and Technology

Supervisor: Dr Thinah Moyo
Faculty of Health, Natural Resources and Applied Sciences
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October 2023

Declaration

I, God'spower Musarurwa, hereby declare that the work contained in the thesis entitled: Determination of vulnerability of food systems to price and climatic shocks in SACU countries: Case of Namibia, Botswana and South Africa is my own original work and that I have not previously, in its entirety or in part, submitted to any university or higher education institution for the award of a qualification.

Signature: ………..…………………………… Date: ……02/03/2024……………………….

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List of Acronyms

SACU- Southern African Customs Union

IPCC- Intergovernmental Panel on Climate Change

AGRA- Alliance for a Green Revolution in Africa

WFP- World Food Programme

FAO- Food and Agriculture Organization

FSIN- Food Security Information Network

BFAP- Bureau for Food and Agriculture Policy

IFPRI- International Food Policy Research Institute

DAFF- Department of Agriculture, Forestry and Fisheries

HLPE- High-level Panel of Experts

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Finally, but not least, I would like to express my deepest gratitude to my family for their generosity, assistance and understanding while I was away from home in pursuit of this degree.

Dedication

To my family and friends, who have been there for me with limitless patience and encouragement throughout this difficult path.

To my mentor, whose counsel and insight moulded not only this thesis but also my development as a scholar.

To the pursuit of knowledge which has sparked my interest and inspired me to explore new frontiers.

May this work, in some tiny way, contribute to the enormous ocean of human understanding.

Abstract

Despite widespread poverty and hunger, there is on-going chronic food and nutrition insecurity throughout Africa. Disruptions in food systems are the result of a combination of long-running conflicts, economic stagnation, price shocks, catastrophic weather occurrences and the degradation of livelihoods and family-based support structures. This research determines vulnerability of food systems to price and climatic shocks in three SACU countries namely Namibia, Botswana and South Africa. The study's specific objectives encompass assessing the influence of rainfall volatility and inflation on food production, exploring the variables shaping the food security model and comparing vulnerability indices across the three countries. The dataset comprises key indicators such as the food production index, inflation, food imports, precipitation, crop production index and livestock production index. The analysis employs Stata to examine time-series data spanning from 2000 to 2022. For the first two objectives, the Vector Error Correction Model (VECM) was employed to examine the causality of variables leading to food system vulnerability. The findings revealed that inflation affects food production in both the short and long run in Namibia, Botswana and South Africa, along with similar impacts of rainfall volatility in Namibia and Botswana. However, rainfall volatility in South Africa does not exhibit a short-run effect on food production. For the second objective, certain variables, particularly the crop production index and livestock production index, emerge as crucial in shaping the food security model across the three countries. Inflation and rainfall volatility affect these variables, thereby influencing overall food production and food security. In addressing the third objective, principal component analysis (PCA) was employed to compare vulnerability indices. The PCA results showed that Botswana has a significant percentage of its vulnerability index classified as "most vulnerable." This suggests that major risks and challenges related to the causes of food insecurity are present in Botswana. According to this vulnerability index, the population of Botswana is far more likely than those in Namibia and South Africa to experience food insecurity. These findings support the preceding explanation in this study that food insecurity is far more prevalent in Botswana than it is in Namibia and South Africa, according to recent statistics. Recommendations stemming from the study include the implementation of climate-resilient agricultural practices, policy harmonisation to address inflation and climatic shocks, and improved access to financing and financial services for small-scale farmers. These findings contribute valuable understanding for policymakers and stakeholders to enhance food system resilience in the face of price and climatic challenges.

Keywords: Food systems, Vulnerability, Inflationary pressures, Rainfall volatility, Food security model

Chapter 1: GENERAL INTRODUCTION

1.1 **Background**

The global food supply network is increasingly becoming vulnerable to systemic risks. Natural, social, political and economic disruptions in a given location can lead to price increases and widespread supply changes globally (Hamilton *et al.*, 2020). Rapidly rising food prices can have immediate, sometimes catastrophic, consequences for the world's poorest people. This is especially true for small producers and people living in urban and peri-urban areas (Benzie and John, 2015). Agricultural production will be even more volatile due to climate change, with the risk of crop failure due to drought, floods and/or particularly hot weather conditions increasing. This, in turn, will make food prices more volatile in international markets, with significant impacts on countries that import a significant portion of their food (Benzie and John, 2015).

Without adaptation, climate change will increase interannual variability and have adverse impacts on the production of essential products such as wheat, rice, and maize in most tropical regions (Benzie and John, 2015). Climate change will directly and indirectly affect the domestic agriculture of many countries, which can lead to price increases in local markets and sometimes food shortages. The most vulnerable countries will be those with agricultural systems that are more sensitive to these direct impacts and generally least able to adapt. Climate change could also increase the volatility of future agricultural commodity markets and exacerbate the impact of price disruptions on import-reliant countries when combined with other underlying causes, including rapid population growth and urbanisation (Benzie and John, 2015).

The actions involved in moving food from farm to table and beyond are called the "food system," which is an integrated system of everything and everyone that affects and is affected by these activities (Parsons, Hawkes and Wells, 2019).

African agricultural systems are extremely fragile and susceptible to shock (AGRA, 2022). The COVID-19 pandemic, the Russia-Ukraine conflict, the EU Green Deal, and climate change are just some of the recent and on-going disruptions currently affecting or having the negative impact on African agricultural systems (Kapuya, 2022). Persistent food crises have been caused by a variety of causes, including economic disruption, climate change, and conflict, long before the COVID-19 pandemic (FAO, 2021). Some people lack access to food in African regions affected by climate change, including the Sahel, the Horn of Africa and southern Africa (Ehui, 2020). The food security situation has worsened in several African countries since Russia invaded Ukraine. Food prices have been rising since the 1960s and will skyrocket in 2022, barring some ups and downs (Refiloe and Jan, 2022).

While many countries in East, West, Middle and Southern Africa import a sizable portion of their wheat, fertiliser, or vegetable oil from Russia and Ukraine, the on-going war has disrupted global commodity markets and trade flows to the continent, driving up already high food costs there (Ehui, 2020). Higher global prices for important commodities have an indirect effect on countries that buy less from the two countries. Today's investors participate in deregulated financial markets to speculate and make profits rather than trade. The sharp price fluctuations are due to the massive entry of speculators into the underlying commodity futures market (Refiloe and Jan, 2022). Fertiliser costs have been rising for several years, with prices in Africa often exceeding the global average. Transportation costs play a key role in rising fertiliser prices in Africa, among other challenges. From January 2020 to December 2021, during the COVID-19 pandemic, nitrogen fertiliser costs increased more than 200 percent, from $250/tonne to $600/tonne (Refiloe and Jan, 2022).

The SACU region is one of the regions in Africa currently experiencing widespread chronic and temporary food insecurity as well as constant threats of acute food insecurity due to the collapse of the food system. The Southern African Customs Union (SACU) is a regional organisation in Southern Africa that fosters economic integration and collaboration among its member countries. The SACU member countries include South Africa, Namibia, Botswana, Eswatini and Lesotho. Rising food insecurity undermines efforts to achieve nutrition and food security goals, including the goals of the Malabo Declaration and the Sustainable Development Goals of eradicating hunger. It also leads to a reversal of development achievements. Therefore, the purpose of this research is to examine the current level of vulnerability of food systems in SACU countries. The 2020–2021 COVID-19 pandemic has reversed two decades of progress in food security and nutrition (May and Mentz-Coetzee, 2021). The unprecedented impacts of the COVID-19 pandemic in South Africa have damaged the ability for regional cooperation to support food security initiatives both locally and internationally, despite the fact that regional cooperation is essential to promote common interests between governments and the development of Africa as a whole.

1.2 **Problem Statement**

Agricultural food production and supply chains are always subject to disruptions such as droughts, floods, armed conflicts and rising food prices (FAO, 2021). Food supply security is compromised by many different factors in an increasingly complex and uncertain world. These include various global change processes (such as population ageing, rapid urbanisation and climate change), unforeseen disruptions (such as natural disasters and financial and political rises) and unpredictable food system responses to these processes and events (Tendall *et al.*, 2015). Longer-term pressures, such as the climate crisis and environmental degradation, are also putting increasing pressure on food systems (FAO, 2021). The COVID-19 pandemic has increased food insecurity and malnutrition globally by making agri-food systems vulnerable to shocks and pressures.

The agricultural sector is increasingly linked to energy and financial markets due to the increase in global food trade (Naylor, 2011; Kalkuhl and Braun, 2016). Analysis of price increases in 2007 and 2008 shows that there are a growing number of factors that can influence the volatility of global food prices. Drought in grain-producing countries, rising energy prices (leading to higher fertiliser and transportation costs), and fluctuations in exchange rates are all thought to contribute to price volatility. Global food prices are higher than they were in the decade before the Russia-Ukraine conflict due to the above disruptions. In many countries already experiencing significant levels of food and nutritional insecurity, food price fluctuations due to the Russia-Ukraine conflict increase the risk of reversing development progress. Achieving food security and nutrition goals becomes more difficult. Food costs have hit a 10-year high and are expected to rise further as global food supply chains are disrupted by conflict (AGRA, 2022).

Rising food prices since 2020 are a result of and have been exacerbated by a number of factors, including logistical challenges caused by COVID-19 combined with high demand for agricultural products after the lifting of lockdown restrictions; high energy and fertiliser prices also reduce farmers' profits; high ocean freight rates (related to energy prices and logistical challenges); climate change and adverse weather conditions in some of the world's major manufacturing regions, leading to layoffs and, more recently (after the outbreak of war in Ukraine), restrictions on trade policies imposed by some of the world's largest exporting countries. Given Russia's importance to wheat, energy and fertiliser exports and Ukraine's importance to grain and oilseed exports, the war in Ukraine has increased pressure on capital markets (FAO, 2022b; FSIN, 2022; SPIAC-B, 2022).

Climate change is expected to lead to increased temperatures and changes in rainfall patterns, as well as an increase in extreme weather events. This poses a significant threat to food security, especially in developing countries that are vulnerable to hunger and malnutrition (Wheeler and von Braun, 2013). Given the harsh climatic conditions in various regions of the world, especially in developing countries, the impact of climate change on food security is a cause for great concern. In fact, the reliance on rain-fed agriculture in many parts of sub-Saharan Africa makes food systems highly sensitive to fluctuations in rainfall (Badolo and Somlanare, 2013). Many studies have used a variety of analytical methods to assess the consequences of climate change on agriculture. Several studies have used crop simulation techniques to assess the direct effects of climate change on specific crops, such as its potential impact on global food production (Wheeler and von Braun, 2013).

One of the regions of Africa that is impacted by shocks to food systems is Southern Africa. Due to the collapse of the food systems, food insecurity and nutrition insecurity in Southern Africa remain unacceptably high, necessitating coordinated measures to create resilience to deal with the numerous and growing shocks that are being faced (SADC, 2022). The extreme climatic events are negatively impacting the residents and economies of Southern Africa. Over the past decade, the region has been experiencing, particularly droughts. Countries in Southern Africa are also affected by global price shocks to food systems, including volatility in commodity markets, increases in energy and fertiliser prices, trade disruptions and the on-going Russia-Ukraine conflict. As households try to stretch their earnings, these shocks are causing food prices to rise dramatically throughout the region and raising food insecurity.

The aforementioned price and climatic shocks have had a significant impact on Southern Africa’s SACU region and despite the urgency of the issue, they have not received enough attention. Only a few studies have looked into how much these shocks have affected the food systems in Namibia, Botswana and South Africa. Some of the studies that tried to determine the vulnerability of food systems in SACU region include: empirical investigation of how the East African Community (EAC) and the Southern African Customs Union, two regional economic communities in Africa, could act as shock absorbers for changes in world output (Brixiová, Meng and Ncube, 2015); assessment of whether SACU countries are self-sufficient in cereals (Sartorius von Bach and Kalundu, 2022); causes of food insecurity in Southern Africa (Abdalla, 2007); forum of food security in Southern Africa (Wiggins, 2003); assessment of food security early warning systems for East and Southern Africa (Braimoh *et al.*, 2018); Lesotho food security issues paper (Mphale and Rwambali, 2003); SACU from 2004 -2019 (SACU, 2019) and promoting agricultural trade to enhance resilience in Africa, (Badiane, Makombe and Bahiigwa, 2014).

This research aims to address this critical gap by examining the intricate dynamics of these countries' food systems, exploring the impact of rainfall volatility and inflation on food production, identifying key variables influencing the food security model and ultimately comparing vulnerability indices. This will contribute to the development of targeted strategies for enhancing resilience and ensuring sustainable food security.

A statistical analysis of one of the SACU countries, South Africa, shows that during the period of drought and recovery, there are marked differences in the evolution of goods and retail prices (DAFF, 2016). In general, in times of scarcity, raw material prices tend to increase. This is expected because drought leads to reduced yields, leading to higher prices. In line with current market dynamics, commodity prices are following expected trends.

In a competitive market, retail prices sometimes react in ways that are contrary to market forces, as indicated by data analysis. During the recovery period, retail prices increased more frequently than during the drought period, suggesting asymmetric price transmission affected by droughts. This means that the impact of the drought on retail prices is uneven and varies depending on market conditions.

As the recovery phase drags on, prices of essential food items remain above necessary levels, contrary to expected price declines. These uneven price responses lead to aggregate welfare losses. This implies that people tend to spend a significant portion of their income on food, even at the best of times when prices are falling. This choice puts them in a financial situation worse than during the drought. People with low incomes are especially affected by rising food prices because they spend the majority of their income on food, about 33 percent, compared with 10 percent for people with higher incomes (BFAP, 2016; Statistics South Africa, 2017). Unfortunately, disadvantaged consumers do not have the financial capacity to cope with these price increases.

It is important to study the vulnerability of food systems in the countries in question as it introduces concepts of resilience and sustainability. There is therefore an urgent need to improve our understanding of vulnerabilities in food systems in order to build resilience, mitigate potential risks, and respond effectively to disruptions in the system. The goal of the research is to determine the vulnerability of food systems to various shocks, including those related to public health, climate change, conflict and other challenges, to facilitate the development of food systems capable of withstanding such pressures in Namibia, Botswana and South Africa.

1.3 **Research Questions**

1. What is the impact of price and rainfall shocks on food production in Namibia, Botswana and South Africa?
2. Which variables significantly influence the food security model in Namibia, Botswana and South Africa and how do they contribute to the vulnerability of food systems, leading to food insecurity in these countries?
3. How do the vulnerability indices in Namibia, Botswana and South Africa differ when assessed using the same indicators?

1.4 **Research Objectives**

The overall objective of the study is to determine the vulnerability of food systems to prices and climatic shocks in selected SACU countries. The specific objectives are:

i. to assess the impact of rainfall volatility and inflation on the food production in Namibia, Botswana and South Africa;

ii. to investigate the impact of certain variables on the food security model in the aforementioned countries, aiming to provide a comprehensive understanding of the factors influencing the vulnerability of food systems and

iii. to compare the vulnerability indices in Namibia, Botswana and South Africa using the same indicators.

1.5 **Hypotheses**

i. H_0: There is no significant impact of rainfall volatility and inflation on food production index in Namibia, Botswana and South Africa.
ii. H_0: The relationship of certain variables and their impact on the food security model in the above-mentioned countries are statistically insignificant.
iii. H_0: There is no significant difference in the overall vulnerability indices in Namibia, South Africa and Botswana.

1.6 **Significance of the Study**

To begin, recognising the vulnerabilities caused by the interplay of price shocks and climatic shocks is critical for developing targeted policies that address the distinct issues that each of these countries faces. Policymakers can customise actions to minimise the specific vulnerabilities that endanger food security in each nation by recognising the distinct susceptibility profiles of Namibia, Botswana and South Africa. This personalised strategy improves the efficiency of policy responses by allocating limited resources where they are most needed, thereby protecting the well-being of local populations.

Second, by emphasising the interconnectedness of economic and environmental challenges, our study contributes to the larger discussion about global food security. The findings are an important resource for the global community because they show how geopolitical events, such as the Russia-Ukraine situation, can induce inflationary pressures in distant areas. This holistic approach underlines the significance of coordinated activities to strengthen global food systems while taking the transnational nature of vulnerabilities into account.

Furthermore, the discovery of long-term vulnerability patterns emphasises the importance of climate resilience solutions. The ability to adapt to changing environmental conditions becomes increasingly important as climate change develops. This study calls for proactive efforts to improve climate resilience within agricultural systems by emphasising the long-term impact of climatic shocks on food supply.

1.7 **Delimitations of the Study**

Complete secondary data for particular years is an issue in the study area. Another drawback is that it is not clear exactly how and how well the data collection process for the already existing secondary data was conducted. This provides difficult information regarding the extent to which issues like a low response rate or respondents' misinterpretations of particular survey questions are having an impact on the results. Sometimes, as with many secondary data sources, this information is easily accessible. However, other secondary data sets do not include this kind of information.

Research on price transmission involves examining prices at different stages of the value chain, including farms, wholesalers and retailers (Moobi, 2019). This was done to identify the factors responsible for the wider profit margins observed among agricultural and retail establishments. The complexity of the food industry makes it difficult to determine exactly which links in the value chain are responsible for widening the price gap between agricultural prices and retail prices (Cutts and Kirsten, 2006). Therefore, this study will only consider commodity prices and retail prices due to the lack of information on wholesale prices. The effectiveness of this method in evaluating the actions of market participants at different levels was confirmed using a similar method (Cutts and Kirsten, 2006).

1.8 **Thesis outline**

The following is the thesis outline: An overview of the research issue is provided in the following section. In the second chapter we present a comprehensive assessment of the pertinent research on the susceptibility of food systems to price and climatic shocks. We outline the empirical process and the data sources in chapter 3 of the thesis. The fourth chapter presents empirical findings, while the final chapter is devoted to the summary.

Chapter 2: LITERATURE REVIEW

2.1 Introduction

A literature review holds significant importance within a thesis, serving as a crucial exploration of existing knowledge. This chapter aims to introduce the current understanding of the sensitivity of food systems to price fluctuations and climatic factors. It summarises key theories, concepts, methodologies for assessing vulnerability to price and climatic shocks and findings from the existing literature. Providing essential context for the research, this review underscores the imperative to comprehend the vulnerability of food systems to external shocks, particularly those related to climate and price variations. This understanding is crucial for developing resilient agricultural practices and ensuring food security in the SACU region.

2.2 Food system vulnerability

Research on vulnerability in food systems emphasises the complex interplay of social, environmental and economic factors. Studies, such as Chodur *et al.* (2018), emphasised the significance of doing a thorough assessment of vulnerability, taking into account not just direct effects on food production but also the entire food supply chain and food environments. The study by Chodur *et al.* (2018) investigated the ways in which food system failures could manifest. Their study highlighted key triggers, including climate change, high prices, contamination, or disease. This insight is particularly relevant as we determine vulnerability in the Southern African Customs Union (SACU) countries—Namibia, Botswana and South Africa.

Food security challenges, as identified by Chodur *et al.* (2018), are exacerbated by high food prices, a phenomenon already posing difficulties for certain populations in affording essential nutrition. The impact of very high food prices is multi-faceted, influencing not only individuals' ability to access a nutritious diet but also contributing to broader societal challenges.

According to Chodur *et al.* (2018), high food prices can be attributed to a range of factors. Production disruptions, driven by climate change or other externalities, can result in decreased supply, directly impacting the availability and affordability of food. Additionally, increases in production, processing, distribution or retail costs, passed on to consumers, further contribute to rising food prices (Chodur *et al.*, 2018). These cost escalations can stem from various sources, including heightened fuel costs in the production and transportation processes.

Chodur *et al.* (2018) employed a top-down methodology, guided by scholarly expertise, existing literature and insights from 36 stakeholder interviews, to construct subtrees utilising fault tree analysis for their research to assess food system vulnerabilities. The results showed the intricate nature of the food system, necessitating the development of 12 subtrees for an in-depth exploration of potential failures. These subtrees explored into aspects of accessibility, encompassing the physical and economic accessibility of vending points within the community. Additionally, the study elucidated that the availability of food was contingent on the efficiency of the food supply chain, with subtrees for processing, wholesale operations, distribution systems and retail centres. Moreover, the research incorporated dimensions of acceptability, considering medical appropriateness, nutritional adequacy, and the cultural acceptability of food.

Their research demonstrated the capability to provide a quantitative assessment of food system failure and recovery, capturing both short-term and long-term hazards within a unified framework. This systems modelling approach pinpointed an extensive array of vulnerability points throughout the food system, emphasising the imperative for interventions at various levels to safeguard communities from the risks of short-term and long-term threats to food security.

2.3 **Price shocks**

Price volatility in global markets can significantly affect the vulnerability of food systems. Price volatility in the agricultural sector has profound implications for food security, particularly impacting vulnerable groups such as smallholder farmers and low-income populations in both rural and urban settings. Price volatility has profound implications for food security, particularly impacting vulnerable groups such as smallholder farmers and low-income populations in both rural and urban settings (FAO, 2010).

The unpredictable fluctuations in prices for essential food commodities create challenges for those who rely heavily on agriculture for their livelihoods (FAO, 2010). Smallholder farmers, already facing numerous challenges, bear the brunt of this volatility as it disrupts income streams and undermines their ability to plan and invest in sustainable agricultural practices. In rural and urban areas with lower income levels, households are disproportionately affected, as they allocate a significant portion of their budget to food expenditures. The negative consequences of price volatility reverberate through the entire food supply chain, exacerbating food insecurity and emphasising the need for effective strategies to mitigate these challenges and build resilience within vulnerable communities.

According to HLPE (2011), the impact of price volatility on food security is significant due to its effects on household incomes and purchasing power. This literature emphasises the importance of analysing how SACU countries, particularly Namibia, Botswana and South Africa, navigate and respond to global price fluctuations. The report outlines three interconnected explanations, addressing short, medium and long-term factors. The first explanation characterizes food price increases as a challenge of "agricultural price volatility," implying that high prices are not likely to persist and are a quasi-natural and constant issue in agricultural markets. The second explanation focuses on international food prices and highlights periodic food crises attributed to the dynamics of agricultural investment. The third explanation views price increases as an early indication of enduring scarcity in agricultural markets.

Despite the serious threat posed by rising international food prices to vulnerable populations in developing countries, the report underscores that domestic food price inflation and volatility are decisive in determining the poverty and food security impacts of international food crises. Price volatility on domestic markets, influenced by both the transmission of international price volatility and purely domestic factors, varies significantly across countries due to factors such as agro-ecological conditions, connectivity, staple food preferences, institutional capacity and macroeconomic health (HLPE, 2011).

The HLPE have highlighted key recommendations for addressing the current challenges in the global food system. Foremost among these is the need to establish a rules-based multilateral trading system that can ensure equitable food access for every nation, presenting a significant challenge for the international community. Additionally, the panel experts the importance of incorporating externalities in the cost of food production, advocating for a comprehensive understanding of the broader impacts associated with food production processes. Furthermore, the promotion of food security strategy programs was underscored as a crucial step in building resilience and ensuring sustainable access to food resources. Lastly, the panel emphasized the significance of investing in agriculture as a strategic measure to enhance productivity and mitigate potential vulnerabilities in the global food supply chain.

2.4 **Climatic Shocks:**

Climate change poses a substantial threat to agriculture and food systems. Climate change exerts an impact on the operations of every element within food systems (von Braun *et al.*, 2023), encompassing a diverse spectrum of participants and their interconnected value-enhancing processes across the production, collection, processing, distribution, consumption and recycling of food items originating from agriculture (including livestock), forestry, fisheries and food industries. This influence extends to the broader economic, societal, and natural contexts within which these activities are situated (von Braun *et al.*, 2023). Understanding how Namibia, Botswana and South Africa adapt to and mitigate the effects of climatic shocks induced by climate change is essential for crafting effective policies and interventions.

von Braun *et al.* (2023) assert in their publication "Science and Innovations for Food Systems Transformation" that climate change will have differentiated effects on food systems in diverse global regions. Key climate variabilities critical to impacting food and nutrition security encompass rising temperatures, shifts in precipitation patterns, and an increased occurrence or heightened intensity of extreme weather events, such as heatwaves, droughts and floods.

In their 2023 publication, von Braun *et al.* underscored the need of addressing vulnerabilities in food systems through a multifaceted approach. They advocated for bolstering national capabilities, particularly in emerging economies like those in the Southern African Customs Union (SACU) region, to enhance implementation strategies. This aligns with the broader research topic on the determination of the vulnerability of food systems to price and climatic shocks in Namibia, Botswana and South Africa. Additionally, the recommendation to develop a clear financial agenda for investments corresponds to the challenges posed by increasing hunger in the SACU countries, emphasising the need to consider the overall 2030 Agenda.

Moreover, the call for better coordination and advancement of institutional innovations aligns with the research focus on understanding vulnerabilities. von Braun *et al.* (2023) highlighted the importance of policy interfaces to enhance implementation at the country level, which resonates with the complexities of policy responses required in the SACU region. The suggested improvements in global-level networked science services are relevant to fostering a comprehensive understanding of vulnerabilities in the food systems of Namibia, Botswana and South Africa.

The need to facilitate stronger synergies of food system actions with key areas, including climate policy, Covid-19-related policies, trade policies and conflict policies, resonates with the interconnected challenges faced by the SACU countries. Addressing these challenges is crucial in mitigating food price inflation and ensuring access to adequate nutrition for populations in the SACU region, aligning with the broader context of the research on vulnerability determination.

2.5 **Regional perspectives**

Although vulnerability is a worldwide issue, geographical differences are important. Badolo and Somlanare (2013) conducted a study investigating the impact of rainfall shocks induced by climate change on food security across sub-Saharan Africa, encompassing 25 countries, which included Botswana and South Africa. Their analysis compared these 25 African nations with 77 developing countries over the period 1960-2008. Employing various statistical techniques such as ordinary least squares (OLS), fixed effects (FE), random effects (RE) and principal component analysis, they observed a negative correlation between rainfall volatility and food supply. This suggests that fluctuations in rainfall negatively affect agricultural production (Badolo and Somlanare, 2013). Their findings highlighted that sub-Saharan countries exhibit greater vulnerability to rainfall volatility compared to other developing nations. Additionally, they discovered that the detrimental impacts of climatic shocks are intensified in countries susceptible to food price shocks. They recommended that African nations adopt agricultural practices that enhance water efficiency, such as investing in improved irrigation systems and crop development. Furthermore, they suggested that the international community provide financial support for stabilisation mechanisms.

Odongo *et al.* (2022) conducted an examination of the dynamics of key climate change indicators and their effects on food prices in Eastern and Southern African countries. With the use of both descriptive and quantitative analysis, the study focused on monthly data from ten different countries from 2001 to 2020. The descriptive analysis showed that throughout the previous 20 years, various events of climate change with increased intensity had become more common in the studied nations. The results of the quantitative study showed that the main causes of food inflation were supply shocks, which were quantified by rainfall amounts and the inflation of imported food prices (Odongo *et al.*, 2022). Subsidies, import inflation and oil prices also turned out to be important factors influencing overall inflation. The research emphasised these nations' ongoing susceptibility to climate change shocks even in the face of macro-level climate change policy actions. The authors suggested using proper irrigation techniques in conjunction with the adoption of renewable energy sources like solar and wind.

According to the World Bank Group (2022), the nations within the Southern Africa Customs Union (SACU), namely Botswana, Eswatini, Lesotho, Namibia and South Africa, face persistent threats from climatic shocks, particularly drought, which present an ongoing risk to lives and livelihoods throughout the subregion. The impact of such climatic shocks tends to disproportionately affect the most economically disadvantaged, leading to exacerbated inequalities and an increased prevalence of poverty. This literature underscores the importance of conducting region-specific assessments and implementing interventions tailored to the socioeconomic and environmental context of Namibia, Botswana and South Africa.

Climate change is one of the major threats to food systems in Namibia. Namibia is the driest sub-Sahara African country and remains one of the most vulnerable countries to the adverse impacts of climate change (WBG, 2021d). Namibia experiences a range of adverse impacts, including increased droughts, unpredictable rainfall and extreme weather events, which have resulted in food insecurity, reduced agricultural productivity and increased vulnerability among rural populations. The agriculture and fishing sectors, two integral components of the food system value chain, are experiencing structural water shortages due to climate change.

Hauwanga (2022) conducted an assessment of the influence of climate change on crop productivity among subsistence farmers in Namibia. The study aimed to explore the effects of climate change on crop production within the Omusati region, utilising data gathered from the Etayi and Elim constituencies. Employing a descriptive research design, the study sought to ascertain the impact of climate change on crop yield productivity. Findings revealed that subsistence farmers encountered prolonged periods of drought and flooding, significantly affecting crop production (Hauwanga, 2022). The study highlighted the vulnerability of subsistence farmers in the Omusati Region due to their limited adaptive strategies to cope with climate change. The author proposed enhancing farmers' understanding of climate change to mitigate its adverse effects on crop production.

A study by Kubik and May (2018) examined the connection between weather shocks and food security in South Africa, particularly as it relates to food prices. With the use of an instrumental variable model, they evaluated the dietary diversity of households by measuring food costs using the standardised precipitation evapotranspiration index (SPEI), a meteorological shock indicator. According to their research, households with low incomes are more vulnerable to price and weather shocks and how they respond to these events depends on how impoverished they are. They also found that household food security is significantly impacted negatively by food prices. For example, a one percent increase in local food prices due to a weather shock resulted in a 2.5 percent fall in the number of food items and a roughly one percent decrease in the number of food groups that households consumed (Kubik and May, 2018). As a recommendation, the authors proposed using self-reported food security measures.

2.6 **Approaches used to determine vulnerability**

2.6.1 Biophysical approach

The biophysical approach assesses the degree of harm inflicted on social and biological systems due to specific environmental pressures. To gauge the economic consequences of climate change on agriculture, one approach might involve investigating the correlations between climate-related variables and agricultural income. Likewise, the impact of climate change on agricultural production can be understood by modelling the connections between climatic factors and crop yields. Researchers also conduct analyses regarding the influence of climate change on human mortality, health outcomes, food and water availability and the state of the environment. Estimations of damage are typically formulated using climate prediction models' projections or estimates (Kurukulasuriya and Mendelsohn, 2007) or by identifying current or future hazards and their frequency to construct sensitivity indicators.

In different academic fields, the relationship to vulnerability has been given distinct terminology. In the field of natural hazards research, we speak of a risk-loss relationship, while epidemiology uses the terms dose-response relationship or exposure-effect relationship. In macroeconomics, we talk about damage functions (Füssel, 2007). When answering questions like “How big is the challenge of climate change? or “Do the costs associated with reducing greenhouse gas emissions exceed the costs associated with the impacts of climate change?” it is often called the "final analysis" (Füssel, 2007).

2.6.2 Socio-economic approach

The socio-economic vulnerability assessment approach places significant emphasis on the socio-economic and political status of specific individuals or social groups (Deressa, 2010). In a given community, differences often exist in factors such as education, gender, wealth, health, access to financial resources, access to technology, social networks (formal and informal), political influence and other personal characteristics (Füssel, 2007). These differences lead to different levels of vulnerability. In this context, vulnerability is considered the initial state or condition of a system before it is exposed to a potentially dangerous event. It is therefore argued that institutional and economic changes have an impact on social vulnerability.

The socio-economic approach mainly revolves around assessing the adaptive capacity of an individual or a community based on its inherent characteristics. To illustrate, a socioeconomic approach was used to assess vulnerability in the coastal lowlands of Vietnam (Füssel, 2007). In this analysis, only socio-economic differences between individuals and social groups are considered when assessing the environmental aspect of Vietnam.

2.6.3 The integrated assessment approach

The integrated assessment approach uses a combination of socioeconomic and physiological methods to assess sensitivity. A good example of this approach is the "hazard-of-place model" (Deressa, 2010). The hazard-of-place model systematically integrates socioeconomic and biophysical factors to determine vulnerability. Another approach, called vulnerability mapping, also incorporates socioeconomic and biophysical factors in the vulnerability assessment process. Many researchers endorse this integrated approach to vulnerability analysis, arguing that climate vulnerability is a product of adaptive capacity, sensitivity and exposure.

The risk-hazard framework in the biophysical approach aligns closely with the concept of "sensitivity" as defined by the IPCC (Deressa, 2010). In contrast, the socioeconomic approach, which considers broader societal developments, is often associated with adaptive capacity. While the IPCC framework defines exposure as external factors, sensitivity and adaptive capacity represent internal factors that are implicitly assumed in the integrated vulnerability assessment framework.

2.6.4 Food security model analysis

The food security model can be used as an approach to assess and analyse food availability, accessibility and utilisation in order to ensure that all individuals, communities and countries have access to adequate, safe and nutritious food in order to live healthy and active lives. This model is crucial for understanding food security dynamics, identifying vulnerabilities and devising effective policies and interventions to address food insecurity. Food security is an essential component of the larger framework of food systems.

2.7 Methodologies used for assessing vulnerability

2.7.1 Vulnerability as expected poverty

In poverty prediction frameworks, vulnerability represents the likelihood that an individual will continue to remain in or fall into poverty in the future (Deressa, 2010). In this context, monetary consumption is used as an indicator of overall well-being, and vulnerability is essentially seen as a precursor to poverty. This method involves estimating the probability that a particular shock or series of shocks will cause household consumption to fall below a specified minimum threshold (such as the poverty line) or, if already below this threshold, will continue to decrease (Chaudhuri, Jalan and Suryahadi, 2002)

Poverty and vulnerability are separate but closely related concepts. In a research project in Vietnam, vulnerability was used as an indicator to predict poverty (Vo, 2018). The study marks a pioneering effort as it introduces the use of standards to assess vulnerability. At the same time, cross-sectional data analysis was extracted from the Vietnam Household Living Standards Survey data set, conducted in 2002, 2004 and 2006. The study examined the level of vulnerability and identified individuals with a higher level of sensitivity (Vo, 2018). Additionally, the study explored the rarely examined relationship between fluctuating poverty levels and vulnerability.

Research results indicated that using reference thresholds to assess vulnerability is considered a more appropriate method to predict poverty in Vietnam than using actual poverty lines. Although vulnerability and poverty rates have generally decreased over time, research has found that vulnerability in one period can lead to poverty in another.

Vulnerability as expected poverty is frequently based on too simple assumptions about future events, economic conditions, and individual behaviour. These simplifications may fail to represent the complexities and changing nature of poverty and vulnerability. As a result, the model's projections and estimates of future poverty risks may be unduly optimistic or pessimistic.

2.7.2 Vulnerability as low expected utility

The concept of vulnerability due to low expected utility (VEU) was introduced by Ligon and Schechter (Mba, Nwosu and Orji, 2021). They define vulnerability as the gap between the satisfaction derived from current levels of consumption and the satisfaction derived from consumption at or above the threshold at which a household is no longer considered vulnerable. Applying this approach to panel data from Bulgaria, Ligon and Schechter found that the effects of risk and poverty on reducing overall well-being are essentially similar (Ligon and Schechter, 2002).

However, the limitation of this approach lies in the difficulty of incorporating an individual's risk preferences, especially since people often lack awareness of their preferences, especially in uncertain situations (Mba, Nwosu and Orji, 2021).

2.7.3 Uninsured exposure to risk and its implications for vulnerability

The uninsured risk vulnerability method involves retrospectively assessing the extent of health impairment resulting from an adverse shock (Mba, Nwosu and Orji, 2021). This method considers the impact of external influences by using panel data to evaluate the resulting variations in consumption. It has been used to study the potential impact of shocks on the Russian economy. In the absence of a risk mitigation strategy, these shocks will lead to a decline in aggregate consumption, resulting in a loss of welfare. This loss can be compared to the cost of purchasing insurance to maintain a household's standard of living.

However, a limitation of this approach is that, due to the lack of comprehensive panel data sets, impact assessments, especially those based on cross-sectional data, can sometimes be biased and are therefore not available. Without panel data, it is impossible to assess the impact of shocks such as floods and droughts on consumption before and after they occur, mainly because of the lack of income data in the household datasets.

2.7.4 Fault tree analysis

A methodical technique to problem-solving, troubleshooting and pinpointing the root cause of a failure is known as a Fault Tree Analysis (FTA) (Chodur *et al.*, 2018). A fault tree analysis is a flexible methodology for root cause analysis since it may be used to investigate a single failure or methodically study a set of components. The merits of using fault tree analysis include mapping the correlation between failures and subsystems; establishing priorities for the system as a whole and implementing changes in product or system design to minimise risks. The model is one one-dimensional. Time is not taken into consideration by FTA, therefore estimating the likelihood of failure is not always attainable.

2.7.5 Principal component analysis

Principal component analysis, or PCA, is a technique for reducing the number of dimensions in large data sets. It does this by condensing a large set of variables into a smaller set that nevertheless retains the majority of the information in the larger set (Liu, Singleton and Arribas-Bel, 2019).

Gbetibouo, Ringler and Hassan (2010) utilised PCA to assess the susceptibility of South African farmers to climate change and variability. They constructed a vulnerability index and examined vulnerability indicators across all nine provinces of the country. Their study identified Limpopo, KwaZulu Natal, and the Eastern Cape as highly vulnerable regions, characterised by densely populated rural areas, many small-scale farmers, reliance on rainfed agriculture and significant land degradation.

The principal component analysis has the advantages of being thorough, straightforward, all-encompassing, realistic and authoritative (Liu, Singleton and Arribas-Bel, 2019). The concept may become more logical if composite-climate-interacts concerns are related to state fragility. The majority of countries can be applied to and used with a country's complete score using simple data. The model can be used to forecast a nation's future fragility. The majority of the selected countries have data that is insufficient, which may have an impact on how accurate the conclusions are (Liu, 2018). When unknowable elements are present, the model is unreliable.

2.7.6 Household vulnerability index

In 2004, the Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN) introduced the Household Vulnerability Index (HVI) as a quantitative measure to assess the level of vulnerability. This measure is rooted in the tradition of sustainable livelihoods and food security in the economic literature (Moret, 2014). HVI seeks to answer two main questions: “How can we identify and support the most vulnerable? and “How can we track and assess the impact of disease outbreaks on household food security over time?”

It is important to note that the Household Vulnerability Index focuses on aspects related to food security and agriculture and therefore may not be suitable for all projects.

2.7.7 Unit root test

When analysing the time series data linked to different systems' components, the unit root test is a statistical technique used to evaluate the susceptibility of food systems. This test is a key tool in econometrics and time series analysis, frequently used to assess a variable's stationarity across time. It aids researchers and policymakers in comprehending the long-term sustainability and stability of food-related aspects like production, accessibility and prices.

A data set covering 25 sub-Saharan African countries over the period 1985–2018 was examined using unit root tests (Affoh *et al.*, 2022). The association between factors associated with climate-related factors such as temperature, rainfall and carbon dioxide emissions and comprehensive aspects of food security, including availability, accessibility and utilisation, was examined. After assessing cross-sectional interdependencies, testing for unit roots and co-integration, estimates were performed using the group's autoregressive distributed lag (ARDL) model.

Panel Group Average (PMG) empirical results showed that rainfall has a long-term and statistically significant positive impact on food availability, access and use (Affoh *et al.*, 2022).

One disadvantage of the unit root test is that it can be sensitive to the size of the sample used for analysis. They may not yield trustworthy results in smaller samples, increasing the likelihood of wrongly concluding that a series is non-stationary when it is, in fact, stationary.

2.7.8 Johansen test

The Johansen Test is a statistical method used to look at the long-term correlations between variables. Although it is not frequently used to explicitly examine the vulnerability of food systems, it can be a useful tool in determining the characteristics that might make such systems more vulnerable.

The method was used to examine how climate and non-climatic factors affected maize output in Bangladesh between 1980 and 2020 (Noorunnahar, Mila and Ila Haque, 2023). The Johansen and Juselius Cointegration (JJC) method was used in the study to verify that there was a long-term relationship between the variables being examined (Noorunnahar, Mila and Ila Haque, 2023). All climatic conditions were found to have a negative impact on maize output, both in the short run and over the long term. On the other hand, non-climatic factors like improvements in agricultural technology had a positive impact on maize production.

While it gives significant information on the long-term relationships between variables, it can be difficult to interpret, particularly for non-statisticians and those unfamiliar with time series analysis. Understanding test results and their implications might be difficult, limiting their accessibility and utility in practical applications.

2.7.9 Vector error correction model

A statistical technique frequently used in econometrics and time series analysis to examine the dynamics and interactions between several variables across time is the vector error correction model (VECM). A VECM can be a useful tool to comprehend and examine the elements leading to the vulnerability of food systems, even though its primary objective is not to directly measure that vulnerability.

To probe the underlying factors contributing to the vulnerability of the Saudi Arabian food system, the VECM (Vector Error Correction Model) method was used (Rahman *et al.*, 2022). The analysis considered variables such as temperature, greenhouse gas (greenhouse gas) emissions, population density, and GDP (gross domestic product). Examining long-run causality suggests a positive causal link between GDP and food demand, implying that an increase in GDP will lead to a sustained increase in food demand. Additionally, the results indicate that Saudi Arabia's population growth and GDP growth are jointly responsible for the increase in total greenhouse gas emissions.

Additionally, an analysis of asymmetric price pass-through and its impact on food security was conducted in India, Peru, Ethiopia, and China using the Vector Error Correction Model technique (VECM). Among these four countries, Ethiopia and Peru show distinct price pass-through patterns, while the results for the other two countries are somewhat less clear (Prakash and Gilbert, 2011). Examination of the Peru case shows growing imbalances and more efficient price transmission during periods of rising world prices. In contrast, Ethiopia shows a different pattern, in which periods of negative bias appear to lead to larger changes than periods of rising international prices.

One of the limitations of VECM models is their data requirements. VECM models are data-intensive, requiring a large amount of time series data to give reliable findings. In practical applications, this can be a severe constraint, especially when dealing with limited or short-term series data. In the absence of historical data, the estimation and interpretation of VECM parameters may become less robust, potentially leading to erroneous conclusions concerning cointegration connections and error correction dynamics.

Due to various compelling factors (e.g. ability to capture both short-term fluctuations and long-term relationships in the system) that make it a good choice among existing methods, the Vector Error Correction Model (VECM) method has been chosen for this study to evaluate the susceptibility of food systems to price and climate shocks in Namibia, Botswana and South Africa. The unit root test and the Johansen test, two crucial statistical tests, will be used in conjunction with the VECM technique. Additionally, Principal Component Analysis (PCA) will be used to assess how vulnerable food systems are to climate and price shocks. The justification for selecting VECM over alternative techniques is as follows:

- With the help of the time-series econometric model VECM, we are able to examine at both short- and long-term correlations between variables. It is critical to consider the interactions between short-term shocks (like price fluctuations) and long-term factors (like climate change) when analysing the vulnerability of food systems. Such dynamics are intended to be captured by VECM.

- The analysis of cointegration among variables is particularly suited for VECM. This is crucial in the context of the vulnerability of food systems because it reveals whether there are consistent, long-term correlations between food prices, climatic variables and other pertinent variables. Cointegration analysis can shed light on the system's fundamental structure.

- The error correction mechanism incorporated into VECM makes it possible to consider deviations from long-term equilibrium. Understanding how the system reacts to shocks and how it gradually corrects itself is crucial when researching vulnerabilities. The VECM word for error correction describes this adjusting procedure.

2.8 **Conceptual framework**

The conceptual framework proposed for this study was adapted from the wheel concept from the previous reports by High Level Panel of Experts on Food Security and Nutrition (HLPE, 2017). The food supply chains and food environments will be the two main pillars of the conceptual framework presented in this section. A portion of the variables in this study will be obtained from the basic conceptual framework of food systems on Figure 1, while others will be investigated for their potential to have a significant influence on the very structure and dynamics of this conceptual framework.

This framework provides an in-depth approach for understanding the interconnected components of food supply chains and the larger food environment, which includes elements like production, distribution and accessibility. By utilising this framework, researchers can systematically examine how price and weather shocks impact every stage of the food supply chain, as well as how these effects disseminate throughout the food environment and ultimately influence food security outcomes.

Food systems represent a continuous spectrum and attempts to classify them into distinct categories should not overshadow the significant diversity present within each category (HLPE, 2017). Different levels of analysis, ranging from the global scale to individual households, can be applied to study food systems. Even within a single country, multiple food systems can coexist simultaneously (HLPE, 2017). While interconnected with neighbouring systems such as energy, ecology and healthcare, the concept of food systems maintains well-defined boundaries. External disruptions, whether related to the economy, the environment or public health, can also impact the food system (Von Braun *et al.*, 2020). The typology introduced in this study examines both food supply chains and food environments, aiming to identify the challenges confronting the food system and to propose context-specific solutions and recommendations for each unique situation.

Figure 1: Wheel concept on food supply chains and food environments
Source: Adapted from (HLPE, 2017)

The food supply chain is made up of the people and systems in charge of transferring food from its production phase to consumption and waste disposal (HLPE, 2017). The numerous operations within this chain include processing, storage, packaging, production, distribution, retail and market operations. Food security is directly impacted when any of these supply chain components fail. At every stage of the food supply chain, these influencing factors have an impact on a wide range of organisations, from big to small-scale operations(HLPE, 2017). At a particular link in the chain, the choices made by actors can have an effect on others. Aside from the nutritional value of the food that is produced and processed, these decisions also have an impact on the four food security and nutrition dimensions of availability, access, utilisation and stability (Downs and Fanzo, 2016).

Aspects like food accessibility, price, nutritional value and diversity are all directly impacted by agriculture and food production systems (HLPE, 2017). Food systems can become more resilient to outside shocks by increasing diversity and integrating production systems at various scales. These include the farm, community, landscape and larger levels. This results in a more diverse food supply, which eventually improves the standard and variety of diets.

The phrase "food environment" refers to a variety of possibilities, circumstances and political, physical, economic and sociological contexts that influence people's dietary habits (HLPE, 2017). Food environment acts as a conduit for customers to obtain food from the larger food supply chain. For some communities, the variety of locally produced and bought foods accessible in close-by marketplaces makes up their food environment. Others see the local, regional and global markets as being more integrated into the food environment (Parsons, Hawkes and Wells, 2019). Physical and financial accessibility of food, advertising and information, food promotion, as well as food quality and safety, are key components of the food environment. These components affect consumers' food choices, food acceptability and dietary patterns.

Food system disruptions can result in a shortage of food availability, which translates to an inadequate supply of food on a local or global level (HLPE, 2017). The main element affecting the physical accessibility of food is the built environment that includes the presence of sites of access to food and appropriate infrastructure to get there. Depending on the situation, a person's lack of access to food (both physically and financially) can raise their risk of malnutrition, obesity and diet related NCDs.

Dietary decisions are impacted by the lack of a specific food (Herforth and Ahmed, 2015). Food availability and consumption are linked in a two-way relationship where one influences the other (Herforth and Ahmed, 2015). The availability of nutritious foods and their consumption are consistently positively correlated, according to studies looking at how food availability affects dietary intake.

Food affordability depends on the cost of food based on household income and purchasing power. Changes in the relative costs of food products can lead to adjustments in consumption patterns. In low- and lower-middle-income countries (LMICs), a significant portion of household income is often allocated to food expenditures. Affordability is influenced by factors such as food prices, taxes and subsidies, which in turn determine food choices. The relationship between changes in food prices and household consumption indicates that consumption is negatively impacted by changes in food prices. Household purchasing power and welfare are impacted by food price levels and volatility. Food security is undoubtedly under risk, especially for low-income people who have few reserves and financial resources to weather tough times (Mitchell, 2008). Cost shocks today have an impact on how affordable food is.

While reduced prices will affect producers, higher prices will impair consumer welfare. Additionally, fluctuating food prices breed uncertainty throughout the whole food system, deterring investment and ultimately harming the Food Security and Nutrition (FSN) Network over time (Gitz and Meybeck, 2013). Being a net importer of commodities like food and energy, Botswana is concerned about the rising world costs. Domestic markets receive a portion of the rises in these commodities' global pricing (Tlhalefang and Galebotswe, 2013).

Food safety includes all potential risks, presented as immediate or long-term threats that could harm the health of consumers. Food safety covers the effects of food on human health. This includes strategies for preventing illness due to the presence of harmful bacteria or chemicals in food that can occur at any stage, from production, processing, storage, transportation and distribution to home food handling (HLPE, 2017). It also refers to the guidelines and regulations put in place to safeguard customers from tainted goods (HLPE, 2017). Food safety and the Food Security and Nutrition (FSN) Network are closely related, as hazardous food can lead to a cycle of illnesses like diarrhoea and malnutrition that disproportionately affects the weaker members of society (such as children, the elderly and the ill).

Food quality includes the characteristics of a food item that determine its worthiness and whether a customer finds it to be acceptable or attractive (HLPE, 2017). This comprises the following: food production or processing methods, texture, colour, size, flavour shape, colour, and food composition. This encompasses both the food's positive and negative qualities, such as its origin, colour, flavour, texture and technique of preparation. Negative qualities include spoiling, contamination with dirt, discolouration and off-odours. Changes in consumer tastes or food price can have an impact on consumption patterns through changes in food quality and safety.

Failure of the food system is both a market failure and a moral failing because the world is capable of preventing it (Rocha, 2007). Foods are promoted to consumers by retail establishments and markets through a variety of strategies, such as advertising, branding and social marketing.

The review of previous research guides the methodology and approach of the present study. This research aims to enhance understanding of the factors affecting vulnerability in Namibia, Botswana, and South Africa by employing various methods, including econometric models like the VECM model, statistical techniques like PCA, and the food security model analysis approach. Additionally, variables obtained from the wheel concept framework will be utilised to achieve an assessment of food system vulnerability.

In conclusion, the literature review demonstrates the critical role of past research in shaping the current study on the vulnerability of food systems in SACU countries. By integrating insights from previous studies and adopting methodological approaches proven effective in past research, this study aims to contribute to the advancement of knowledge in this field and inform policy interventions aimed at enhancing food security in the region.

Chapter 3: METHODOLOGY

3.1 Introduction

A thesis' methodology chapter is essential since it ensures that the research process is well-organised, systematic and rigorous. This chapter goes through the various tools and methodologies used. A crucial step in doing research is outlining a methodology since it demonstrates how the research will be conducted and how its results will be determined. The methods for estimating the long- and short-run equilibrium relationships between climate and price variables are also outlined in this chapter.

3.2 Study area

The Southern African Customs Union (SACU) comprises five countries located in the southern region of Africa: Botswana, Lesotho, Namibia, South Africa and Eswatini, as illustrated in Figure 19.This area is distinguished by a wide variety of agro-ecological zones, from arid and semi-arid regions to regions with considerable rainfall. The SACU member states' economies rely heavily on agriculture, with many small-scale farmers engaging in subsistence farming. The primary crops raised in the area include maize, sorghum, millet, wheat, as well as a number of different vegetables and fruits. Moreover, raising livestock, especially goats and cattle, is crucial to the region's food sources.

However, due to the effects of climate change and rising global food price volatility, there is growing worry about how vulnerable food systems are in this region to price and climatic shocks. Climate fluctuations and alterations, such as elevated temperatures, reduced precipitation and a heightened occurrence of extreme weather occurrences, can lead to crop loss, diminished harvests and elevated food costs. The region is also heavily dependent on imported food, which makes it susceptible to fluctuations in world food prices. Food self-sufficiency is under strain from a variety of factors, including shifting income levels, the Russia-Ukraine war, pandemics, meteorological circumstances and the trade environment (Sartorius von Bach and Kalundu, 2022). In addition, the region's high rates of poverty and inequality make food systems more vulnerable because many residents cannot afford to seek alternate food sources during times of scarcity or buy food at higher prices. In some regions of the region, this has resulted in food instability and malnutrition.

Figure 2: SACU countries
Source: (Tralac, 2019)

The study area of the research encompasses three countries in SACU, namely Namibia, Botswana and South Africa. Each of these countries has distinct climatic, geographic and socioeconomic factors that might influence how vulnerable their food systems are to price and climate shocks. Hence, it is crucial to consider the unique circumstances and difficulties each member state has while doing research on the SACU's food systems' susceptibility to price and climatic shocks. Data accessibility was the criterion that was used to choose those three countries. Eswatini and Lesotho were excluded due to a lack of data because the study's variables were acquired from secondary sources.

3.2.1 Namibia

Namibia, situated in southern Africa, is a nation with a low population density, covering an expansive landmass exceeding 823,000 square kilometres (Mendelson *et al.*, 2003). Despite its large size, much of the land in Namibia is arid, with the Namib Desert covering much of the country's western coast. With a population of only about 2.5 million (as of 2020) and a 1,500-km-long South Atlantic coastline, Namibia is a geographically vast nation (World Bank, 2022). Namibia, sharing its borders with South Africa, Botswana, Zambia, and Angola, stands as the driest nation in Sub-Saharan Africa. Abundant in mineral wealth, it boasts the extraction of valuable resources like diamonds and uranium. Namibia ranks among the least densely populated countries globally, with a population density of approximately 3 individuals per square kilometre. The nation's populace reflects a variety of ethnicities, including Ovambo, Kavango, Herero, Damara, Nama, San and Baster. Although English serves as the official language, many Namibians communicate in native languages such as Oshiwambo, Otjiherero and Nama. Namibia possesses a relatively youthful population, with roughly two-thirds of its inhabitants aged below 30 years.

Namibia's land is home to a variety of ecosystems, including savannas, grasslands, deserts and wetlands. These ecosystems are home to a wide variety of plant and animal species, many of which are unique to Namibia. For example, the Welwitschia plant is found only in the Namib Desert and is considered a living fossil due to its longevity and unique appearance. The land in Namibia is also important to the country's economy, with agriculture, mining and tourism being major industries. Approximately 70 percent of Namibia's population is involved in agriculture, and the country is known for its production of beef, dairy products and crops such as maize and millet (MIT, 2020).

Today, Namibia's food systems are diverse and complex, reflecting the country's varied ecological zones and cultural traditions. Smallholder farmers and pastoralists continue to play a crucial role in food production, while larger-scale commercial agriculture is also important. The country is known for its production of livestock, including cattle, goats and sheep, as well as for its cultivation of crops such as maize, sorghum and millet. However, Namibia's food systems still face significant challenges, including climate change, soil degradation and unequal access to land and resources.

Food security remains a critical concern in Namibia, with a significant section of the population vulnerable to food shortages and hunger. In 2021, an estimated 26 percent or more of the population faced severe food insecurity, which was classified as IPC Phase 3, indicating an urgent need for help (IPC, 2022). Furthermore, 4 percent of the population was in an emergency, classified as IPC Phase 4, signifying an exceedingly critical situation. Additionally, 35 percent of the population was affected by moderate food insecurity (IPC Phase 2), indicating a high level of vulnerability. While not currently facing severe food insecurity, the remaining 35 percent of the population was classified as food secure to mildly food insecure (IPC Phase 1)(IPC, 2022). These numbers highlight the complex challenges that remain in resolving food security issues across Namibia's diverse regions, needing comprehensive efforts and measures to secure adequate, nutritious food for all the people.

In Namibia, one of the significant impacts of climate change on the food system is reduced agricultural productivity. Changing weather conditions have disrupted established planting and harvesting schedules, leading to lower yields of the country's major food crops, including corn, millet, and sorghum. According to FAO research, Namibia's corn output could decrease by up to 50% by 2030 due to the effects of climate change (FAO, 2018b). The decline in crop yields has also had a negative effect on food security in Namibia, with an estimated 35% of the population currently experiencing food insecurity (WFP, 2021a).

Namibia endured a national drought in 2019 and the majority of its areas are still recuperating. For the past seven years, there has been a drought in some areas, notably Kunene region. The effects of the drought had an influence on livestock and crop production. Due to a lack of sufficient grazing land and drinking water, farmers used to experience high rates of animal mortality in their traditional livestock production techniques. Farmers are gradually restocking their herds, but cattle diseases are still a problem. In addition, crop insect infestations, wildfires and human-wildlife confrontations in areas like Kavango East, Kavango West, or Omusati regions also reduced food production, leaving people with insufficient supplies (IPC, 2020).

Another effect of climate change on the food systems in Namibia is degradation of natural resources. The increasing frequency and intensity of droughts have led to the depletion of water resources, resulting in reduced crop yields and livestock productivity (FAO, 2018b). The degradation of natural resources has also led to increased soil erosion and desertification, further reducing the productivity of agricultural lands. The adverse effects of climate change on food systems in Namibia are not limited to crop production. The changing climate has also had a significant impact on livestock production. Livestock production is a critical source of food and income for many rural households. The increasing temperatures and reduced water availability have led to reduced grazing areas and livestock productivity, resulting in decreased food security and income.

The ND-GAIN index evaluates and ranks countries based on a score that measures their vulnerability to climate change. The index also quantifies vulnerabilities relative to other global challenges and assesses their readiness to build resilience (WBG, 2021c). A country's score decreases as its vulnerability increases, while its score increases as its readiness to build resilience improves. The index's central goal is to help businesses and the government sector more accurately identify vulnerabilities and preparedness. This aims to improve investment prioritisation to respond more effectively to global challenges. According to the ND-GAIN Index 2020, Namibia is considered vulnerable to the consequences of climate change, ranking 104 out of 181 countries. This susceptibility is believed to be due to a combination of political, geographical, and social factors (WBG, 2021c).

Food prices in Namibia are influenced by a variety of factors, including global commodity prices, transportation costs, and local supply and demand. The country relies on imports to meet its food needs, particularly for staple foods such as maize, wheat and rice. These imported goods are very sensitive to changes in world prices and these fluctuations can significantly affect domestic prices.

Data from the Namibian Statistics Authority shows that in August 2021, the Consumer Price Index (CPI) for food and non-alcoholic beverages in Namibia increased by 5.5% compared to the same month last year (NSA, 2021). Fish and seafood prices surged by 9.2%, while bread and cereal prices increased by a notable 12.5%. The cost of meat also saw an uptick of 4.4%. In contrast, fruit and vegetable prices decreased by 4.1% and 4.8%, respectively. The annual inflation rate saw a significant increase, from 4.0% in July 2021 to 6.8% in July 2022 (NSA, 2022).

In comparison to the preceding month, the monthly inflation rate remained constant at 1.0%. The transportation sector contributed 3.0 percentage points, and the food and non-alcoholic beverage category added 1.5 percentage points to the overall annual inflation rate (NSA, 2022). The inflation rates across different zones in July 2022, Zone 2 (Khomas) exhibited the highest annual inflation rate, standing at 7.7 percent. On the other hand, Zone 1, encompassing Kavango East, Kavango West, Kunene, Ohangwena, Omusati, Oshana, Oshikoto, Otjozondjupa and Zambezi, registered the lowest annual inflation rate at 6.2 percent. Following closely was Zone 3, covering Hardap, Omaheke, //Karas and Erongo, with an annual inflation rate of 6.6 percent. Zones 2 and 3 both reported monthly inflation rates of 1.1 percent, which were the highest, while Zone 1 recorded the lowest monthly inflation rate at 0.7 percent.

The key drivers of the annual inflation rate in July 2022 were the transportation sector (contributing 3.0 percentage points), food and non-alcoholic beverages (contributing 1.5 percentage points), alcoholic beverages and tobacco (contributing 0.7 percentage points), housing, water, electricity, gas and other fuels (contributing 0.5 percentage points), as well as furnishing household equipment and regular house maintenance (each contributing 0.4 percentage points) (NSA, 2022).

The category of food and non-alcoholic beverages, constituting 16.5 percent of the CPI basket, witnessed inflation in July 2022, with an annualised rate of 8.4 percent, compared to 6.1 percent in the preceding year. In terms of monthly variations, the prices in this category rose by 0.8 percent during the observed period, in contrast to the 0.7 percent increase in the previous month (NSA, 2022).

There are several causes of high food prices in Namibia, including:

- Drought and climate change: Namibia is a country with a dry climate, and droughts can significantly reduce crop yields. Climate change has exacerbated this problem, leading to more frequent and severe droughts that can affect food production and drive-up prices.
- Transportation costs: Namibia is a vast country with a small population, which makes transportation of goods expensive. Most food items are imported from neighbouring countries such as South Africa, which adds to the cost of food.

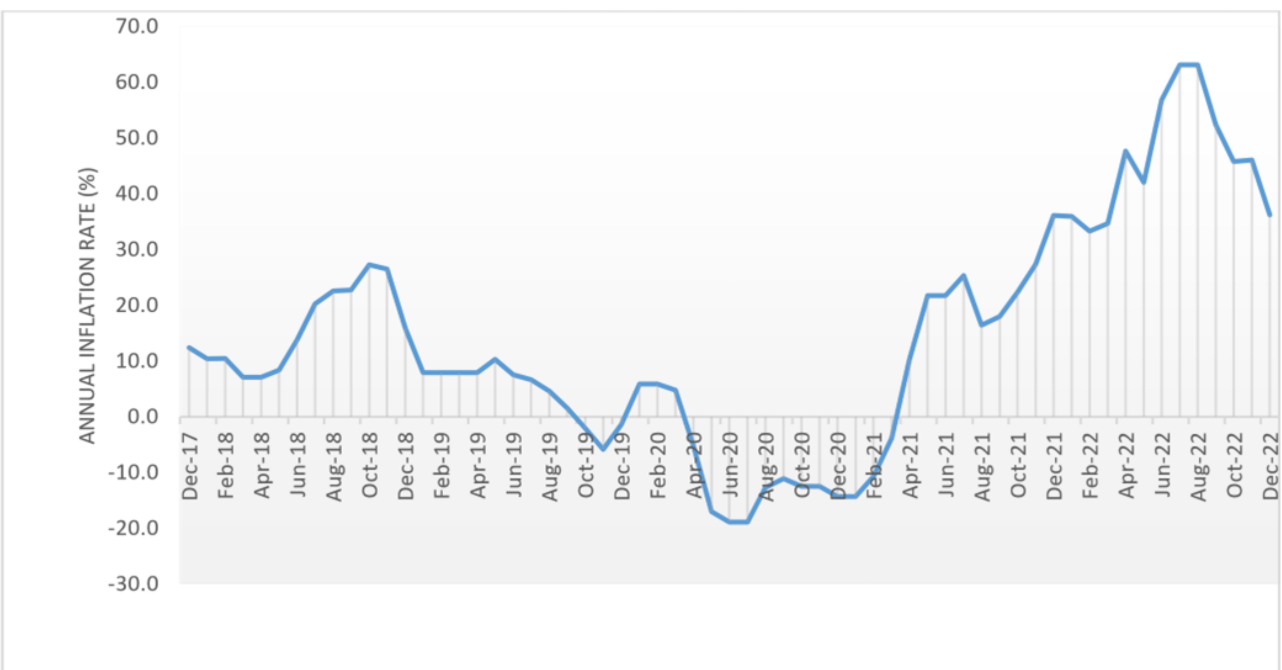

Figure 3: Annual inflation rate in Namibia for petrol/diesel (December 2017- December 2022)
Source: (NSA, 2022)

- Weak infrastructure: Poor road and transport infrastructure in rural areas can make it difficult to transport goods, resulting in higher prices for consumers.
- Market dominance by a few large players: A few large companies dominate the food retail market in Namibia, which can limit competition and result in higher prices for consumers.
- Currency fluctuations: Namibia's economy is closely tied to the South African economy and fluctuations in the exchange rate between the Namibian dollar and the South African rand can affect the price of imported goods, including food.
- Limited agricultural production: Agriculture in Namibia is often limited by factors such as water scarcity, lack of access to inputs and limited infrastructure. This can limit the production of food, leading to higher prices for consumers.

The COVID-19 pandemic has had a significant impact on food prices in Namibia, both directly and indirectly. Here are some of the ways that the pandemic has affected food prices in Namibia:

- Supply chain disruptions: The COVID-19 pandemic disrupted global supply chains, making it harder for Namibia to import some types of food. This has led to shortages of certain products, which in turn has driven up prices.
- Increased demand for staple foods: As the pandemic has led to economic hardships for many people in Namibia, there has been an increased demand for staple foods such as maize meal and rice. This increased demand has also contributed to higher prices for these products.
- Reduced agricultural production: The pandemic negatively affected agricultural production in Namibia, as restrictions on movement and other measures have made it difficult for farmers to access markets and inputs. This has led to lower production of some crops, which has also contributed to higher prices.
- Exchange rate fluctuations: The pandemic has caused instability in global financial markets, which has led to fluctuations in the value of currencies, including the Namibian dollar. This has affected the cost of importing food and contributed to higher prices for some products.
- Government policies: The Namibian government has implemented policies to mitigate the impact of the pandemic on the economy, including measures to support small businesses and provide social assistance to vulnerable households. However, these policies have also increased government spending, which could lead to inflation and higher food prices in the long term.

3.2.2 Botswana

Botswana is a landlocked country located in southern Africa. It shares its borders with South Africa to the south and southeast, Namibia to the west and north and Zimbabwe to the northeast. Botswana's population, numbering 2,346,179, is predominantly situated in the eastern regions of the country (Statistics Botswana, 2022) residents living in cities, it has a relatively small rural population. The diamond industry, which contributes around one-third of the country's GDP, dominates the economy. The tourism industry, cattle production and copper-nickel mining are further significant industries. The Okavango Delta, a UNESCO World Heritage Site, is one of the national parks and wildlife reserves of Botswana. Visitors from all over the world flock to these locations to observe a variety of animals, such as elephants, lions, giraffes and hippos. Despite its many successes, the nation still has a number of problems, notably in rural areas, where there is a significant level of income disparity, unemployment and poverty.

With a total size of 581,730 square kilometres, 45.63 percent of Botswana has been designated as an agricultural producing zone Although though it accounts for less than 2 percent of GDP, many residents who run subsistence farms rely on agriculture for their living. Livestock, especially cattle, which are significant to the cultural and economic character of Botswana, are the main emphasis of the country's agricultural economy. In recent times, the Botswana government has been actively engaged in diversifying the country's agricultural production and promoting the cultivation of crops like sorghum, maize and beans.

Cereals are the predominant crops in the agricultural sub-sector. However, challenges such as low productivity, unreliable water sources, and the presence of deserts and poor-quality soils covering roughly 70 percent of Botswana's land area hinder the sector's growth. In 2018, the national cereal production amounted to 36,284 metric tonnes (MT), which marked an increase from 23,470 MT recorded in 2017 (ITA, 2022). Sorghum, maize and millet are Botswana's three main cereal producers. Furthermore, Botswana's agricultural output in 2017 included 2,348 metric tonnes (MT) of beans, 145 MT of groundnuts and 78 MT of sunflowers (ITA, 2022). The Strategic Grain Reserve is managed by the Botswana Agricultural Marketing Board (BAMB), which is a key element in guaranteeing the nation's food security (SGR).

The country's food systems are vulnerable to economic shocks, such as the global economic recession, which can result in a decline in diamond prices, affecting the purchasing power of households (World Bank, 2022). Reduced purchasing power can lead to food insecurity, as households may not afford adequate and nutritious food. Economic shocks can also impact the supply of food in Botswana as food producers may experience difficulties accessing finance and inputs, leading to reduced productivity and food availability (UNDP, 2012).

Botswana's food systems face susceptibility to climate shocks, influenced by several factors such as the nation's semi-arid climate, reliance on rain-dependent agriculture and a scarcity of infrastructure for irrigation and water storage (WBG, 2021b). The issue is exacerbated by climate change, which results in more frequent and severe occurrences of droughts, floods, and other extreme weather events. This vulnerability poses a substantial threat to both food security and the livelihoods of rural communities in the country.

Botswana, positioned at the 94th spot among 181 nations in the 2019 ND-GAIN Index, is regarded as notably susceptible to the consequences of climate change, owing to a combination of political, geographical and social factors (World Bank, 2014). Botswana and Namibia are two of the world's most drought-prone countries (Syed and Gomez, 2022). Because of its short rainy season, Botswana is semi-arid. In the south, the dry season lasts from April to October, whereas in the north, where rainfall totals are often higher, it lasts from April to November. The entire nation experiences scorching summers with typical peaks of roughly 26 °C (78.8 °f) (Botswana Vulnerability Assessment Committee, 2019).

The country's food systems are vulnerable to climatic shocks, such as droughts and floods, which have been prevalent in recent years (Moseley, 2016; WBG, 2021b). Droughts can lead to crop failures, reduced livestock productivity, and water scarcity, which can result in food shortages, increased food prices and malnutrition (Federal Ministry of Environment (FMEnv.), 2018; SADRI, 2021). Floods, on the other hand, can lead to crop destruction and infrastructure damage, reducing food availability and access (OCHA, 2000; Statistics Bostwana, 2016; Maripe and Maundeni, 2020).

Botswana's food systems are additionally at risk from health-related shocks, such as pandemics, which have the potential to disrupt food supply chains, impede food production, and result in reduced food accessibility (Kasimba *et al.*, 2019; Leepile, 2022). The food systems in Botswana have been influenced by the COVID-19 pandemic, leading to interruptions in food supply chains and elevated food prices stemming from decreased production and transportation (UN Botswana, 2020; UNICEF, 2022). Many people lost their jobs due to the COVID-19 pandemic, leading to increased food insecurity. This has been exacerbated by the disruptions to food supply chains and the higher cost of food items.

Botswana is vulnerable to price shocks, which can lead to food insecurity, malnutrition and poverty (Kgathi, Ngwenya and Wilk, 2007; IMF, 2022; WBG, 2022). The country heavily relies on food imports and changes in global food prices can have significant impacts on the country's food security. Factors contributing to price shocks:

- Global food prices: Botswana is a net food importer and changes in global food prices can have significant impacts on the country's food security (BIDPA, 2008). High global food prices can increase the cost of food imports, leading to higher food prices in the country.
- Currency fluctuations: Botswana's monetary unit, the Pula, is fixed to a currency basket that incorporates the South African Rand. Fluctuations in the exchange rate can impact the cost of food imports, leading to changes in food prices (IMF, 2022).
- Trade policies: Botswana's food systems are also vulnerable to changes in trade policies. For instance, trade restrictions such as tariffs and quotas can limit the supply of food, leading to higher prices.
- Weather conditions: Weather conditions such as droughts and floods can impact food production, leading to reduced food supply and higher prices (SADRI, 2021).

Recent data indicates that when compared to Namibia and South Africa, Botswana experiences a higher prevalence of food insecurity. The proportion of individuals in Botswana facing severe food insecurity has notably risen, surging from 20.16 percent in 2021 to 26.16 percent in 2022 (Xinhua, 2023). Conversely, based on statistics from 2021, approximately 11.6 percent of South Africa's population, which corresponds to roughly 2.1 million individuals, indicated experiencing hunger (Stats SA, 2023).

Between September and December 2022, Namibia faced a significant food insecurity crisis. The latest IPC Acute Food Insecurity Analysis conducted in September 2022 classified a total of 367,000 individuals, equivalent to 14 percent of the population, as being in a crisis or worse (IPC Phase 3 or above) (IPC, 2022). Nevertheless, it is anticipated that within Namibia, a considerable segment of the populace, estimated at approximately 22 percent, which corresponds to around 579,000 individuals, encountered heightened levels of food insecurity categorized as IPC 3 or higher during the timeframe spanning from July to September 2023 (ReliefWeb, 2023).

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3.2.3 South Africa

At the southernmost point of the African continent is the nation of South Africa. It boasts a diversified population of over 60 million (Stats SA, 2021) people with a diversity of ethnic groups and dialects, including 11 official languages. 30.75 million people, or about 51.1 percent of the population, are female (Stats SA, 2021). With influences from native Africans, the Dutch, the British and other European colonial settlers, the nation has a rich cultural legacy. Agriculture, mining, manufacturing and services all make up South Africa's diverse economy. It is regarded as having one of Africa's most advanced economies. Yet, the nation continues to suffer serious economic difficulties, such as high unemployment and income inequality.

South Africa is a nation rich in diversity. It offers an incredible variety of vegetation kinds, biodiversity, temperatures and soil types in addition to a strong cultural diversity. The nation can be divided into many agricultural zones, and there are many different types of farming practises, from intensive crop production in high-rainfall areas throughout the winter and summer to cattle ranching in the bushveld and sheep farming in the more desert parts. Agro industries are thriving, and the nation's 40 000 farms provide 80 percent of its food, making up the competitive commercial food sector. As a result, the agri-food sector contributes roughly 5 percent of GDP and 14 percent of all exports of goods, despite the fact that its share of overall GDP is constantly dropping (FAO *et al.*, 2022).

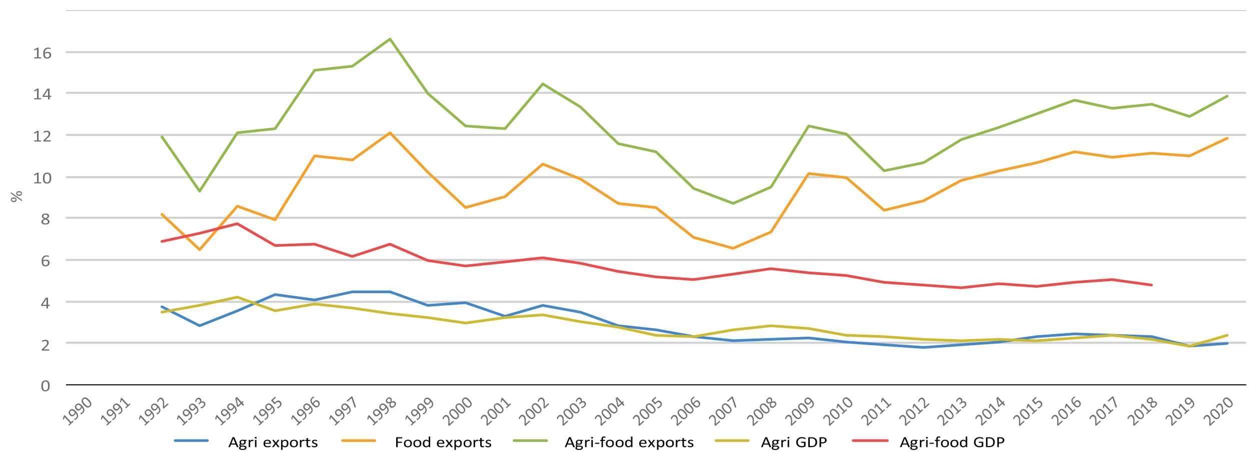

Figure 4: Contribution of the agri-food sector in South Africa
Source: (FAO *et al.*, 2022)

South Africa's well-developed policies and initiatives pertaining to food, nutrition, and agriculture enable the nation to uphold a positive food balance. Nevertheless, the outcomes within its food system raise concerns. These results encompass critical issues such as severe malnutrition and over-nutrition, unsustainable agricultural practices, significant geographical disparities, and a gradual shift towards inclusivity. Moreover, the legacy of apartheid compounds historical injustices stemming from the colonial era, further entrenching the country within its food system.

Statistics South Africa's General Household Survey (GHS) data shed light on the situation of food insecurity and hunger in South Africa for the year 2021 (Stats SA, 2023). According to the conclusions of this survey, the majority of the population, specifically 80 percent, could be classified as food secure, showing constant access to adequate and nutritious food. However, the survey also stated that a sizable section of the population experienced varying degrees of food insecurity. Approximately 15 percent of respondents experienced moderate food insecurity, indicating difficulties in obtaining a consistent food supply. Furthermore, a troubling 6 percent of people were suffering from extreme food insecurity, signifying a perilous condition in which food was scarce and unreliable.

The food systems in South Africa face significant susceptibility to climate change impacts, chiefly stemming from their reliance on rain-dependent agriculture (Masipa, 2017; WBG, 2021a; Mutengwa, Mnkeni and Kondwakwenda, 2023). Droughts, floods and other extreme weather events have already affected the country's agricultural productivity and food security (WFP, 2021b). South Africa has, on average, received an annual rainfall of 600 mm since 1904. Furthermore, climate change is anticipated to compound pre-existing difficulties, including land degradation, soil erosion, water scarcity, as well as pest and disease issues (Nhemachena *et al.*, 2020; WFP, 2021b).

Droughts present a significant concern for South Africa's food systems, as they have the potential to result in substantial crop failures and livestock losses. As per the Department of Agriculture, Land Reform, and Rural Development, the nation underwent a severe drought period from 2015 to 2018, which led to agricultural sector losses exceeding R16 billion (Moobi, 2019). South Africa has grappled with recurrent droughts over the years, with 2015 experiencing the lowest recorded rainfall levels since 1904, totalling only 403 mm (Moobi, 2019). These drought events consistently exert adverse effects on tangible agricultural production, with maize being the most adversely affected during the most recent 2015 drought. Given that 83% of white maize cultivation relies on rain-dependent agriculture, climatic anomalies such as droughts can have a substantial impact on the white maize market in South Africa (Moobi, 2019).

The agricultural, way of life and towns have all been significantly impacted by the drought. In the Western Cape alone, an estimated R5.9 billion in agricultural economic loss was forecast, with a subsequent loss of 30 000 jobs and a 13–20% decline in exports (WWF, 2018). This was brought on by decreased agricultural output and new income losses as a result of a fall in export volumes. The drought also had a significant impact on food prices and availability, particularly for maize, which is a staple food in South Africa (Moobi, 2019). The country's GDP has been declining since 2018 with the decline in agricultural output cited as the primary cause (Mthethwa and Wale Zegeye, 2022). This phenomenon poses a threat to all aspects of food insecurity and worsens the setback caused by food insecurity in a nation already dealing with the aforementioned problem. Drought intervals vary widely, which has an impact on crop productivity.

Floods are another climate-related risk to South Africa's food systems that contribute to the vulnerability indices. Flooding can damage crops, destroy infrastructure, and lead to soil erosion and nutrient depletion. In addition, floods can increase the risk of waterborne diseases, which can affect food safety and public health. In 2022, the country experienced severe flooding in the provinces of KwaZulu-Natal and Eastern Cape, which caused significant damage to infrastructure and crops (FAO, 2022a).

The floods in KwaZulu-Natal (KZN), South Africa, had repercussions on food distribution. The extensive damage caused by the heavy rainfall in KZN had a profound impact on the agricultural sector. Farms bore the brunt of the destruction, with critical infrastructure such as buildings and irrigation systems suffering significant damage. Furthermore, access roads to farms and the transportation of goods were also adversely affected (Baloyi, 2022). The disruptions in the supply chain resulted from reduced activity at ports and on the roads, as well as the permanent closure of factories and other businesses due to a lack of insurance or financial support, leading to interruptions in the flow of food and consumer goods within the economy (Burger, 2022).

Studies revealed that South Africa's provinces exhibit a broad range of variation in terms of the socioeconomic and environmental situations. Throughout the last century, instances of extreme events such as droughts and floods have been most frequent in the coastal provinces of Kwazulu-Natal, the Eastern Cape, and the Western Cape. By the year 2050, the desert regions of the Northern Cape, as well as the semi-arid regions of the Free State and Mpumalanga, are anticipated to encounter the most significant temperature rises. Simultaneously, Gauteng and the North West provinces are projected to undergo the most substantial alterations in terms of rainfall patterns (Gbetibouo, Ringler and Hassan, 2010).

Anticipated climate change is poised to heighten the occurrence and dispersion of pests and diseases, as well as foodborne illnesses, with the potential to exert a substantial influence on agricultural output and the safety of food products (FAO, 2015). For example, the fall armyworm, a pest that can cause significant damage to maize crops, was first detected in South Africa in 2017 and has since spread to other parts of the country (ARC, 2017). Furthermore, climate change is projected to elevate the vulnerability to plant diseases like wheat rust and citrus greening, which have the potential to impact the yield of these crucial crops.

Several factors contribute to price shocks in the South African food system, including climate change, input prices, currency fluctuations and trade policies (Pereira *et al.*, 2014). Climate change has resulted in more frequent and severe droughts, floods, and other extreme weather events, which have disrupted food production and supply chains. Input prices, such as fuel, fertiliser and seed, have increased significantly, making farming more expensive and reducing the profitability of smallholder farmers. Currency fluctuations, especially the depreciation of the South African rand, have led to higher import costs for food products, especially for staple foods like maize and wheat. Finally, trade policies, such as export restrictions, have reduced the availability of food products on the domestic market, leading to higher prices.

On the production side, most people in South Africa had to deal with disruptions like rising input costs, restricted access to some inputs, labour shortages, transportation issues, COVID-19 deaths, agricultural advisors (private and government) not visiting farms, an increase in theft, uncertainty and anxiety (Wegerif, 2022). Russia is a significant source market for South Africa, which imports between 70 and 80 percent of the fertilisers used in its agricultural sector. Russia is the third-largest market for fertiliser imports after Saudi Arabia and China (Holtz, 2022). The local agriculture industry in South Africa has issued warnings due to the influence on crop yields and, eventually, the price of food for consumers. The suspension of Russian exports and the sharp rise in Brent crude oil prices had a major impact on fertiliser, fuel and agrochemical prices in South Africa. Transporting food into and to the South becomes more expensive as a result of the war's tightening of supplies and rising prices, notably those for gasoline.

When compared to January 2021, the cost of primary agricultural inputs has already soared by more than 100% in South Africa (Glenneis, 2022). The local-scale food production in the aforementioned SACU nations was impacted by COVID-19, which had an impact on food supply, affordability and accessibility. Reduced availability to labour and inputs caused a pause in agricultural activities, which impacted the quality and quantity of products, slowed down operations and raised the cost of production. Despite the fact that the agriculture sector was categorised as critical, the COVID-19 shock interfered with timely delivery and access to crucial agricultural inputs (Nhemachena and Murwisi, 2020).

The COVID-19 pandemic had a significant impact on food prices in South Africa (Hart *et al.*, 2022; Stats SA, 2022b). The lockdowns and restrictions led to disruptions in supply chains, which resulted in shortages and higher prices for certain foods. The pandemic also resulted in a loss of income for many households, which made it difficult for them to afford food.

South Africa's currency, the rand, has been volatile over the years. When the rand devalues, it becomes more expensive to import food, which can lead to higher prices. For example, in 2016, the rand weakened significantly, which led to a sharp increase in the price of imported foods. Trade restrictions can also have an impact on food prices in South Africa. For example, in 2020, the country imposed restrictions on exports of certain food items, such as rice, in an attempt to ensure food security for its citizens (Lubinga, 2020). However, this led to higher prices for these items on the domestic market. The price of fuel is an significant factor in the cost of food production and distribution (Van der Heijden and Tsedu, 2008). When fuel prices increase, the cost of transporting food increases and as a results food prices increase (Stats SA, 2022a). For example, in July 2021, the price of fuel in South Africa increased significantly, which resulted in higher food prices.

After a gradual increase through much of 2022, the inflation rate for food and non-alcoholic beverages in South Africa reached 13.6% year-on-year in February 2023 (BFAP, 2023). The primary contributors were meat and fish (3.9 percentage points), bread and cereals (3.8 percentage points), dairy and eggs (1.8 percentage points) and vegetables (1.2 percentage points) (BFAP, 2023). Many of the factors influencing food inflation in South Africa throughout 2022 are not unique to the nation. Globally elevated prices for agricultural commodities, as well as heightened energy costs, impact the prices of inputs such as fuel and fertilisers.

The on-going conflict between Russia and Ukraine, both significant exporters of grains and oilseeds, is a primary factor contributing to the sustained high prices. Load shedding has already imposed substantial costs throughout the value chain. If load shedding is reduced, these costs might decrease; however, the prevailing consensus suggests that load shedding is likely to remain at relatively elevated levels for the foreseeable future. This will continue to be a key factor in keeping food prices in South Africa elevated for an extended period (BFAP, 2023). In February 2023, South African food inflation was lower than that of the European Union but higher than in Kenya, Zambia, Brazil, the United States and China. While food inflation rates in China, the United States and Brazil have declined since January 2023, rates in Kenya, the European Union and South Africa have risen.

3.3 **Sample selection**

The research sample size comprises three SACU countries: Namibia, Botswana and South Africa, for the purpose of the study. National datasets were utilised to obtain information on key variables, ensuring a broad representation of the population in each country. The sample aimed to be representative of the overall population, considering both urban and rural settings, various agro-ecological zones and economic strata.

The availability and accessibility of data were the practical criteria used to choose these countries. Access to thorough and trustworthy data on the various components of the food system, such as supply chains and food surroundings, is necessary for doing research. Compared to other SACU countries, these countries have greater data infrastructure and documentation.

Another reason for selecting these countries was their geographical diversity within the SACU region. These countries cover different climate zones, ranging from arid and semi-arid in Namibia and Botswana to temperate and Mediterranean in parts of South Africa. This diversity allows us to assess the impact of price and climatic shocks on food systems in varied environmental conditions.

3.4 Data collection and data variables

The study relied on secondary data collected from a diverse range of national web resources. These sources included the World Bank, Statistics Botswana, FAOSTAT, Stats SA and the Namibia Statistics Agency. The data collection encompassed several critical variables, such as the food production index, inflation rate, food imports, crop production index, livestock production index and the level of rainfall variability.

3.5 Data Analysis

In this study, the relationship between the dependent variable(s) and the independent variables was analysed and investigated using Stata. To determine how changes in the independent variables affect the dependent variable(s), regression analyses were conducted using Stata. In these analyses, coefficients were estimated, statistical significance was evaluated, goodness-of-fit was assessed and conclusions regarding the direction and strength of the investigated relationships were reached. To make the results easier to grasp, the quantitative data was summarised in tables and graphs.

The study will make use of unit root tests, Johansen tests, VECM and PCA. These techniques provide a comprehensive, rigorous, and practical method for evaluating and managing food system vulnerability to price and climatic shocks. These techniques also provide vital insights into the dynamics of food systems, allowing us to make educated decisions and execute effective risk-mitigation strategies.

The study relies on the food production index, a fundamental metric used to assess and examine food production patterns. In this investigation, the food production index plays a critical role. A sustainable food system (SFS) ensures the provision of nourishment and food security for all while upholding the foundations of society, politics, and the environment for the well-being of future generations (FAO, 2018a). A country's capacity to provide sustenance for its population, either independently via domestic food production or in collaboration with imported food, is termed food production (Jeder, Hattab and Frija, 2020). Typically, the most crucial quantitative aspect of a nation's overall food security pertains to its domestic food production (Jeder, Hattab and Frija, 2020). A nation's food system faces instability when there is a scarcity of food, leading to hunger and potentially even famine.

The food production index (FPI) is an important metric for determining how vulnerable food systems are to shocks. It assesses changes in a country's overall production of food items over time. The FPI includes agricultural and livestock output and is an important instrument for analysing a country's ability to meet food demands and resist external shocks. The food production index provides useful insights into the following areas when estimating the vulnerability of food systems:

- Self-Sufficiency: The FPI represents a country's level of food production self-sufficiency. A high FPI suggests that the country generates a considerable amount of its food needs domestically, minimising reliance on imports and making the food system more resilient to global market shocks.
- Agricultural production: FPI changes represent changes in agricultural production throughout time. Higher FPI scores indicate that food production technologies are more efficient and effective. Increased productivity makes the food system more resilient to a variety of issues, such as climate change and price changes.

- Climate resistance: The FPI contributes to the assessment of the food system's resistance to climate shocks. Countries with a diverse agricultural base and flexible farming practises are better suited to recover from extreme weather events like droughts and floods while maintaining food production levels, minimising vulnerability to climate-related disruptions.

- Stability of the food supply chain: A strong FPI contributes to a stable food supply chain. It guarantees that food commodities flow consistently from production to distribution, lowering the risk of shortages and price volatility during shocks or crises.

- Price Stability: A high FPI helps to keep food prices stable within a country. A steady and robust food production base can help to reduce price volatility, making critical foods more inexpensive and available to the public, especially during times of crisis.

- Food Security: The FPI is closely related to a country's food security situation. Higher FPI values generally correspond to improved food security, as they indicate a country's ability to produce enough food to meet its population's nutritional demands.

- Economic Resilience: A robust food production system helps to maintain overall economic stability. A high FPI can improve a country's economic resilience to external shocks by reducing the demand for costly food imports and strengthening the agricultural sector.

A nation heavily reliant on domestic food production faces significant challenges when a major climate event impacts its agricultural output. This scenario can lead to a shortage of food, prompting the country to augment its food reserves by increasing reliance on global food imports to meet the demands of its population.

However, if global food prices are already elevated due to scarcities in other regions or market fluctuations, the importing nation incurs higher expenses for food. This, in turn, results in a subsequent surge in domestic food prices, posing economic challenges for the population. The vulnerability of countries to fluctuations in food costs exacerbates the adverse consequences of climate-induced disruptions on food availability (Dell, Jones and Olken, 2012).

In such situations, the combination of reduced food supplies due to weather-related disruptions and higher food prices intensifies food insecurity in affected regions. This, in turn, leads to social discontent, hunger, and malnutrition as individuals struggle to access sufficient and affordable food. Additionally, nations heavily dependent on food imports may face economic difficulties due to rising costs, potentially jeopardizing overall economic stability.

The empirical outline will be used as a representation of a food system for food production. The model can be articulated as follows:

$FPI = F(INF, FIM, PREC, CPI, LPI)$……………………………………………………………………………………………………..... (1)

In log terms equation 1 becomes

$In\ FPI = \alpha_0 + \alpha_1 In\ INF_t + \alpha_2 In\ FIM_t + \alpha_3 In\ PREC_t + \alpha_4 In\ CPI_t + \alpha_5\ In\ LPI_t + \varepsilon_t$ …………………………………….... (2)

Where

FPI = Food production index

INF = Inflation (%)

FIM = Food imports (% of merchandise imports)

PREC = Precipitation (mm)

CPI = Crop production index

LPI = Livestock production index

α_0, α_1, α_2, α_3, α_4, α_5….. = coefficient of explanatory variables

ε = error term t= time series

Tests and statistical methods are employed to scrutinise the food security model, which aids in assessing the susceptibility of food systems to price fluctuations and climatic perturbations. The time series dataset underwent scrutiny via assessments like the unit root test, co-integration examination, and the error correction model (ECM) methodology.

3.5.1 Unit root test

The stationarity of each variable in this food security model is assessed using the unit root test. To make sure that the variables used in the analysis do not show erroneous correlations, it is crucial to verify the stationarity of the time series data prior to estimating the econometric model. The time series properties of the variables used in this study are determined using the standard Augmented Dickey-Fuller (ADF) test. The ADF test is administered by:

$Y_t = \alpha_1 + \alpha_2 Y_{t-1} + \mu_t \quad t = 1,2,3$……………………………………………………………………………………………… (3)

Where

Y_t = variable y at time t

Y_{t-1} = variable y at legged t

The equation is subtracted by Yt-1 for easy unit root testing and equation (4) is formulated:

$\Delta Y_t = \beta_1 + \beta_2 \Delta Y_{t-1} + \varepsilon_t$ and $\beta_2 = \rho - 1$ (4)

The hypothesis for unit root testing is:

H_0:β_2=0; y_t is non-stationary

H_1:β_2<0; y_t is stationary.

3.5.2 Johansen test

To ascertain co-integration within time series data, the Johansen test is employed. Its primary objective is to investigate the enduring connection between the dependent and explanatory variables in the food security model. This test is executed when all the variables indicate co-integration at the same level and it encompasses two likelihood-ratio tests known as the maximum eigenvalue test and the trace test.

The initial Johansen test juxtaposes the alternative hypothesis of co-integration for both test statistics against the null hypothesis, which postulates a lack of co-integration. These two tests differ in their alternative hypotheses. The trace test's null hypothesis posits that "r" exceeds the number of co-integration vectors within the model, while the eigenvalue test's null hypothesis suggests that "r" equals the number of co-integration vectors within the model. The number of co-integration vectors might encompass a fixed value, include a trend term or incorporate both, akin to the unit root test. This approach is then applied to delve into the enduring impacts of the explanatory factors on the food security model.

The Johansen test is used in the analysis to assess the impact of rainfall volatility and inflation on food production in Namibia, Botswana and South Africa.

3.5.3 Vector error correction model

The Vector Error Correction Model (VECM) approach is employed when co-integration is observed among the variables in Vector Autoregressive Models (VAR). According to the Granger representation theorem, an Error Correction Term (ECT) is a key feature that characterizes the short-term adjustments or corrections of co-integrated variables towards their equilibrium values. The ECT comprises the lagged first differences of the endogenous variables along with a co-integrating equation.

The calculation of the Error Correction Term (ECT) can be performed through the Restricted Vector Autoregression (VAR) technique. Specifically, by modelling variations in the dependent variables as a function of the extent of imbalance in the co-integrated relationship (indicated by the ECT) and changes in other explanatory variables, the Error Correction Model (ECM) can be constructed. This approach aims to illustrate the model's short-term adaptation rate. Equation (5) outlines the resulting error correction model:

$\Delta In\ FPI = \alpha_0 + \alpha_1 \Delta In\ INF_t + \alpha_2 \Delta In\ FIM_t + \alpha_3 \Delta In\ RV_t + \alpha_4\ \Delta In\ CPI_t + \alpha_5 \Delta In\ LPI_t + \alpha_6 ECT_{t-1}\, \delta_t$………… (5)

Where

ECT_{t-1} represents the Error Correction term and δ denotes the random error term

The VECM is utilised in the analysis to assess the impact of rainfall volatility and inflation on food production, as well as to investigate the influence of certain variables on the food security model in Namibia, Botswana and South Africa. This aims to enhance understanding of the factors influencing the vulnerability of food systems.

3.5.4 Principal component analysis

Principal Component Analysis (PCA) is used to rank vulnerability across all three countries. This reliable statistical method is a standard procedure for systematically assessing and quantifying susceptibility to different stressors, including but not limited to, price and climatic shocks. The degree of susceptibility increases with the percentage of the PCA score that is higher.

3.6 Ethical considerations

A primary ethical concern was making sure that all data gathered from online secondary sources was accessible to the general public and did not violate anyone's or any organisation's privacy or confidentiality. In order to protect sensitive information and respect the ethical ideal of informed consent, this action was crucial. The research's dedication to data quality and reliability was another crucial feature. It was ethically required to make every attempt to confirm the reliability of the used online secondary sources. Using reliable and current data, this strategy attempted to uphold the research's validity and integrity.

Chapter 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter contains the findings of a data analysis procedure along with explanations of the findings. In order to comprehend the dynamics of food system vulnerability in the setting of Namibia, Botswana, and South Africa, the study includes a number of critical variables that are essential. These variables include the food production index, inflation, food imports, rainfall volatility, the crop and livestock production indices and imports of food. The conclusions drawn from these variables are crucial in illuminating the general level of food security and resilience in the investigated countries. Tables and graphs are used to display the results.

The initial two specific objectives entail a comprehensive analysis to evaluate the influence of various variables on both short-term and long-term dynamics. This necessitates the implementation of a vector error correction model (VECM), beginning with critical assessments such as unit root tests, Johansen tests and the utilisation of the restricted vector autoregression (VAR) method. Furthermore, the third objective calls for an in-depth investigation employing principal component analysis (PCA) to examine the overall vulnerability indices within each country from 2000 to 2022. In this context, particular emphasis is placed on the percentage representation of these vulnerability indices to further enhance the comprehensive assessment.

4.2 Results of the first two specific objectives

4.2.1 Namibia

The ADF unit root test results in Table 1 provide important insight into the stationarity qualities of the variables investigated in this study. At the specified level of significance, the t-statistic values for all variables, including the food production index (FPI), crop production index (CPI), livestock production index (LPI), inflation (INF), rainfall volatility (RV) and food imports (FIM), were found to be statistically significant. This means that when these variables were examined at their original levels, they showed non-stationarity.

The crucial conclusion, however, occurs when these factors are translated into their initial differences. Hence, the findings suggest that all first-order series are integrated, I (1). The fact that they were stable after differencing implies that their levels have a unit root, which indicates a time-dependent trend or random walk behaviour. This transformation emphasises the value of differencing as a tool for achieving stationarity, which allows for more reliable statistical analyses and modelling.

In essence, these findings emphasise the importance of considering initial differences when working with these variables in order to prevent non-stationarity difficulties, which can lead to misleading correlations and unreliable conclusions. The distinct distinction between non-stationary behaviour in levels and stationary behaviour in initial differences emphasises the significance of suitable data pre-treatment procedures in time series analysis and econometric modelling.

Table 1: Unit root test results for testing stationarity in the food security model variables in Namibia

Variable	Test statistic	5% Critical value	First difference	Lags	Optimal lag selection
InFPI	0.222	-1.950	-8.272	1	3
InCPI	1.642	-1.950	-4.667	1	3
InLPI	-0.950	-1.950	-4.811	1	1
InRV	-0.413	-1.950	-7.710	1	0
InINF	-1.323	-1.950	-3.649	1	2
InFIM	-0.111	-1.950	-4.263	1	1

The co-integration results in Table 2, which are based on the Trace statistic and the Max-eigenvalue, show the presence of three co-integrating equations at the 5 percent significant level. These data clearly imply that the variables under investigation are actually co-integrated. Furthermore, the results of both tests confirm the existence of a statistically significant long-run link between the food production index and the explanatory factors at the 1 percent significance level.

This co-integration implies that changes in the explanatory variables have a long-term effect on the food production index. It indicates that any deviations from the co-integrating equations' established equilibrium connection will eventually be adjusted, returning the system to its long-term equilibrium. These findings have important implications for understanding the dynamics of food production and how they relate to the explanatory variables. The substantial co-integration findings highlight the need of addressing these variables collectively in order to fully understand the underlying mechanisms impacting food production patterns.

Table 2: Johansen Co-integration test results for long-term variable relationships in food supply chains and environments

Hypothesised number of CE(S)	Trace statistic	0.05 Critical Value	Max-Eigen Statistic	0.05 Critical Value
0	174.4327	94.15	82.2715	39.37
1	92.1612	68.52	38.0392	33.46
2	54.1220	47.21	29.0835	27.07
3	25.0385**	29.68	12.7031	20.97

Notes: Trace test indicates 3 co-integrating equations at the 5% level.

Maxi-eigenvalue indicates 3 co-integrating equations at the 5% level.

***denotes rejection of null hypothesis at 5% level.*

The observed correlation between the dependent and independent variables in the study substantiates the hypothesis that persistent concerns related to price fluctuations and climatic changes may exert a significant influence on the food systems of Namibia. As a result, it is essential to take proactive steps to reduce susceptibility and implement changes that can maintain and improve food security in Namibia. Notably, INF (inflation) and FIM (food import) are two variables included in Table 3 that are predicted to show negative trends. Inflationary pressures can have a notably significant impact on food output.

Inflation (INF) can cause a drop in demand for goods, including food. Consumers may delay purchases in anticipation of additional price cuts, resulting in a drop in sales. This decrease in demand may lead to poorer revenues for food producers. Lower profitability can subsequently lead to lower investments in agriculture, technology and infrastructure, all of which are required to maintain and increase food production levels. Inflation can also disrupt supply chains by causing enterprises to shrink operations when demand falls. This interruption may have an impact on the timely supply of food-production inputs such as fertilisers, insecticides and machinery. If these supplies are delayed or limited, agricultural output will suffer, affecting food production.

Due to inflation, farmers' revenue decreases as the prices they obtain for their produce fall. This can put them in financial straits, thereby reducing their motivation and capacity to invest in their farms. Furthermore, decreasing profitability may result in labour cuts, reducing employment possibilities in the agricultural sector. Profit reductions owing to inflation may result in cost-cutting measures that jeopardise quality control requirements in food production. Furthermore, with less capital available, fewer resources may be committed to research and development for refining agricultural processes and producing new crop varieties.

Inflation has a notable impact on the cost of agricultural inputs, for example, fertilisers. In Namibia, where fertiliser production is not domestically produced, the increasing trend in fertiliser prices poses a significant challenge for farmers, hindering their access to these essential inputs and consequently affecting food production. This observation aligns with the findings reported by the Integrated Food Security Phase Classification (2022).

The negative sign in the co-integration equation suggests that food imports (FIM) and food production (FPI) in Namibia have an inverse relationship. This means that when the volume of food imports rises, Namibia's food output is projected to fall. In other words, increased reliance on food imports is linked to a probable decrease in domestic food production. Food imports can supplement or replace domestic food production. If food imports are complimentary, they may meet additional demand beyond what home production can supply, hence increasing food availability. Increased food imports, on the other hand, may displace domestic production, reducing incentives for local farmers to produce. Concerns about food security might arise from an over-reliance on food imports. A country's reliance on imports makes it vulnerable to supply disruptions, price volatility and geopolitical concerns that might affect food availability in the domestic market.

As a result, Namibia's ability to sustain its food supply locally is decreased, leaving the country reliant on outside sources to meet its food needs.

This vulnerability is exacerbated by the presence of two crucial elements:

- Price Shocks: Any fluctuations in imported food costs can have a direct impact on Namibia's food security. If prices rise, the country's resources and budget may be strained, potentially leading to food scarcity or affordability concerns.

- Climatic Shocks: The climatic circumstances of importing countries can have a considerable impact on their own food production and, as a result, their ability to export. If exporting countries encounter bad weather events, such as droughts or floods, their food output may be disrupted, resulting in supply shortages and higher prices in Namibia.

Crop production (CPI) and livestock production (LPI) play a pivotal role in positively shaping food systems. They contribute to food security, economic growth, nutrition and overall sustainability in Namibia. Crop and livestock production both contribute to a varied range of food products that meet a population's nutritional demands. Crops provide staples such as grains, fruits, and vegetables and livestock provide protein in the form of meat, dairy and eggs. This variety promotes a well-balanced diet and reduces reliance on a small number of food choices. Adequate agricultural and livestock production helps to maintain steady food availability, lowering the danger of food shortages and ensuring that communities have access to the food they require. A diverse crop and livestock mix can provide resilience in the face of single component failure owing to variables such as climate variability or disease outbreaks.

The results of co-integration show that differences in rainfall volatility (RV) effect food production and vice versa. This means that historical and on-going patterns of rainfall variability in Namibia impact food production techniques and agricultural practises. This result aligns perfectly with findings reported by the World Bank Group (2021) that historically, rainfall in Namibia has been extremely variable. The existence of a long-term equilibrium link between rainfall volatility and food production in Namibia shows the presence of a long-term equilibrium relationship between these variables. This could imply that variations in rainfall volatility have a long-term impact on the country's food production trends.

Table 3: Results of Co-integrating equation for rainfall volatility and inflation's impact on food production index

Co-integration equation			*Log likelihood 79.6308*		
Normalised co-integration coefficients					
FPI	CPI	LPI	RV	INF	FIM
1.000000	.3409688***	.6695325***	-.0796343***	-.3347639***	-1.12491***

****Significant at 1% level of significance*

The specific goal of Namibia being vulnerable to rainfall volatility (RV) is consistent with the notion that the country's agriculture is primarily reliant on rainfall and its fluctuation can pose obstacles to food supply. This vulnerability stems from Namibia's dry and semi-arid climates, in which water resources are scarce and unpredictable. As a result, prolonged periods of drought or unusually heavy rainfall can have a considerable influence on agricultural activity and food production. The negative coefficient indicates that higher rainfall volatility (RV) in Table 3 has a long-term detrimental impact on Namibian food output. This study shows that the country's food security is determined by its ability to manage and adapt to variations in rainfall patterns over long periods of time. Given the enormous influence of rainfall instability on food production, Namibia's food systems should be strengthened.

The co-integration equation reveals that the long-term stability of Namibia's food systems is under threat. Therefore, using a VAR model when the variables show co-integration and reporting their first differences would be improper, as this strategy would result in a large loss of crucial information on the interconnectedness within the dataset (Baffoe-Bonnie and Gyapong, 2012). The use of an error correction model is preferable to employing a VAR model when the variables show co-integration in their initial differences.

This analysis incorporates an error correction term derived from the VECM findings presented in Table 4. When the coefficient value of this error correction term exceeds one (ECTt-1 > 1), it indicates that short-term deviations rapidly converge towards long-term equilibrium. Conversely, if the coefficient value in the error correction term falls below one (ECTt-1 < 1), the error correction term demonstrates a gradual return to long-term equilibrium.

Table 4: Results for estimated VECM short-run dynamics of the food security model variables

Variables	Coefficient	t-statistic	Prob.
Constant	-0.533941	-1.37539	0.8841
$\Delta In\ FPI_{t-1}$	2.406487	4.29201	0.2317
$\Delta In\ CPI_{t-1}$	3.575691	5.68971	0.0073***
$\Delta In\ LPI_{t-1}$	1.391101	4.80628	0.0062***
$\Delta In\ RV_{t-1}$	-.305410	6.75419	0.0291**
$\Delta In\ INF_{t-1}$	-.763850	-1.06861	0.0146**

$\Delta In\ FIM_{t-1}$	-1.068615	-1.64832	0.0003**
FPI_{t-1}	-.93842	-0.63079	0.0023***
R-squared	0.779358		
F-statistic	5.764281		

****Significant at 1% level of significance; **Significant at 5% level of significance*

The provided results indicate that the ECTt-1 coefficient exhibits statistical significance at the 1% level and is negative, implying that the series do not diverge significantly over time and that long-term convergence is achieved. When the variables diverge from equilibrium, the negative sign of the coefficient -0.93842 implies that there is a process that drives them back to equilibrium. A negative error correction coefficient, such as -0.93842, indicates that Namibian food production is sensitive to shocks and disturbances. When adverse events have an influence on food production, the system tends to make corrective adjustments to lessen the consequences of those shocks, contributing to its resilience against vulnerabilities.

The magnitude of the coefficient (-.93842) indicates how quickly food production adjusts to its equilibrium level. This indicates that when food production is subjected to shocks that induce deviations from equilibrium, it tends to recover rather rapidly. An R-squared score of 0.77935 indicates that the independent variables in the ECM explain roughly 77.93 percent of the variability in the dependent variable, food production. This shows that the variables have an extremely strong association. The high R-squared value indicates that the model fits the observed data points perfectly. The model's predictions closely match the dependent variable's actual values.

The results also indicate robust short-term relationships between the food security model and the explanatory variables, as represented by the proxy food production index. As an example, in the short term, inflation has a negative impact on the food production index. Specifically, in Namibia, a 1 percent increase in inflation (ΔIn INF_t-1) is associated with a 0.763850 percent decrease in the food production index (ΔIn FPI_t-1). This observation underscores the detrimental effect of inflation on the country's food output. Moreover, ΔIn INF_t-1 is statistically significant at a 5 percent confidence level, signifying that food production in Namibia is susceptible to the influence of inflation.

In the short run, a 1 percent increase in rainfall volatility $\Delta In\ RV_{t-1}$ is expected to result in a 0.305410 percent drop in food output $\Delta In\ INF_{t-1}$. This implies that even minor variations in rainfall variability can have a significant negative impact on food production, underlining agricultural systems' susceptibility to climate change. Addressing this link is critical for ensuring food security, particularly during times of greater climatic uncertainty, in order to maintain stable food production levels and minimise the potentially negative effects of increased rainfall variability.

Table 5: Summary of autocorrelation testing for food security model variables in the VEC model.

Lag	chi2	Df	Prob > chi2
1	44.5380	36	0.15544
2	28.9574	36	0.79139

Based on the Lagrange-multiplier test in Table 5, we fail to reject the null hypothesis that there is no autocorrelation. The Prob > chi2 values are greater than the usual threshold of 0.05, which indicates a lack of strong statistical evidence supporting the presence of autocorrelation in the dataset. The absence of autocorrelation, or the null hypothesis, in this situation denotes that the errors or residuals in the model do not show any observable association over various time intervals. Any discernible connections between the residuals are most likely caused by stochastic fluctuations rather than by any systematic, meaningful pattern, according to the observation of test statistics that are in line with the null hypothesis.

Table 6: Summary of results for testing normality- Jarque-Bera test in the VEC model

Equation	chi2	Df	Prob > chi2
D_FPI	0.226	2	0.89309
D_CPI	4.032	2	0.13318
D_LPI	0.377	2	0.82836
D_RV	1.848	2	0.39686
D_INF	2.343	2	0.30983
D_FIM	5.632	2	0.05985
All	14.459	12	0.27238

The Jarque-Bera test in Table 6 yields a p-value of 0.27238, indicating that the data does not deviate significantly from a normal distribution, lending credence to the assumption of normality.

4.2.2 Botswana

In the case of Botswana, as indicated in Table 7, the t-statistic values for all variables, which encompass the food production index (FPI), crop production index (CPI), livestock production index (LPI), inflation (INF), rainfall volatility (RV) and food imports (FIM), do not exhibit statistical significance at the designated level of significance. The observation that the null hypothesis of non-stationarity cannot be refuted at any significant level suggests that all the variable series are characterized by non-stationarity and contain a unit root.

However, when we analyse the t-statistic values after taking the first difference, they reveal significance. As a result, we can reject the null hypothesis of non-stationarity, indicating that all variables are inherently stationary. This discovery suggests that all series possess a first-order integration, which is denoted as I (1). The challenge of spurious regression arises due to the integrated nature of the model's variables, all of which are I (1). Consequently, the following sections will focus on the results of the co-integration study, beginning with the determination of the optimal lag duration using the VAR lag order selection criterion.

Subsequent to the unit root test, the Johansen co-integration test was performed, and it revealed that all variables exhibit a I (1) status, signifying they are stationary at the same order. Both the trace test and the max-eigenvalue test serve as co-integration examinations, encompassing a linear deterministic trend with associated constraints.

The outcomes of the co-integration test, derived from both the Trace statistic and the Max-eigenvalue, signal the presence of a solitary co-integrating equation at a 5 percent significance level. Both sets of findings validate the co-integration of the variables, thus establishing a significant long-term relationship at a 1 percent significance level between the food production index and the explanatory factors, excluding food imports.

Table 7: Unit root test results for assessing stationarity in the food security model variables in Botswana.

Variable	Test statistic	5% Critical value	First difference	Lags	Optimal lag selection
InFPI	0.205	-1.950	-2.721	1	2
InCPI	1.523	-1.950	-3.345	1	2
InLPI	-0.037	-1.950	-2.550	1	3
InRV	0.013	-1.950	-4.892	1	0
InINF	-0.231	-1.950	-2.926	1	1
InFIM	-0.557	-1.950	-3.336	1	1

Table 8: Johansen Co-integration test results for long-term variable relationships in food supply chains and environments

Hypothesised number of CE(S)	Trace statistic	0.05 Critical Value	Max-Eigen Statistic	0.05 Critical Value
0	54.7537	47.21	30.0969	27.07
1	24.6568**	29.68	12.8915	20.97

Notes: Trace test indicates 1 co-integrating equation at the 5% level.

Maxi-eigenvalue indicates 1 co-integrating equation at the 5% level.

***denotes rejection of null hypothesis at 5% level.*

Table 9: Results of Co-integrating equation for rainfall volatility and inflation's impact on food production index

Co-integration equation			*Log likelihood 292.7013*		
Normalised co-integration coefficients					
FPI	CPI	LPI	RV	INF	FIM
1.000000	.1256248***	.8637542***	-.0109646***	-.0674472**	.0277415**

****Significant at 1% level of significance; ** Significant at 5% level of significance*

The significant relationship between the dependent variable (FPI) and the independent variables (CPI, LPI, RV, INF and FIM) supports the view that the vulnerability of Botswana's food systems is a long-term issue and that some causes threaten food security as shown in Table 9.

In the context of Botswana, a negative sign of rainfall volatility (RV) in a co-integration equation suggests that there is an inverse link between rainfall volatility and food production. In other words, when the volatility of rainfall increases, it tends to impair the country's food output. The negative indicator may also indicate that the country's agricultural industry is susceptible to fluctuations in rainfall patterns. When rainfall is more volatile, it can cause problems such as droughts, floods or irregular growing conditions, which can diminish crop output and quality, impacting food production. These results are consistent with the World Bank's findings (2021), indicating that Botswana's rainfall is highly vulnerable to climate variability and change, primarily because of its heavy reliance on rain-fed agriculture.

The negative sign of inflation (INF) in Table 9 indicates that when the level of inflation in Botswana rises, food output tends to fall. Inflationary pressures frequently raise production costs, including expenses for inputs such as seeds, fertiliser and machinery. As these expenses rise, farmers' ability to produce food becomes more expensive, perhaps leading to a drop in food production. Inflation can cause supply chain disruptions, reducing the availability of essential inputs and resources required for food production. Farmers' ability to produce food efficiently may suffer as a result. Inflationary pressures can diminish customers' purchasing power, resulting in lower demand for food goods. Farmers may be discouraged from growing more food if they expect decreased sales.

Inflationary pressures may wreak havoc on the economy, making it harder for farmers and businesses to plan for the future. Because of the uncertainty, investments in agriculture and food production may be discouraged, resulting in lower output. Inflation can also have an impact on a country's trade balance and currency exchange rates. If Botswana imports important agricultural inputs, excessive inflation could raise the cost of these inputs, reducing food production.

A positive sign for the crop production index (CPI) in Table 9 indicates that as crop output in Botswana increases, so does the food production index (FPI) (dependent variable). This indicates a favourable association between crop productivity and overall food production in the country. In practise, greater crop production levels in Botswana lead to an increase in the availability of raw materials for food production, which in turn aids in satisfying the population's food demand. This suggests that crop output has a considerable impact on food production levels.

Similarly, a positive coefficient for the livestock production index (LPI) in Table 9 indicates that as the level of livestock production in Botswana increases, so does the food production index. This means that there is a positive relationship between livestock production and overall food production in the country. Livestock contributes to the food supply in the form of meat and other animal products. Increased livestock output provides extra food sources for the population, contributing to the overall food production index.

Table 10: Results for estimated VECM short-run dynamics of the food security model variables

Variables	Coefficient	t-statistic	Prob.
Constant	-0.95896	-0.212086	0.9106
$\Delta In\ FPI_{t-1}$	1.82210	1.335194	0.1885
$\Delta In\ CPI_{t-1}$	2.59388	3.918625	0.0048***
$\Delta In\ LPI_{t-1}$	3.53123	1.253140	0.0012***
$\Delta In\ RV_{t-1}$	0.048749	3.248027	0.0407**
$\Delta In\ INF_{t-1}$	-1.80769	3.385157	0.0009***
$\Delta In\ FIM_{t-1}$	-1.25285	-1.697329	0.0832
FPI_{t-1}	-0.294703	-0.05731	0.0068**
R-squared	0.84261		
F-statistic	7.29075		

****Significant at 1% level of significance; significant at 5% level of significance*

Based on the data depicted in Table 10, the analysis incorporates an error correction term. When the error correction term takes on a negative value, it implies that the variables in the model tend to converge towards their long-term equilibrium when deviations from that equilibrium occur. The magnitude of the error correction term, specifically -0.294703 in this instance, represents a gradual adjustment process with the goal of attaining the long-term equilibrium. The estimated coefficient of the error correction term indicates that the rate of adjustment is approximately 29 percent, and it demonstrates statistical significance at the 1 percent confidence level. This suggests that the process of correcting deviations from equilibrium unfolds at a relatively gradual pace, accounting for roughly 29 percent of the adjustment within a year (considering annual data). Consequently, the variables relevant to Botswana collectively hold a 29 percent level of significance at the 1 percent confidence level.

The results from the investigation into the vulnerability of Botswana's food system provide convincing evidence of substantial short-term associations between food security, represented by the proxy food production, and critical explanatory variables as shown in Table 10. These connections offer insight on critical elements influencing the resilience and stability of the country's food system. The study found a significant link between rainfall volatility $\Delta In\ RV_{t-1}$ and food production $\Delta In\ FPI_{t-1}$, particularly in the short run. Within this short-term period, a 1 percent increase in rainfall volatility equates to a 0.048749 percent increase in food output. This research emphasises the favourable impact of increased rainfall variability on agricultural productivity, while also giving useful insights for timely responses to climatic fluctuations. In the long run, a 1 percent drop in rainfall volatility is anticipated to result in a commensurate loss in food output in Botswana. This symmetry in the influence of rainfall volatility demonstrates the agricultural sector's sensitivity to climate conditions, both positive and negative deviations from the average.

4.2.3 South Africa

The economic indicators show that the initial unit root tests for stationarity for the Food Production Index (FPI), Crop Production Index (CPI), Livestock Production Index (LPI), Inflation (INF), Rainfall Volatility (RV) and Food Imports (FIM) indicate non-stationarity in South Africa in Table 11. This implies that these variables have a stochastic tendency over time and may lack a consistent mean or variance. Nonetheless, when we submit these variables to a first difference transformation, we notice a significant movement towards stationarity. The achievement of stationarity following this differencing process implies that these variables have undergone a transformation in which short-term fluctuations or random shocks have been dampened. This transformation from non-stationarity to stationarity after differencing shows that these variables were subject to temporary disruptions or irregular influences, which have been corrected by this transformative process.

Table 11: Unit root test results for testing stationarity in the food security model variables in South Africa

Variable	Test statistic	5% Critical value	First difference	Lags	Optimal lag selection
InFPI	1.205	-1.950	-3.517	1	3
InCPI	1.030	-1.950	-6.504	1	3
InLPI	1.573	-1.950	-2.165	1	1

InRV	-0.663	-1.950	-4.595	1	0
InINF	-0.962	-1.950	-4.843	1	4
InFIM	0.328	-1.950	-2.532	1	1

We performed the Johansen Co-integration Test after thoroughly applying the VAR lag order selection criteria to the food production index (FPI), crop production index (CPI), livestock production index (LPI), inflation (INF), rainfall volatility (RV) and food imports (FIM) data. This integrated methodology provides us with a solid analytical framework for understanding the complex linkages contained in this set of variables. After applying the VAR lag order selection criteria, we discovered that a lag order of 4 lags is the best representation of the variables' relationships as shown in Table 11. This choice creates a balance between collecting significant dynamics and avoiding over fitting risks, allowing the model to deliver accurate insights into the subtle interplay among various indicators over time.

Following that, we investigated the Johansen Co-integration Test, which was crucial in revealing long-term and meaningful linkages among the FPI, CPI, LPI, INF, RV and FIM variables. We investigated the various co-movements and equilibrium relationships that could shape the interactions between these variables by focusing on the FPI as the dependent variable and the others as independent variables. The results of our study indicated the presence of three co-integrating equations, indicating that there are three different and stable correlations between these variables that endure across time. These co-integrating equations provide important insights into the latent forces that drive the interactions and interdependencies in this food systems’ landscape.

Table 12: Johansen Co-integration test results for long-term variable relationship in food supply chains and food environments

Hypothesised number of CE(S)	Trace statistic	0.05 Critical Value	Max-Eigen Statistic	0.05 Critical Value
0	171.6570	94.15	71.1475	39.37
1	100.5095	68.52	50.9050	33.46
2	49.6045	47.21	30.5628	27.07
3	19.0416**	29.68	12.0493	20.97

Notes: Trace test indicates 3 co-integrating equations at the 5% level.

Maxi-eigenvalue indicates 3 co-integrating equations at the 5% level.

***denotes rejection of null hypothesis at 5% level.*

A negative sign for food imports in Table 13 indicates that South Africa's food imports (FIM) and food production index (FPI) are linked in such a way that when the country imports more food, domestic food production index tends to fall and when food imports fall, domestic food production index (FPI) tends to rise. The negative sign on inflation (INF) suggests that an increase in inflation is related with a long-run drop in food output. This implies that rising inflation could result in greater production costs for farmers and agricultural enterprises, thereby hurting profitability and diminishing their drive to produce food. Rising inflation rates distort market signals and affect price linkages between inputs and outputs. If farmers foresee unfavourable pricing dynamics, this can provide disincentives for them to grow food.

The negative coefficient on rainfall volatility (RV) in Table 13 means that increased volatility in rainfall patterns has a negative long-term influence on food output. Rainfall volatility can cause agricultural outputs to be uncertain and unpredictable, making it difficult for farmers to plan their planting, cultivating and harvesting activities. These results are consistent with the conclusions drawn by Carter and Gulati (2014), indicating that variations in rainfall patterns significantly increase the likelihood of long-term reductions in food production.

Table 13: Results of Co-integrating equation for rainfall volatility and inflation's impact on food production index

Co-integration equation		*Log likelihood 79.6308*			
Normalised co-integration coefficients					
FPI	CPI	LPI	RV	INF	FIM
1.000000	.4297022***	.5587929***	-.0004536***	-.1074731***	-.0736558***

****Significant at 1% level of significance*

Increase in crop and livestock production indices (CPI) (LPI) are connected with higher levels of food production index (FPI). This shows that both agricultural sectors are working together to improve total food availability. Positive coefficients may indicate that crop and livestock products are efficiently integrated into the food production process via the agricultural supply chain. This could result in increased food supply and accessibility.

Table 14: Results for estimated VECM short-run dynamics of the food security model variables

Variables	Coefficient	t-statistic	Prob.
Constant	-0.19829	-1.64372	0.101
$\Delta In\ FPI_{t-1}$	-.110990	-0.02914	0.984
$\Delta In\ CPI_{t-1}$	1.55258	2.36046	0.0007***
$\Delta In\ LPI_{t-1}$	1.62273	2.00576	0.0019***
$\Delta In\ RV_{t-1}$	-.009851	-.009851	0.5012
$\Delta In\ INF_{t-1}$	-1.37949	-4.18852	0.0004***
$\Delta In\ FIM_{t-1}$	.084284	0.128963	0.1732
FPI_{t-1}	-1.57914	-2.39203	0.0017***
R-squared	0.635201		
F-statistic	4.215682		

****Significant at 1% level of significance*

Based on Table 14, an Error corrective Term (ECT) of -1.57914 at lag t-1 implies a considerable and powerful corrective process towards the long-run equilibrium in the prior time period (t-1). Such a large magnitude implies that the model's variables are correcting errors at a rapid rate, predicting a reasonably quick return to equilibrium. A negative ECTt-1 shows that the system was moving considerably towards its long-run equilibrium in the preceding time period (t-1) after encountering deviations from that equilibrium.

In South Africa, a 1 percent increase in $\Delta In\ INF_{t-1}$ is expected to result in a -1.37949 percent decline in $\Delta In\ FPI_{t-1}$ in the near run. This suggests that throughout this time period, inflation has a considerable negative impact on food production in the country. Such findings highlight the necessity of managing inflationary pressures and their possible consequences on the agricultural sector in order to maintain consistent food production, which is critical for food security and economic stability.

According to the analysis, rainfall volatility in South Africa is not substantial in the short run as shown in Table 14. This implies that changes in rainfall patterns have no statistically significant impact on food production in the short run. It means that food production in South Africa may not be very vulnerable to short-term variations in rainfall variability over this time period.

4.3 **Results of the third objective**

In Namibia, the six indicators listed in Table 15 are subjected to a main component analysis in order to statistically assess the overall vulnerability index. Data analysis and statistical software, notably STATA, were used to conduct this investigation. We first discovered six components during the PCA step, but it soon became clear that only the first three were statistically significant according to the Kaiser criterion, which demands an eigenvalue greater than 1.

Together, these three significant components accounted for 85 percent of the variance in the sample. The first factor had the greatest bearing, accounting for 45 percent of the variance. The third principle component explained 17 percent of the variance, whereas the second principal component was responsible for 22 percent of it. To create the vulnerability index as a percentage, the first component was then employed. The indicators on this first component are given weights (or scores) in Table 16, along with the statistical characteristics that go along with them.

The assigned weights were used to construct a comprehensive vulnerability index, following the methodology outlined by Filmer and Pritchett in their seminal 2001 work. This index encompasses a range of distinct variables, each of which has undergone a normalization process to standardize their values on a scale from 0 to 100 (Refer to Appendix 2 for details).

Figure 6 depicts the period from 2000 to 2022, demonstrating Namibia's persistently high vulnerability index, which peaked at 27.27. The nation's on-going vulnerability over these years is highlighted by these data. Due to this vulnerability, Namibians are now seriously concerned about food insecurity. The nation's food systems have shown to be extremely vulnerable to outside shocks like increases in inflation and irregular rainfall patterns. As a result, the vulnerability of the food systems has contributed to persistent problems with food insecurity in the country, having an effect on the welfare of its citizens.

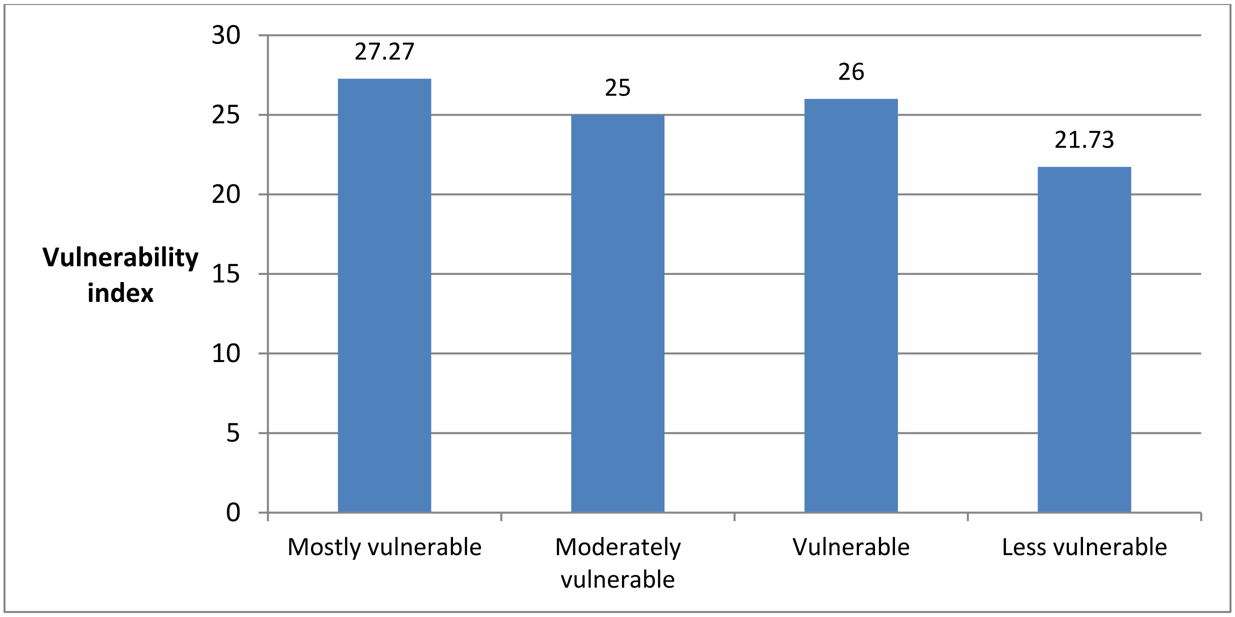

Figure 5: Namibian vulnerability indices (%) from 2000 to 2022

Table 15 shows the results of the PCA and the associated statistics in each and every country.

Table 15: Comparison PCA scores and their relevant statistics in Namibia, Botswana and South Africa

Namibia					
Variable	Eigenvalue	Difference	Proportion	Cumulative	PCA Comp1
FPI	2.74918	1.41582	0.4582	0.4582	-0.2455
CPI	1.33336	.305699	0.2222	0.6804	-0.5826
LPI	1.02766	.295452	0.1713	0.8517	0.4955
RV	.732207	.581453	0.1220	0.9737	0.1434
INF	.150754	.14391	0.0251	0.9989	0.4532
FIM	.00684406	.	0.0011	1.0000	0.3589
Botswana					
FPI	2.47059	.97959	0.4118	0.4118	0.5861
CPI	1.491	.331973	0.2485	0.6603	-0.2272
LPI	1.15903	.569312	0.1932	0.8534	0.6194
RV	.58972	.300325	0.0983	0.9517	0.3312
INF	.289394	.28914	0.0482	1.0000	0.3074
FIM	.000254703	.	0.0000	1.0000	-0.1306
South Africa					

FPI	3.62441	2.56534	0.6041	0.6041	0.5184
CPI	1.05907	.214359	0.1765	0.7806	0.4666
LPI	.844709	.511968	0.1408	0.9214	0.5052
RV	.332741	.211083	0.0555	0.9768	-0.1990
INF	.121658	.104245	0.0203	0.9971	0.0052
FIM	.0174136	.	0.0029	1.0000	0.4676

Six components were extracted during the initial step of the analysis of the data from Botswana, corresponding to the PCA. The first three components were declared statistically significant. These three important factors together accounted for 85 percent of the overall variation in the dataset, which is a large amount of variation that they helped to explain. The first principal component had the most impact, accounting for 41 percent of the variance. The second and third principal components came in at 25 percent and 19 percent, respectively.

Figure 7 depicts the “most vulnerability index” of 30.27 percent during the period 2000–2022. These findings highlight the region's continued concerns about food security. Concerns regarding Botswana's ability to maintain a steady and reliable food supply are raised by the country's continually high vulnerability index, which highlights the need for all-encompassing strategies and actions to address these problems.

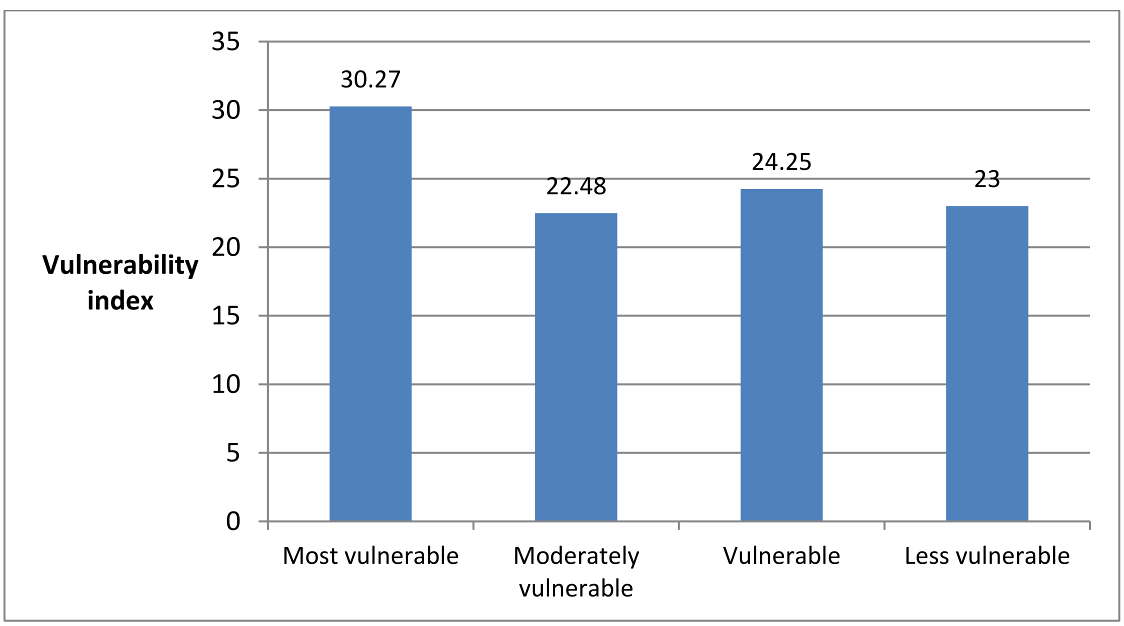

Figure 6: Vulnerability indices (%) of Botswana from 2000 to 2022

It is important to note that, in the case of South Africa, only the first two of the components were shown to be statistically significant. Together, these two major components explained 78 percent of the variance in the dataset, which is a large amount of variation. The first principal component had a significant impact, explaining 60 percent of the variance and the second principal component added another 18 percent. Consequently, the percentage-based vulnerability index was built using the first component.

Figure 8 shows how South Africa's condition contrasts with that of its neighbours, Namibia and Botswana. With a vulnerability index of 26.18 percent, South Africa showed a reduced percentage in the "mostly vulnerable" category over the years 2000 and 2022. This ostensibly better number does not, however, allay worries about food insecurity in the area. South Africa still faces problems with food security despite having a lower vulnerability index, demonstrating how complicated and multidimensional the problem is and how it goes beyond a single statistic. South Africa has persistent food security issues despite having a lower vulnerability score than other countries.

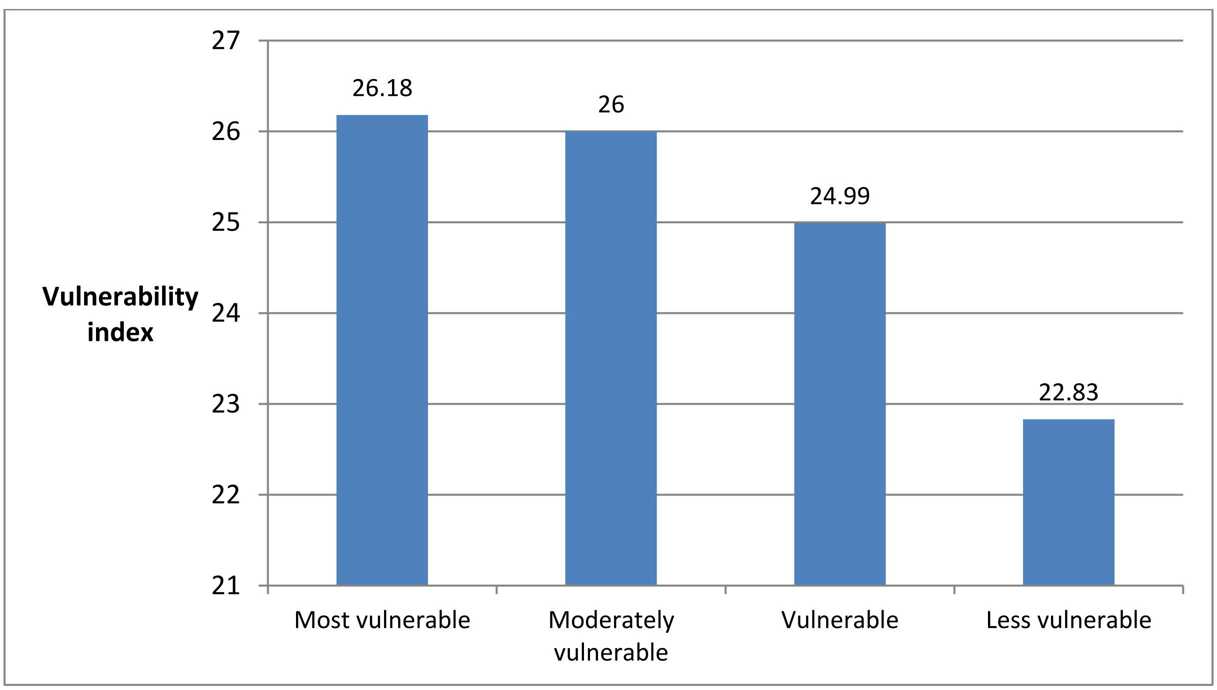

Figure 7: South African vulnerability indices (%) from 2000 to 2022

The graphical illustration in Figure 9 shows Namibia, Botswana and South Africa experienced various levels of vulnerability from 2000 and 2022. Appendix 2 lists the years in which each country's vulnerability changed, along with the accompanying vulnerability index for each of those years.

The PCA results in Figure 9 show that Botswana has a significant percentage of its vulnerability index classified as "most vulnerable." This suggests that major risks and challenges related to the causes of food insecurity are present in Botswana. According to this vulnerability index, the population of Botswana is far more likely than those in Namibia and South Africa to experience food insecurity. These findings support the preceding explanation in this study that food insecurity is far more prevalent in Botswana than it is in Namibia and South Africa, according to recent statistics. In 2022, Botswana experienced a proportion of 26.16% of its population facing severe food insecurity (Xinhua, 2023). During the same period, Namibia reported 14% of its population experiencing severe food insecurity (IPC, 2023). However, due to a lack of statistics for South Africa in 2022, data from 2021 indicates that approximately 2.1 million households, equivalent to 11.6% of the population, reported food insecurity (Stats SA, 2023).

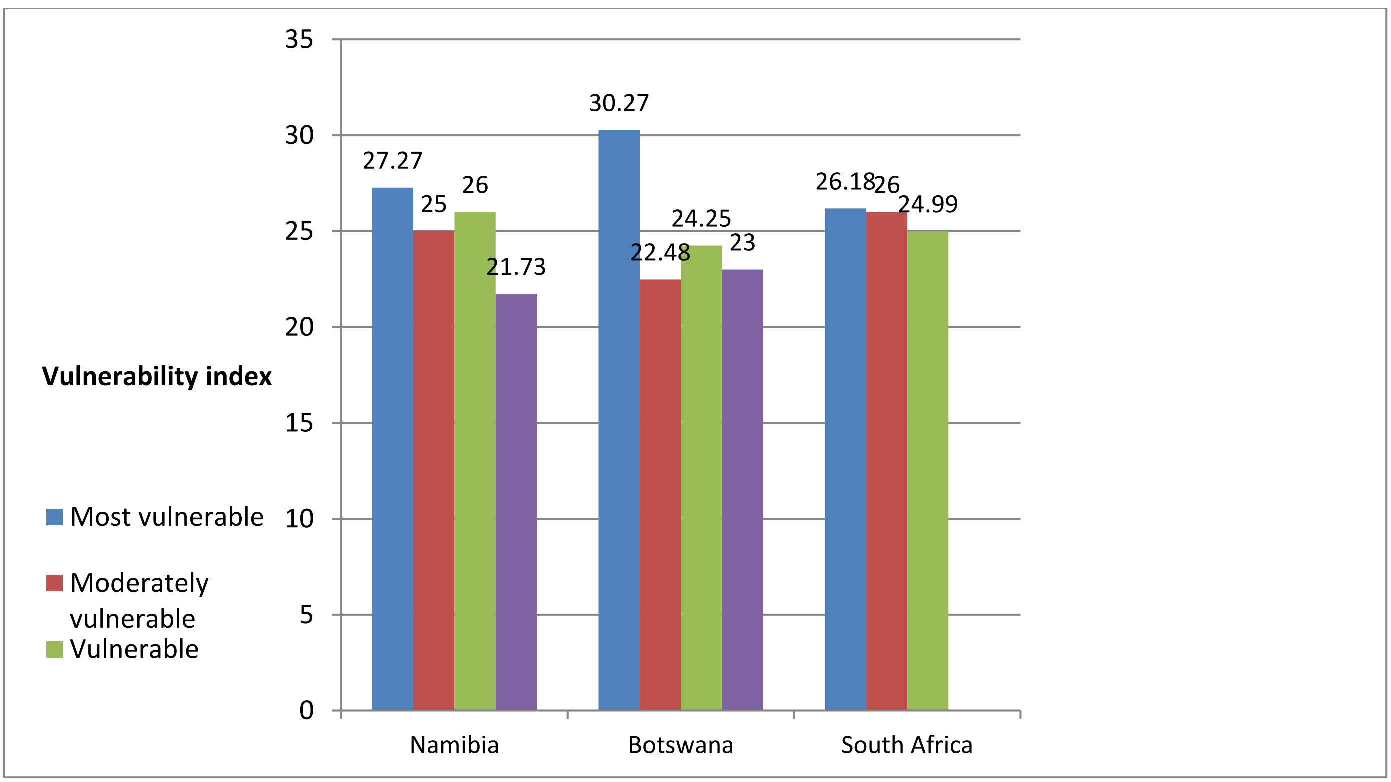

Figure 8: Vulnerability indices (%) from 2000 to 2022

Chapter 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The final chapter of this thesis offers the conclusions and recommendations drawn after an extensive examination of the vulnerability of food systems in Namibia, Botswana and South Africa.

5.2 Conclusion

Food system vulnerability in the SACU region is a key issue of enormous relevance for the region's everyday life, given that the majority has an average income. This research focused on the determination of vulnerability in the food systems of Namibia, Botswana and South Africa, particularly focusing on the impact of price and climatic shocks. The study pursued three specific objectives: assessing the influence of rainfall volatility and inflation on food production, investigating variables affecting the food security model and comparing vulnerability indices across the three countries. The dataset encompassed variables such as the food production index, inflation, food imports, precipitation, crop production index and livestock production index, spanning from 2000 to 2022.

For the first objective, the Vector Error Correction Model (VECM) revealed that inflation significantly affects food production in the short and long run across all three countries, while rainfall volatility impacts Namibia and Botswana but not South Africa in the short run. The second objective highlighted the importance of variables like the crop production index and livestock production index in shaping the food security model, with inflation and rainfall volatility affecting crop and livestock production, consequently influencing overall food production and food security.

In addressing the third objective, principal component analysis (PCA) was employed to compare vulnerability indices. The PCA results showed that Botswana has a significant percentage of its vulnerability index classified as "most vulnerable." This suggests that major risks and challenges related to the causes of food insecurity are present in Botswana. According to this vulnerability index, the population of Botswana is far more likely than those in Namibia and South Africa to experience food insecurity. These findings support the preceding explanation in this study that food insecurity is far more prevalent in Botswana than it is in Namibia and South Africa, according to recent statistics. Overall, this research contributes valuable understanding to the multifaceted dynamics of food system vulnerability in the studied countries, providing a foundation for targeted interventions and policy considerations.

5.3 Recommendations

The following practical recommendations are put forth in light of the thesis's findings regarding the short- and long-term effects of inflation on food production in all three countries, as well as the short-term differences in the impacts of rainfall volatility on Namibia, Botswana and South Africa:

i. Governments should put price stabilisation mechanisms in place to lessen the negative effects of inflation on the costs of agricultural inputs and output, given the substantial impact that inflation has on food production in all three of these countries. To protect against price volatility, this may entail creating programmes to boost commodity prices, setting up strategic food stores and providing targeted subsidies to farmers. Food prices can also be stabilised, and consumer affordability and accessibility guaranteed by policies targeted at improving market efficiency and removing supply chain bottlenecks.

ii. Since the agricultural systems in the region are interrelated, policymakers, researchers and stakeholders in Namibia, Botswana and South Africa need to work together more and share information more frequently. In order to manage inflationary pressures and climatic threats, regional efforts that share best practices, knowledge and technologies can improve food security and foster resilience on a larger regional scale. Facilitating the interchange of experiences and lessons learned through the establishment of platforms for dialogue, collaborative research projects, and coordinated policy responses can result in more sustainable and effective solutions to shared difficulties within the agricultural sector.

iii. Given that the three nations are differently vulnerable to fluctuations in rainfall, it is critical to give priority to climate resilience plans that are adapted to the unique requirements and difficulties of each area. Investments in drought-resistant crop varieties, climate-smart agricultural techniques and water management infrastructure are critical in Namibia and Botswana, where rainfall instability has a major long-term and short-term impact on food supply. To counteract the possible long-term effects of rainfall unpredictability on food production, South Africa, on the other hand, may concentrate on strengthening water conservation measures, diversifying irrigation systems and encouraging sustainable land management techniques.

The following suggestions are put forth considering the importance of variables like the livestock and crop production indices in forming the food security model, as well as the effects of inflation and rainfall volatility on crop and livestock productivity and overall food security:

i. To increase crop and livestock productivity, governments and relevant stakeholders should give agricultural research and development (R&D) top priority when making investments. The primary goals of this investment should be to create livestock breeds resistant to illness, crop varieties resistant to drought, and new farming methods to lessen the negative impacts of rainfall variability on agricultural output. Furthermore, boosting extension services and encouraging sustainable farming methods can raise yields and support long-term food security.

ii. Regarding the impact of inflation and fluctuations in rainfall on livestock and crop productivity, it is critical to create thorough risk management plans to protect food security. The establishment of monitoring methods and early warning systems by governments is necessary to predict and alleviate the effects of inflationary pressures and extreme weather events on agricultural productivity. This could entail developing emergency relief plans, crop insurance plans, and financial assistance systems for farmers who are impacted by market volatility and climate-related hazards.

The following recommendations are proposed considering the thesis findings, which underscore Botswana's significant vulnerability rating and its increased susceptibility to food insecurity compared to Namibia and South Africa.

i. Invest in initiatives aimed at enhancing Botswana's resilience to better withstand the shocks and strains that lead to food insecurity. This could entail strengthening efforts to adapt to climate change, broadening the range of agricultural production systems and encouraging alternative livelihoods in rural regions. Through enhancing resilience at the individual, household and community levels, Botswana can lessen its vulnerability to food insecurity and more effectively handle outside stressors.

ii. Create initiatives that prioritise interventions to enhance food accessibility, boost agricultural productivity, advocate for sustainable management of natural resources, and reinforce social safety nets for marginalised communities. By tackling the underlying causes of food insecurity- including poverty, unemployment and environmental deterioration, Botswana can diminish its vulnerability and enhance food security for its populace.

5.3.1 Recommendations for further research

i. Incorporate qualitative research methods like focus groups, interviews and participatory approaches alongside quantitative analysis to gather insights and perspectives from key stakeholders such as farmers, traders, policymakers and consumers. This combined approach would enhance the research and unveil deeper insights into the underlying factors contributing to vulnerability.

ii. Involve relevant stakeholders throughout the entirety of the study to ensure the relevance, reliability and utility of the findings. This may involve collaboratively designing research methodologies, verifying results and collectively generating knowledge to enhance uptake and influence.

iii. Add additional aspects to the analysis, such as access to resources, market dynamics, environmental degradation, social capital and institutional arrangements, in addition to price and climate shocks. This all-encompassing strategy would offer a more thorough comprehension of food system vulnerability.

iv. Evaluate the efficacy of current food system vulnerability policies and governance frameworks in Namibia, Botswana and South Africa with regard to food security, agriculture and climate change adaptation. This could help in identifying gaps and opportunities for policy reform.

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Appendices

Appendix 1 Field Sheet for Data Collection

Namibia

Country code	Year	FPI	CPI	LPI	RV	INF	FIM
1	2000	107	65.6	131.8	318.39	10.2	17
1	2001	95.9	69.5	112.2	289.99	10.2	13
1	2002	93.9	66.9	110.3	291.91	12.7	12.5
1	2003	98.8	70.9	115.7	283.98	7.1	15
1	2004	93.6	82.8	102.8	287.81	4.1	18.5
1	2005	94.3	82.1	101.7	264.49	2.3	18
1	2006	97	94	99.4	424.87	5	16
1	2007	96	87.4	101.3	276.29	6.5	15.5
1	2008	96.6	85.8	103	283.5	9.1	14
1	2009	97.4	88	103.7	348.39	9.5	14.5
1	2010	99.5	93	104.2	276.62	4.9	14.5
1	2011	100.4	94.1	104.5	350.31	5	14
1	2012	104	97	106.2	312.46	6.7	13
1	2013	100.6	91.1	105.8	245.6	5.6	13
1	2014	104.2	100.7	103.4	330.24	5.4	11.5
1	2015	99.8	103.3	97.9	231.8	3.4	12.4
1	2016	97.8	96	98.7	246.74	6.7	12.7
1	2017	104.9	108.5	102.7	290.91	6.1	13.5
1	2018	102.4	110.8	97	288.24	4.3	11.4
1	2019	97.1	98.7	96.3	282.9	3.7	12.5
1	2020	103.2	115.6	92.2	289.95	2.2	12.5
1	2021	105.6	118.2	98.1	278.98	3.6	10.6
1	2022	101	110	98.9	269.24	6.1	14.2

Botswana

Country code	Year	FPI	CPI	LPI	RV	INF	FIM
2	2001	102	68.8	107.6	426.75	6.6	14
2	2002	89.8	73	92.8	360.24	8	15
2	2003	90.1	74.5	92.8	358.92	9.2	14
2	2004	99.1	70.6	103.9	423.03	6.9	14
2	2005	103.6	79.5	108.3	377.29	8.6	14
2	2006	102.3	75.9	106.8	427.24	11.6	14
2	2007	103.6	73.2	108.7	361.55	7.1	13
2	2008	109	81.1	113.5	407.18	12.7	12
2	2009	115.1	81.3	120.4	405.92	8	13
2	2010	126.1	90.8	131.7	474.49	6.9	15
2	2011	130.8	107.5	134.4	473.42	8.5	10
2	2012	127.7	83.9	134.5	368.82	7.5	9
2	2013	115.1	76.7	121.1	393.59	5.9	8
2	2014	99.9	93.1	101	379.96	4.4	8
2	2015	105.4	104.1	105.6	351.79	3.1	9
2	2016	94.7	102.8	93.5	385.94	2.8	11
2	2017	93.2	101.7	91.9	447.05	3.3	13
2	2018	96	134.9	89.9	386.9	3.2	12
2	2019	100.9	115.7	98.5	384.84	2.8	13
2	2020	100.7	178.3	88.5	405.28	1.9	13
2	2021	106	147.3	99.5	404.58	7.2	11
2	2022	104	151.2	98.5	403.87	11.7	13.3

South Africa

Country code	Year	FPI	CPI	LPI	RV	INF	FIM
3	2000	71.2	89	56.9	638.57	5.3	5
3	2001	68.1	81.3	58.3	547.08	5.7	4

3	2002	72.3	88.8	59	422.1	9.5	5
3	2003	72.8	86.2	61.9	377.19	5.7	5
3	2004	74.5	86.7	64.7	477.67	-0.7	5
3	2005	79	91.9	68.6	401.17	2.1	4
3	2006	76.7	81.3	73.1	575.61	3.2	4
3	2007	78.8	80.4	77.7	429.44	6.2	5
3	2008	88.6	98	80.3	445.8	10.1	5
3	2009	87.4	94.7	80.9	482.78	7.22	8
3	2010	90	93.5	86.9	483.9	4.09	7
3	2011	89.2	93.8	85.3	551.97	5	8
3	2012	92.2	97.7	87.2	468.45	5.7	8
3	2013	97.4	101.6	93.5	427.9	5.8	8
3	2014	103	107.9	98.4	456.32	6.13	8
3	2015	101	100.7	101.5	373.61	4.54	8
3	2016	96.1	91.4	100.2	433.48	6.57	9
3	2017	105.8	117.3	95.6	431.76	5.18	8
3	2018	104.3	111.9	98	389.73	4.52	8
3	2019	104.5	106.9	103	390.05	4.12	8
3	2020	111.4	119.7	104.4	468.19	3.21	9
3	2021	114.3	125.5	104.2	526.6	4.61	8
3	2022	96.2	115.9	103	464	6.9	6.38

Appendix 2 Normalised data and vulnerability scores

Namibia

Year	normalised_FPI	normalised_CPI	normalised_LPI	normalised_RV	normalised_INF	normalised_FIM	vulnerability_score	vulnerability_index
2000	100	2.90E-06	99.99999	44.84902	76.19048	81.01266	3.611692	Less vulnerable
2001	17.16419	7.414452	50.50505	30.13933	76.19048	30.37974	2.151766	Less

								vulnerable
2002	2.238817	2.471486	45.70707	31.13379	100	24.05063	2.599238	Less vulnerable
2003	38.80598	10.07605	59.34343	27.02647	46.66667	55.6962	1.941002	Less vulnerable
2004	1.14E-05	32.69962	26.76768	29.0102	18.09524	100	1.142071	Vulnerable
2005	5.223891	31.36883	23.9899	16.93168	0.952381	93.67088	0.585905	Vulnerable
2006	25.37314	53.9924	18.18182	100	26.66667	68.35443	0.480949	Vulnerable
2007	17.91046	41.44487	22.9798	23.04346	40.95238	62.02531	0.557187	Vulnerable
2008	22.38807	38.40305	27.27273	26.77785	65.71429	43.03797	0.883483	Vulnerable
2009	28.35822	42.58556	29.04041	60.38742	69.52381	49.36708	1.174168	Less vulnerable
2010	44.02986	52.09126	30.30303	23.21438	25.71428	49.36708	-0.14344	Moderately vulnerable
2011	50.74627	54.18251	31.06061	61.38188	26.66667	43.03797	-0.03643	Vulnerable
2012	77.61195	59.69582	35.35354	41.7776	42.85714	30.37974	-0.2929	Moderately vulnerable
2013	52.23881	48.47909	34.34344	7.147666	32.38095	30.37974	-0.29606	Moderately vulnerable
2014	79.10448	66.73004	28.28283	50.98669	30.47619	11.3924	-1.03939	Moderately vulnerable
2015	46.26866	71.67301	14.39394	-1.58E-06	11.42857	22.78481	-1.7241	Most vulnerable
2016	31.34329	57.79468	16.41415	7.738125	42.85714	26.58228	-0.60916	Moderately vulnerable
2017	84.32836	81.55894	26.51516	30.61584	37.14286	36.70886	-1.09586	Most vulnerable
2018	65.67165	85.93156	12.12122	29.23292	20	10.12658	-2.05821	Most vulnerable
2019	26.11941	62.92776	10.35354	26.46708	14.28571	24.05063	-1.22842	Most vulnerable

2020	71.64179	95.05704	7.71E-06	30.11861	-4.54E-07	24.05063	-2.74087	Most vulnerable
2021	89.55224	100	14.899	24.43673	13.33333	-4.83E-06	-2.76728	Most vulnerable
2022	55.22388	84.41065	16.9192	19.39193	37.14286	45.56962	-1.09535	Moderately vulnerable

Botswana

Year	normalised_FPI	normalised_CPI	normalised_LPI	normalised_RV	normalised_INF	normalised_FIM	vulnerability_score	vulnerability_index
2001	29.75609	-2.79E-06	41.52174	61.0921	43.51852	85.71429	0.238243	Vulnerable
2002	-7.44E-06	3.835614	9.347826	6.88671	56.48148	100	-1.62448	Most vulnerable
2003	0.7317	5.205477	9.347826	5.810915	67.59259	85.71429	-1.45332	Most vulnerable
2004	22.68292	1.643833	33.47826	58.06031	46.2963	85.71429	-0.09126	Vulnerable
2005	33.65853	9.771687	43.04348	20.78239	62.03704	85.71429	-0.00581	Vulnerable
2006	30.4878	6.484015	39.78261	61.49144	89.81481	85.71429	0.669464	Vulnerable
2007	33.65853	4.018262	43.91304	7.954354	48.14815	71.42857	-0.18223	Vulnerable
2008	46.82926	11.23287	54.34783	45.14262	100	57.14286	1.302836	Vulnerable
2009	61.70731	11.41552	69.34782	44.11573	56.48148	71.42857	1.373545	Less vulnerable
2010	88.53658	20.09132	93.91304	100	46.2963	100	2.788856	Less vulnerable
2011	99.99999	35.34246	99.78261	99.12796	61.11111	28.57143	3.470753	Less vulnerable
2012	92.43902	13.78995	100	13.87938	51.85185	14.28571	2.447903	Less vulnerable
2013	61.70731	7.214609	70.86957	34.06683	37.03704	0	1.409803	Less vulnerable

2014	24.63414	22.19178	27.17391	22.95843	23.14815	0	-0.65115	Moderately vulnerable
2015	38.04877	32.23744	37.17391	-6.96E-06	11.11111	14.28571	-0.71214	Moderately vulnerable
2016	11.95121	31.05023	10.86957	27.83211	8.333333	42.85714	-1.60015	Most vulnerable
2017	8.292675	30.04566	7.391304	77.63651	12.96296	71.42857	-1.22056	Moderately vulnerable
2018	15.12194	60.3653	3.043478	28.6145	12.03704	57.14286	-1.94328	Most vulnerable
2019	27.07316	42.83105	21.73913	26.93561	8.333333	71.42857	-1.29173	Most vulnerable
2020	26.58536	100	0	43.59413	2.21E-07	71.42857	-2.10357	Most vulnerable
2021	39.51219	71.68949	23.91304	43.02364	49.07407	42.85714	-0.47558	Moderately vulnerable
2022	34.63414	75.25114	21.73913	42.44499	90.74074	75.71429	-0.34615	Moderately vulnerable

South Africa

Year	normalised_FPI	normalised_CPI	normalised_LPI	normalised_RV	normalised_INF	normalised_FIM	vulnerability_score	vulnerability_index
2000	6.70996	19.06873	-3.21E-06	100	55.55555	20	-2.84722	Most vulnerable
2001	3.30E-06	1.995562	2.947365	65.47026	59.25926	0	-3.19275	Most vulnerable
2002	9.090912	18.62527	4.42105	18.30088	94.44444	20	-2.09997	Most vulnerable
2003	10.17316	12.86031	10.52631	1.351153	59.25926	20	-1.96218	Most

								vulnerable
2004	13.85282	13.96896	16.42105	39.27385	-1.10E-07	20	-2.10739	Most vulnerable
2005	23.59307	25.49889	24.63158	10.40158	25.92593	0	-1.67036	Moderately vulnerable
2006	18.61472	1.995562	34.10526	76.23792	36.11111	0	-2.51155	Most vulnerable
2007	23.16017	-3.38E-06	43.78947	21.07111	63.88889	20	-1.61827	Moderately vulnerable
2008	44.37229	39.02439	49.26315	27.24562	100	20	-0.58295	Moderately vulnerable
2009	41.77489	31.70732	50.52631	41.20245	73.33333	80	-0.03886	Moderately vulnerable
2010	47.4026	29.04656	63.15789	41.62515	44.35185	60	-0.08095	Moderately vulnerable
2011	45.67099	29.71175	59.78947	67.31582	52.77778	80	-0.0796	Moderately vulnerable
2012	52.1645	38.3592	63.78947	35.79409	59.25926	80	0.478175	Vulnerable
2013	63.41991	47.00665	77.05263	20.48989	60.18518	80	1.123576	Vulnerable
2014	75.54112	60.97561	87.36842	31.21604	63.24074	80	1.62389	Vulnerable
2015	71.21212	45.01109	93.89474	5.53E-06	48.51852	80	1.626699	Vulnerable
2016	60.60606	24.39024	91.15789	22.59587	67.31481	100	1.167458	Vulnerable
2017	81.60173	81.81818	81.47368	21.94671	54.44444	80	2.049938	Less vulnerable
2018	78.35497	69.84479	86.52631	6.083942	48.33333	80	1.996447	Less vulnerable
2019	78.78787	58.75831	97.05263	6.204715	44.62963	80	1.975275	Less vulnerable
2020	93.72294	87.13969	100	35.69596	36.2037	100	2.768605	Less vulnerable
2021	99.99999	100	99.57894	57.74079	49.16666	80	2.640689	Less

								vulnerable
2022	60.82251	78.71397	97.05263	34.11459	70.37037	47.6	1.341312	Vulnerable