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ASSESSING EFFECTS OF RAINFALL AND TEMPERATURE VARIABILITY ON TOMATO PRODUCTION AMONG SMALLHOLDER FARMERS. A CASE STUDY OF MPINGU EPA IN LILONGWE DISTRICT.

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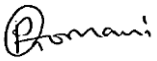
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DISCLAIMER

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ABSTRACT

This study assesses the trends and relationships between climatic variables—rainfall and temperature—and tomato production in the Mpingu EPA from 2012 to 2023. Utilizing the Mann-Kendall trend test, the analysis reveals no statistically significant trend in annual rainfall over the period, suggesting that the rainfall pattern remains relatively stable with no consistent increase or decrease observed. This stability in rainfall can be attributed to various factors such as local and regional climate, topography, land use, and human activities. Similarly, the analysis of average annual temperature trends shows no significant increase, indicating a steady temperature pattern over the past decade. The empirical evaluation of tomato production demonstrates a significant upward trend in annual production, indicating substantial improvements likely driven by advances in agricultural practices, market dynamics, and technological innovations. Despite the importance of climatic factors, the weak correlation coefficients between average annual temperature, total annual rainfall, and tomato production suggest that other factors, including soil quality, pest control, and crop management practices, play more crucial roles in influencing tomato production. These findings underscore the complex interplay of multiple factors affecting agricultural productivity and highlight the need for comprehensive strategies to enhance agricultural resilience and sustainability in Mpingu EPA.

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ACRONYMS

DCCMS: Department of Climate Change and Meteorological Science

ENSO: El Niño Southern Oscillation

EPA: Extension Planning Area

GDP: Gross Domestic Product

IOD: Indian Ocean Dipole

IPCC: Intergovernmental Panel on Climate Change

ITCZ : Intertropical Convergence Zone

LWAO: Lilongwe West Agriculture Office

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CHAPTER ONE

INTRODUCTION

In the introduction part, the study covered the background, problem statement, hypothesis, main objective, and specific objectives.

1.1. Background

Malawi experiences a subtropical climate characterized by clear seasonal patterns From November to April, the country undergoes a warm and wet season, while the period from May to October (Government of Malawi, 2016). Rainfall patterns in Malawi are highly variable, with some regions receiving as little as 725mm annually and others exceeding 1000mm, but generally not falling below 400mm(Government of Malawi, 2016). "Climate variability" is a larger term used to refer to fluctuations at all levels of the climate and has posed a major national, regional, and global observable environmental challenge(Niño, 2018). It may also be due to natural processes, such as the El Niño-Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO), both of which bring about climate variability, together with other human-related activities, including greenhouse gas emission and land use (McLeod et al., 2011). On the other hand, climate variability, a component of rainfall variability, refers to the changes in time of specified periods of the amount, timing, intensity, and duration of precipitation over an area(Stocker et al., 2013). These variations, influenced both by natural factors such as the El Niño/La Niña cycle and anthropogenic actions, can wreak havoc on sustainable development if left unattended (Robert H. Stull, 1995). On the other hand, temperature variability refers to the change and fluctuation difference in temperature patterns of changes within a specified area and period. It ranges from the mean value of temperature, temperature extremity, and to the seasonal ranges of temperature(IPCC, 2018). The Ministry of Environment and Climate Change Management (2010), therefore, underscores the impact of climate variability on rainfall and temperature variability towards the development of Malawi. It, therefore, follows that disturbances to these natural ecosystems pose key threats to the very weather-sensitive sectors, such as agriculture, which forms the country's economic mainstay.

Agriculture in Malawi is characterized by a heavy dependence on crop production, especially maize and tobacco production, which in turn supports almost 85% of the working population. In addition to that, these crops contribute highly to the GDP (35%) and foreign exchange (90%) (Government of Malawi, 2016). The maize and tobacco decline in production in the recent past (Ricciardi et al., 2018) has left the farmers with no option but to look for a substitute for the two as alternative cash crops, where tomatoes prove to be viable. Tomatoes (Solanum lycopersicum) form one of the major cash crops grown by smallholder farmers in Mpingu EPA, and they contribute substantially to food security and the generation of household income. These crop fruit most of them were native to South America have a great contribution to the world economy, totaling an annual value of over 90 billion US dollars (Peralta & Spooner, 2007). Ideal annual rainfall for cultivation success ranges from 500 to 800 mm, as it brings the best moisture during the growing season of the tomatoes. The average temperature that can ensure successful farming of tomatoes in Lilongwe should be around 20˚c to 30 °c during the day. Tomatoes are sensitive to extremes of hot and cold temperatures. Ideally, during the night, the temperatures should at no point get below 15°c so that fruit set would take place, to curtail problems like blossom drop (Chisonga Fackson et al., 2020). This also indicates tomatoes as the most profitable vegetable crop by far (98%) among Malawian farmers (Mango et al., 2015).

Although the world's tomato business is growing and tomatoes are grown both with irrigation and without, rainfall and temperature fluctuations are a major danger to tomato output. Rainfall variability characteristics are defined as irregular rainfall patterns with erratic onsets, prolonged dry spells, and unseasonal precipitation events. These patterns can interfere with tomato plant growth and development, resulting in lower yields and financial losses for growers (Mloza-Banda et al., 2018). Temperature variability shows that throughout the blooming and fruit-setting stages, high temperatures over the ideal range (25˚c–30°c) can reduce pollen viability, alter pollination dynamics, and cause physiological diseases such as sunscald and heat-induced fruit abortion (Hatfield et al., 2011). Furthermore, extended heat stress hastens the ripening process of fruit, impairing its color, flavor, and shelf life (Bita & Gerats, 2013). This project aims to assess the effects of both rainfall and temperature variability on tomato production in Mpingu EPA, a major tomato-producing area in Malawi. By

understanding these impacts, the project can contribute to developing solutions for the challenges faced by tomato farmers and pave the way for further research in this critical area.

1.2. Problem Statement

Rainfall and temperature fluctuation in Lilongwe are a major challenge to tomato production. Rainfall and temperature fluctuations in Lilongwe lead to irregular growth, low yields, and poor quality of the final crop. Unpredictable rainfall and temperature can stress tomato plants, making them more vulnerable to pests and diseases. This can lead to poor quality and quantity of the harvest. Lilongwe's climate is characterized by a unique wet and dry season. This makes planting and irrigation schedules difficult for farmers. The lack of access to modern technology and agricultural practices also contributes to tomato farmers' economic losses.

Mwangwela et al. (2020) conducted a study in the central region of Malawi which revealed that rainfall and temperature variability had a significant impact on tomato production. This resulted in lower yields and higher incidence of pests and diseases. On the specific effects of rainfall and temperature variability on tomato production among smallholder farmers in Mpingu EPA, Lilongwe, there has not been much research though. The purpose of this study is to close this knowledge gap regarding how temperature variability and rainfall affect tomato yield. Rainfall and temperature fluctuations are two factors that affect tomato production and must be addressed to increase the marketability and quality of tomatoes.

1.3. Main objective

The main objective was to assess the effects of rainfall and temperature variability on tomato production among smallholder farmers in Mpingu EPA, Lilongwe district.

1.3.1. Specific Objectives

- To evaluate the rainfall and temperature trend from 2012 to 2023.
- To assess the tomato production trend during the years 2012 to 2023.
- To relate the rainfall, temperature, and tomato production trends from 2012 to 2023.

1.4. Research hypothesis

H0 1. There was no significant trend in annual rainfall and temperature from 2012 to 2023.

H0 2. There was no significant trend in tomato production during the years from 2012 to 2023.

HO 3. There was no significant relationship between annual rainfall, temperature, and tomato production during the years from 2012 to 2023.

1.5. Significance of the study

To begin with, tomato production is critical to food security and economic development in many countries, including Malawi. Understanding the patterns and trends of rainfall and temperature variability can help farmers and policymakers anticipate and mitigate the risks associated with extreme weather events such as drought and floods, which can significantly affect tomato production(Ndiritu et al., 2021).

Furthermore, the study of rainfall and temperature variability in tomato production is significant for promoting the economic development of rural communities. Smallholder farmers in many countries, including Malawi, rely on tomato production for their livelihoods. Understanding the impact of rainfall and temperature variability on tomato production can help identify strategies that support smallholder farmers, such as improving access to irrigation systems and providing training on sustainable agricultural practices(Ndiritu et al., 2021).

Additionally, the study of rainfall and temperature variability in tomato production is significant for promoting sustainable agricultural practices. Sustainable agriculture is essential for protecting natural resources and reducing greenhouse gas emissions, which are major contributors to climate change. By understanding the impact of rainfall and temperature variability on tomato production, researchers can identify sustainable agricultural practices that are resilient to changes in weather patterns and contribute to mitigating climate change(Ndiritu et al., 2021).

On the fourth point, policymakers and stakeholders can develop tomato varieties that are more tolerant to rainfall and temperature variability, such as drought- or flood-tolerant varieties. These varieties can help farmers maintain yields even in the face of changing weather patterns(Shaown Khan, 2023).

Finally, the transformation of agriculture will require a shift from low production to high production of tomatoes and from subsistence-oriented agriculture to a highly productive commercialized agriculture system. This will attract investment in value addition and agro-processing, resulting in employment and an economy of self-reliance for the nation and its people.

CHAPTER TWO

LITERATURE REVIEW

In the literature review, the study explained much about rainfall and temperature variability and the effects of rainfall and temperature variability on tomato production among smallholder farmers.

2.1. Climate Variability

Climate variability involves the natural shifts and alterations in climate patterns across different timeframes, spanning from months to decades and possibly centuries (Niño, 2018). Multiple factors can lead to these variations, such as interactions between the ocean and atmosphere and external influences like volcanic eruptions and changes in solar radiation, within the Earth's climate system.

Patterns of air and water movement in the atmosphere and ocean have a major impact on causing climate changes. Phenomena such as the El Niño-Southern Oscillation (ENSO) in the Pacific Ocean and the North Atlantic Oscillation (NAO) can cause changes in weather patterns worldwide, impacting temperature, precipitation, and other climatic factors(Dr. Richard A. Feely & Dr. Michael McPhaden, 2020).

Changes in the Earth's orbit and axial tilt, along with variations in solar radiation, can also impact climate variability over the long term. Moreover, events such as volcanic eruptions can release aerosols into the air, which can lead to a temporary cooling effect on the climate by preventing sunlight from reaching the Earth.

Human actions, specifically the release of greenhouse gases like carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), are also factors in climate change caused by humans(Jeff Berardelli, 2021). The increased greenhouse effect triggered by these emissions results in a prolonged period of rising temperatures, changing precipitation patterns, and worsening extreme weather occurrence(IPCC, 2018)s.

Comprehending climate variability is crucial for adjusting to and lessening the effects of climate change. Scientists can use paleoclimate data from sources like ice cores, tree rings, and sediment layers to investigate previous climate changes. This research helps differentiate between natural climate cycles and human-caused influences on the climate system.

2.1.1. Climate variability in Malawi

Climate variability in Malawi has an intricate mix of weather patterns and trends, which significantly affect the agricultural, economic, and social aspects of the country situated in the southern part of Africa, Malawi faces a high risk of being impacted by climate change because of its dependence on rainfall for farming and its exposure to severe weather conditions. Its vulnerability is worsened by its geographical characteristics, such as being located in the tropics and having a varied topography with high plateaus, mountains, and lowlands. Malawi's climate shows significant differences between areas and times of the year due to the effects of the Inter-Tropical Convergence Zone (ITCZ), El Niño Southern Oscillation (ENSO), and Indian Ocean Dipole (IOD) (Department of Climate Change and Meteorological Services, 2022).

One of the key indications of climate variability in Malawi is the unpredictability and lack of uniformity in rainfall schedules. The nation usually has two clear seasons: a rainy season lasting from November to April, and a dry season from May to October. Nevertheless, the beginning and length of these seasons have become more uncertain,

resulting in frequent droughts, floods, and irregular rainfall patterns (Shaba & Kanyanga, 2019). An example is the agricultural season in Malawi in 2015/2016, which saw long periods without rain and unpredictable rainfall, leading to large-scale crop losses and widespread food insecurity affecting millions of individuals (FAO, 2017).

Multiple research projects have emphasized how global climate events influence the fluctuations in Malawi's weather patterns. The El Niño and La Niña phenomena, which are part of the ENSO cycle, have a significant impact on the distribution of rainfall in the area. In years with El Niño, Malawi typically sees less rainfall and drought, whereas during La Niña events there is usually more rainfall and a higher risk of floods(NOAA, 2023). Furthermore, the Indian Ocean Dipole, which is defined by the difference in temperature between the eastern and western Indian Ocean, can influence Malawi's weather by changing precipitation patterns and increasing the severity of droughts or floods (Reason et al., 2017).

The consequences of climate variability in Malawi are extensive and diverse, with agriculture experiencing the most significant effects. Small-scale farmers, who make up the larger part of the population and rely mainly on rain-fed farming for their income, are especially at risk of climate-related disruptions. Unpredictable precipitation and severe weather conditions disturb planting timelines, decrease agricultural production, and worsen food scarcity, perpetuating poverty in rural areas. Additionally, there is frequently an increase in waterborne diseases after floods, which presents notable public health difficulties (Nakhumwa, 2017).

Efforts to combat climate variability in Malawi include a range of adaptation and mitigation tactics to strengthen resilience and decrease vulnerability. This involves encouraging climate-smart farming techniques like conservation agriculture, crop diversification, and utilizing drought-resistant crop species. Furthermore, by investing in weather forecasting and early warning systems, communities can better predict and get ready for severe weather events, ultimately reducing their negative effects on livelihoods and infrastructure (Chipungu, 2020).

2.2. Rainfall and temperature variability in southern Africa

Southern Africa is characterized by rainfall and temperature variability, which poses significant challenges for agriculture, water resource management, and food security in the region (Simatele & Nhamo, 2016). Rainfall variability refers to the year-to-year fluctuations in the amount, timing, and distribution of rainfall within a particular area. Temperature variability includes variations in mean temperatures, temperature extremes, and seasonal temperature ranges(IPCC, 2018). Several factors contribute to rainfall and temperature variability in Southern Africa, including global climate change, atmospheric circulation patterns, oceanic phenomena, and vegetation land use changes.

Climate change is one of the primary drivers of rainfall and temperature variability in Southern Africa. Increasing greenhouse gas emissions have led to shifts in global climate patterns, resulting in altered precipitation regimes in many regions, including Southern Africa (Engelbrecht et al., 2015). Climate models project that Southern Africa will experience changes in rainfall and temperature patterns, with some areas becoming drier and others experiencing increased rainfall variability, exacerbating existing water stress and food insecurity challenges (Hachigonta et al., 2019).

Atmospheric circulation patterns, such as the El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD)(Palmer et al., 2023), significantly influence rainfall and temperature variability in Southern Africa. During El Niño events, warmer sea surface temperatures in the eastern Pacific Ocean led to reduced rainfall in parts of Southern Africa, particularly in the summer rainfall region, while La Niña events can bring above-average rainfall (Rudnick et al., 2020). Similarly, positive IOD events are associated with below-average rainfall in the region, while negative IOD events can enhance rainfall (Wainwright Caroline, 2019).

Oceanic phenomena, such as the Benguela Niño and the Atlantic Niño, also contribute to rainfall variability in Southern Africa. The Benguela Niño, characterized by warmer sea surface temperatures off the coast of southwestern Africa, can lead to reduced rainfall in the region through its influence on atmospheric circulation patterns (NOAA, 2020). Conversely, the Atlantic Niño, marked by warmer sea surface temperatures in the tropical Atlantic Ocean, can enhance rainfall in parts of Southern Africa (NOAA, 2020).

Vegetation and land use changes, including deforestation, urbanization, and agricultural expansion, can alter local and regional climate patterns, contributing to rainfall and temperature variability in Southern Africa. Deforestation, for example, can reduce evapotranspiration rates, leading to changes in atmospheric moisture levels and precipitation patterns (Hansen et al., 2013). Similarly, urbanization can modify surface albedo and heat absorption, affecting temperature changes (Feddema et al., 2005).

In conclusion, rainfall and temperature variability in Southern Africa is influenced by a combination of factors, including climate change, atmospheric circulation patterns, oceanic phenomena, and land use changes(Palmer et al., 2023). Understanding these drivers and their interactions is essential for developing effective strategies to mitigate the impacts of rainfall variability on agriculture, water resources, and food security in southern Africa (Palmer et al., 2023).

2.2.1. Rainfall and temperature variability in Malawi

In terms of climatic variability and trends observed over the period, there is increasing evidence of observed changes in extremes such as hot extremes, heavy precipitation, droughts, and tropical cyclones (Parmesan, 2021). They are given because emissions of greenhouse gases (e.g., carbon dioxide, methane, water vapor, and ozone) in the atmosphere are expected to be subjected to increasing temperatures and changing precipitation patterns with the accumulative effects of reducing plant growth and yields (Guodaar et al., 2017). Rainfall and temperature variability in Malawi is a subject of significant importance due to its implications for agriculture, particularly in terms of crop production. Malawi's climate is characterized by distinct wet and dry seasons, with the majority of rainfall occurring during the wet season, typically from November to April (Malawi Meteorological Department, 2002). The distribution and intensity of rainfall in Malawi are influenced by various atmospheric and oceanic phenomena, including the Intertropical Convergence Zone (ITCZ) and the El Niño Southern Oscillation (ENSO)(Sharon Nicholson et al., 2014).

The Intertropical Convergence Zone (ITCZ) is a belt of low pressure near the equator where trade winds from the Northern and Southern Hemispheres converge, resulting

in uplift and the formation of convective clouds and rainfall(Sharon Nicholson et al., 2014). The north-south passage of the ITCZ across Malawi brings the rainy season, which is crucial for agricultural activities, particularly for rain-fed crops like maize and tomatoes (Haghtalab, Mohammadi, et al., 2019).

In addition to the ITCZ, the El Niño Southern Oscillation (ENSO) also plays a significant role in influencing rainfall variability in Malawi. ENSO refers to the periodic fluctuation in sea surface temperatures and atmospheric pressure in the equatorial Pacific Ocean, which can have far-reaching effects on global weather patterns(NOAA, 2023). During El Niño events, which are characterized by warmer-than-average sea surface significantly influences temperatures in the central and eastern Pacific Ocean, Malawi tends to experience drier conditions and reduced rainfall, leading to droughts and water scarcity (World Health Organisarion, 2023).

Conversely, during La Niña events, which are characterized by cooler-than-average sea surface temperatures in the central and eastern Pacific Ocean, Malawi may experience increased rainfall and above-average precipitation, which can also have implications for agriculture and food security in the region (Haghtalab et al., 2019).

Overall, understanding the patterns and drivers of rainfall variability in Malawi is essential for developing effective strategies for water resource management, agricultural planning, and climate adaptation in the face of changing climatic conditions.

Kumbuyo et al. (2015) carried out a study of inter-annual rainfall fluctuation in Malawi, where they found that geographical location and topography are both key factors in the distribution of precipitation, and they also included that rainfall is seasonal to a large extent. Many similar studies have been conducted all around the world, and significant variations in precipitation in southern Africa, especially during recent decades, have been found (Fauchereau et al., 2003). present a study in which they find that inter-annual rainfall variations have been increasing since the end of 1960 and that the trend is moving more rapidly in recent years. The major consequence of this climatic variability that Fachereau et al. (2003) find is excessive droughts. Temperature variability in Malawi is influenced by factors such as altitude, proximity to water bodies, and regional climate patterns. Generally, temperatures are cooler in the highlands of northern and central Malawi compared to the lower-lying areas in the south.

Studies such as (Ngongondo et al., 2014) have observed a warming trend in Malawi over the past few decades, with temperatures gradually increasing. This temperature rise has implications for various sectors, including agriculture, health, and water resources.

Higher temperatures can affect crop yields and livestock productivity, as certain crops may become less viable in warmer conditions. Additionally, warmer temperatures can increase the risk of heat-related illnesses and vector-borne diseases such as malaria(CDC, 2024).

2.3. Tomato production in southern Africa

Tomato (Solanum lycopersicum) is a vital vegetable crop in Southern Africa, contributing significantly to food security, nutrition, and economic development in the region. However, tomato production faces various challenges, including climate variability, pest and disease pressure, limited access to inputs and technologies, and market constraints, which vary across countries in Southern Africa.

Climate variability, including erratic rainfall patterns, droughts, and temperature extremes, poses significant challenges to tomato production in Southern Africa. For example, in Zimbabwe, irregular rainfall and prolonged dry spells during critical growth stages can lead to reduced yields and poor fruit quality (Mabasa et al., 2019). Similarly, in Zambia, fluctuations in temperature and precipitation patterns can affect tomato production, with extreme heat and water scarcity impacting crop development and yield potential (Chipanshi et al., 2016).

Tomato crops in Southern Africa are susceptible to various pests and diseases, which vary in prevalence and severity across countries in the region. In South Africa, the tomato leafminer (Tuta absoluta) has emerged as a significant threat to tomato production, causing extensive damage to crops and reducing yields(Rwomushana Ivan et al., 2019). In Malawi, bacterial wilt (Ralstonia solanacearum) and fungal diseases such as early blight (Alternaria solani) and late blight (Phytophthora infestans) pose significant challenges to tomato farmers, necessitating integrated pest and disease management strategies (Kamangira et al., 2018).

Limited access to quality seeds, fertilizers, pesticides, and modern agricultural technologies is a common constraint faced by tomato farmers across Southern Africa. In Mozambique, smallholder farmers often lack access to improved tomato varieties and agronomic practices, resulting in low productivity and income levels (Resopre, 2018). Similarly, in Botswana, inadequate access to irrigation infrastructure and high-quality inputs limits the potential for intensive tomato production, particularly during the dry season (Hambira et al., 2019).

Market constraints, including poor market infrastructure, price fluctuations, and limited access to markets, affect tomato producers' profitability and competitiveness in Southern Africa(Ndlovu & Masuku, 2021). In Namibia, smallholder tomato farmers struggle to access formal markets due to inadequate transportation networks and inconsistent market demand, leading to post-harvest losses and reduced incomes (Ndlovu & Masuku, 2021). Similarly, in Lesotho, limited market opportunities and a lack of market information hinder tomato farmers' ability to maximize returns on their produce (Fifas, 2018).

2.3.1. Tomato production in Malawi

Tomato production in Malawi is influenced by various factors, including rainfall patterns, temperature, soil fertility, and agronomic practices(Eviness et al., 2022a). Understanding the optimal conditions for tomato cultivation is essential for maximizing yields and ensuring food security in the country.

Rainfall and temperature are critical in tomato production, as water and temperature are vital for plant growth, development, and fruit formation. The amount of rainfall required for successful tomato cultivation in Malawi typically ranges between 500 to 800 millimeters annually(Chisonga Fackson et al., 2020). Adequate and well-distributed rainfall during the growing season ensures sufficient moisture levels in the soil, promoting healthy plant growth and optimal fruit development.

In addition to rainfall, the temperature is another crucial factor influencing tomato production in Malawi. Tomatoes thrive in warm climates with temperatures ranging from 20 to 30 degrees Celsius (Agrownet, 2006). Extreme temperatures, either too hot

or too cold, can adversely affect plant growth, flowering, and fruit set. Therefore, maintaining suitable temperature conditions through proper crop management practices and environmental control measures is essential for maximizing tomato yields in Malawi.

Moreover, soil fertility plays a significant role in tomato production, as tomatoes require well-drained soils rich in organic matter and essential nutrients. Soil testing and appropriate fertilization practices are essential for ensuring optimal soil fertility levels and addressing nutrient deficiencies that may hinder tomato growth and development.

In terms of agronomic practices, farmers in Malawi employ various techniques to enhance tomato production, including drip irrigation, mulching, and integrated pest management (Jere et al., 2019). Drip irrigation systems help conserve water and deliver precise amounts of moisture directly to the plant roots, ensuring efficient water use and reducing water stress during dry periods. Mulching with organic materials helps suppress weed growth, conserve soil moisture, and regulate soil temperature, creating favorable conditions for tomato growth. Integrated pest management involves the use of environmentally friendly pest control methods, such as biological control agents and cultural practices, to minimize pest damage and reduce reliance on chemical pesticides.

By optimizing rainfall management, temperature control, soil fertility, and agronomic practices, farmers in Malawi can enhance tomato production, improve crop yields, and contribute to food security and economic development in the country.

According to an article in The Nation by Mwafulirwa (2015), tomato farming has become a source of hope for farmers in Lilongwe, Malawi's capital city. Lilongwe is one of the top tomato-producing districts in Malawi, with farmers benefiting from favorable weather conditions and access to markets in the city. The article highlights the success of a local farmer, John Phiri, who has increased his tomato yield to over 50 tons per hectare through modern farming techniques such as drip irrigation and improved seed varieties. Phiri's success has inspired other farmers in the area to adopt similar practices, leading to an increase in tomato production and improved livelihoods for smallholder farmers(Eviness et al., 2022a). Despite these successes, however, tomato farming in Malawi still faces several challenges, including limited access to credit, high input costs,

and market fluctuations. Tomato production in China, India, and the United States of America showcases significant agricultural contributions in each country.

2.4. Effects of rainfall and temperature variability on tomato production in Africa

In a study conducted in Tanzania, researchers found that rainfall variability significantly affected tomato production, leading to reduced yields and poor-quality fruits. The study also highlighted the importance of irrigation as a strategy to mitigate the effects of rainfall variability (Makoko et al., 2019). A study conducted in Mocambique found that rainfall variability was a major challenge to tomato production, leading to increased pest and disease incidence and reduced yield. The study suggested that using drought-tolerant tomato varieties and irrigation could help mitigate the effects of rainfall variability (Olaoye et al., 2020). In a review of tomato production in sub-Saharan Africa, researchers found that rainfall variability was a major challenge, particularly in areas with unreliable rainfall patterns. The review highlighted the need for improved irrigation systems and drought-tolerant tomato varieties to mitigate the effects of rainfall and temperature variability (Ndiritu et al., 2021). In a study conducted in Ethiopia, researchers found that rainfall and temperature variability affected tomato production, leading to decreased yields and an increased incidence of pests and diseases. The study suggested that using irrigation and improved agronomic practices could help mitigate the effects of rainfall variability on tomato production (Birhanu et al., 2018). A review of tomato production in Kenya found that rainfall variability was a major challenge, particularly in semi-arid areas. The review suggested that using drought-tolerant tomato varieties and improved irrigation systems could help mitigate the effects of rainfall and temperature variability on tomato production (Gachanja et al., 2018). Overall, these studies and reviews highlight the significant impact of rainfall and temperature variability on tomato production in Africa and suggest strategies to mitigate its effects(Karienye et al., 2018). Improved irrigation systems, drought-tolerant tomato varieties, and better agronomic practices are some of the key strategies that can help overcome the challenges posed by rainfall variability in tomato production in Africa.

2.4.1. Effects of rainfall and temperature variability on tomato production among smallholder farmers

In a study conducted in the southern region of Malawi, researchers found that rainfall and temperature variability significantly impacted tomato production, leading to reduced yields and an increased incidence of pests and diseases(Amosi & Anyah, 2024). The study suggested that using irrigation and improved soil fertility management could help mitigate the effects of rainfall and temperature variability (Chisonga Fackson et al., 2020). Another study conducted in Malawi found that rainfall and temperature variability was a major challenge for tomato production, particularly in the northern region of the country(Amosi & Anyah, 2024). The study highlighted the need for improved irrigation systems and drought-tolerant tomato varieties to overcome the challenges posed by rainfall and temperature variability (Masumba et al., 2019). A review of tomato production in Malawi found that climate variability, including rainfall and temperature variability, was a major challenge for tomato farmers in the country(Eviness et al., 2022b). The review highlighted the need for improved irrigation systems, the use of drought-tolerant tomato varieties, and better soil management practices to mitigate the effects of rainfall and temperature variability on tomato production (Jere et al., 2019). A study conducted in central Malawi found that rainfall and temperature variability significantly impacted tomato production, leading to reduced yields and increased pest and disease incidence. The study suggested that using improved irrigation systems and better crop management practices could help mitigate the effects of rainfall and temperature variability on tomato production (Mwangwela et al., 2020).

CHAPTER THREE

METHODOLOGY

3.1. Research design

This study used a correlation design, correlation design is a research approach that aims to understand the relationship between two or more variables without the researcher manipulating them(Bhandari, 2023). In this research design, the primary aim of correlation design is to assess the relationship between changes in rainfall and temperature associated with changes in tomato production. In tomato farming, rainfall and temperature both have important roles in the growth and development of tomato plants. Rainfall and temperature are selected as independent variables due to external factors that can impact tomato production. The dependent variable in the study is tomato production which is affected by variations in rainfall and temperature. A positive correlation occurs when both variables increase or decrease at the same time(Muhammad Hassan, 2024). A strong positive correlation is indicated by a correlation coefficient close to +1. A negative correlation occurs when one variable increases while the other variable decreases. A strong negative correlation is indicated by a correlation coefficient close to -1. When there is no correlation between variables is indicated by a correlation coefficient of 0 (Johnson, 2010). The research aimed to establish the relationship between annual average figures of rainfall, temperature, and tomato crop production over a fixed period of 11 years, from 2012 to 2023. The study was conducted in the Mpingu Extension Planning Area (EPA) in Lilongwe district, where there was a lack of information on the impacts of rainfall and temperature variability on tomato crop production(Cudjoe et al., 2021).

3.2. Research Methods

This study employed the quantitative research method due to its emphasis on numerical measurement and unchanging data. The study used annual rainfall and average annual temperature data as well as tomato production, both of which were expressed in numerical values. Quantitative research was characterized by its focus on the

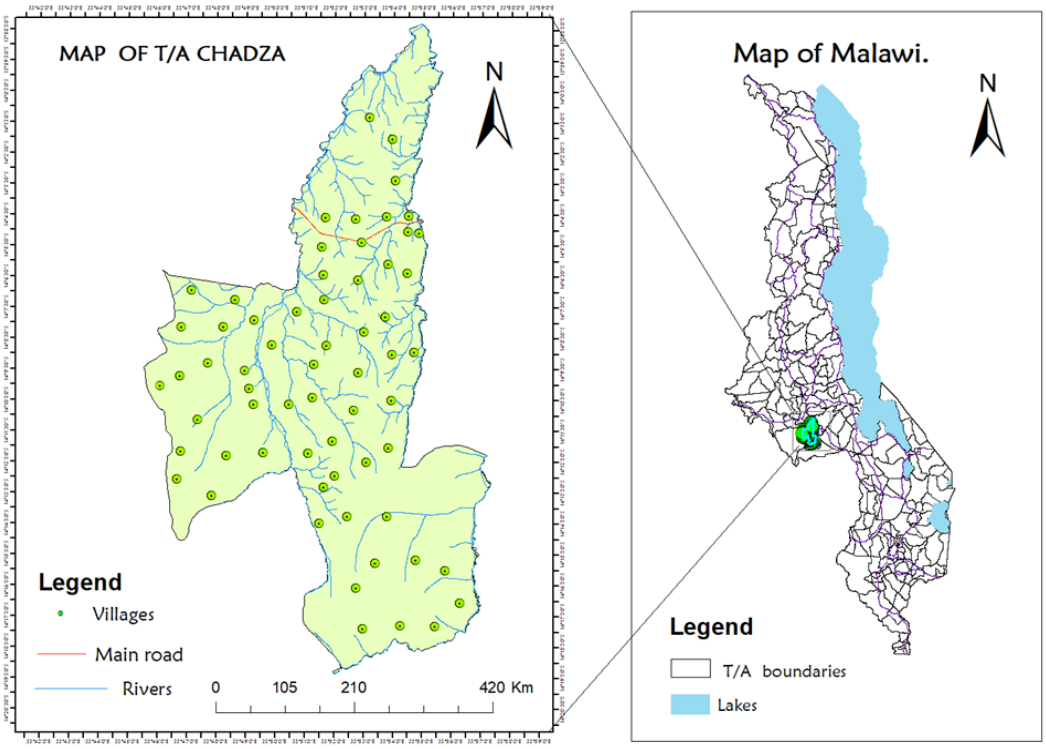
measurement and analysis of numerical data. In this study, the independent variable was rainfall and temperature, representing the varying levels of precipitation and temperature, while the dependent variable was tomato production, indicating the production of tomatoes. The differentiation between the independent variable (rainfall and temperature) and the dependent variable (tomato production) lies in their relationship. Rainfall and temperature serve as the factors influencing tomato production, making them the independent variables, while tomato production is influenced by rainfall and temperature, rendering it the dependent variable. This differentiation is crucial in understanding the cause-and-effect relationship between these variables.

3.3. Study area

The study area of this research is the Mpingu Extension Planning Area (EPA) situated within Lilongwe West, Malawi. Central region's capital Lilongwe is approximately 21 kilometers away from Mpingu EPA. The geographic coordinates of Mpingu EPA are latitudes $13^0$59'21.7''S and longitudes is $33^0$35'33.3''E. Mpingu EPA covers areas such as Chinsapo, Likuni, Chitedze, Mpingu, Nsalu, and Namitete. Mpingu EPA occupies a total land area of about 486 hectares of which some 230 hectares are under cultivation, 200 hectares are under buildings and indigenous pastures, and 26 hectares are under tree plantations. Mpingu EPA has a mean annual temperature of 20^0 c, and the amount of rainfall required for successful tomato cultivation in Mpingu EPA typically ranges between 500 to 800 millimeters annually(Chisonga Fackson et al., 2020). The highest temperature is in October, when the mean temperature is 24°C, while the coolest month's mean temperature is 16°C (Station Guide, 1998). Mpingu EPA is a region that thrives on agriculture, with a major portion of its vast lands dedicated to crop cultivation. The staple crops grown here include maize and a variety of vegetables like tomatoes. However, since the region depends heavily on rain-fed agriculture, there is a need to explore and implement advanced irrigation methods, particularly during dry spells, to boost productivity. Apart from agriculture, the region is also home to various livelihood pursuits, such as small-scale enterprises, livestock husbandry, and ongoing infrastructure development (Station Guide, 1998). This study used a map that shows

the borders of an area led by Traditional Authority (T/A) Chadza. This area includes the Mpingu EPA, which is managed by T/A Chadza, who is the main leader there.

Figure 1 Shows the map of the study area



3.4. Data collection

Average annual rainfall and temperature data from 2012 to 2023 was collected from the Department of Climate Change and Meteorological Services (DCCMS) headquarters in Blantyre. The rainfall and temperature data within the Mpingu EPA was obtained and measured from the Chitedze weather station which later was sent to the Department of Climate Change and Meteorological Services at Blantyre for data storage.

Farmers encountered difficulties in recalling tomato production data due to a lack of record-keeping, spanning from 2012 to 2023, which prompted the study to rely on secondary data sources. The tomato production data was collected from different farmers in Mpingu EPA which later was sent to Lilongwe West Agriculture Office

(LWAO) which is the headquarters of Mpingu EPA. The tomato production data for Mpingu EPA was obtained from the Lilongwe West Agriculture Office.

3.5. Data analysis

3.5.1. Evaluate the rainfall and temperature trend from 2012 to 2023.

Rainfall and temperature data adopted in this study were from the Chitedze Agriculture Station and covered 11 years, specifically from 2012 to 2023. It had been pointed out that this climatic dataset was subject to the Mann-Kendall analysis to find out its trends. To this end, linear graphs were used to depict trends in Excel over the stipulated timescale. The magnitudes of trends were then indicated in the graphs and measured using the slope estimator of Sen (Sen, 1968). The graphic representations helped in ascertaining whether indeed there were any differences in the patterns for rainfall and temperatures from one point to another. Imputation was a method used to fill in for the missing values where there were major gaps.

These included rainfall, temperature, and production patterns of tomatoes, among other steps, for data collection, preparation, analysis, and prediction. First, rainfall and temperature data for the years 2012 to 2023 were collected from the Chitedze Agriculture Station, with the intention that, by finding their relationship with tomato production, years of poor production due to changing weather would be pointed out. After collection, the data underwent rigorous cleaning and organizational processes. This was to identify and correct missing or otherwise erroneous values, in addition to standardizing data formats. Temporal alignment between datasets was also ensured to make sure they were coherent during analysis.

Statistical analysis was done to check for the presence of trends within the datasets. In this regard, Mann-Kendall formulas were able to indicate the non-parametric statistical techniques best adapted to detecting trends in time-series data, particularly if certain conditions were assumed and attributed to normality or linearity, which may not hold (Mann & Kendall, 1945). The Mann-Kendall analysis test was carried out to verify the possibility of trends, either monotonically increasing or decreasing with time, in the rainfall and temperature data series.

$$sgn(x_i - x_j) = \begin{cases} 1, & x_i - x_j > 0 \\ 0, & x_i - x_j = 0 \\ -1, & x_i - x_j < 0 \end{cases}$$

$$E(S) = \sum_{i=1}^{n} \sum_{j=i+1}^{n} sgn(x_i - x_j)$$

$$Var(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{p=1}^{n} t_p(t_p - 1)(2t_p + 5)]$$

$$z_{mk} = \begin{cases} \dfrac{E[S] - 1}{\sqrt{Var(S)}}, E[S] > 0 \\ 0, \quad E[S] = 0 \\ \dfrac{E[S] - 1}{\sqrt{Var(S)}}, E[S] > 0 \end{cases}$$

This test compared consecutive data values and was especially useful for non-uniformly distributed data, like meteorological data. The results of the test helped to understand the relationship between rainfall, temperature, and tomato production. This research also used time series forecasting to predict future trends in rainfall, temperature, and tomato production based on the data from 2012 to 2023. I finally, presented findings through visual representations such as charts, graphs, or other visualizations.

3.5.2. Assess the tomato production trend during the years 2012 to 2023.

The tomato data was collected from the Lilongwe West Agricultural Office for the Mpingu EPA from 2012 to 2023. The tomato data was the annual tomato production quantity. Tomato production data was analyzed using Mann-Kendall to determine if there is a monotonic trend (i.e., a consistent increase or decrease) in the data over time(Donald W. Meals et al., 2011). The negative Kendall's Tau values indicated a downward trend while the positive Kendall's Tau indicated an upward trend. Linear graphs were used to show the yield trend for the Mpingu EPA. Sen's slope is a statistical measure used to estimate the magnitude of change between two variables, typically used in the context of time-series data or paired observations. It is particularly employed in the Mann-Kendall trend test, which assesses the presence and direction of trends in a

dataset over time. The imputation technique was to find the missing values of the tomato production dataset.

3.5.3. Correlating annual rainfall, average annual temperature, and tomato production data of the Mpingu EPA.

Correlation analysis was carried out to understand the linear relationship between rainfall and temperature variability and the tomato production quantity of Mpingu EPA, student-tabulated values were used to test the significance of the correlation. The degree of the relationship between rainfall, temperature variation, and tomato production was analyzed using Pearson's correlation coefficient (r).

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

In the above equation, r is the product of the moment correlation coefficient, n means positive or negative relationship, x stands for test variable, which in this case is tomato production quantity, and y stands for control variable, which in this case was rainfall and temperature data, while the $\sum$ symbol stands for summation. The value of the correlation coefficient "r" usually varies between -1 and 1(JMP Statistical Discovery LLC, 2024). A perfect positive correlation is shown by a value of 1, a perfect negative correlation by -1, and no correlation by 0(JMP Statistical Discovery LLC, 2024). A stronger correlation between variables is observed when the value of "r" approaches either 1 or -1(Kozak, 2023).The sign of the correlation coefficient indicates the orientation of the correlation between the variables (Kozak, 2023). A positive "r" value shows a positive correlation, meaning that as one variable goes up, the other variable also tends to increase(JMP Statistical Discovery LLC, 2024). On the other hand, if the "r" value is negative, it suggests a negative correlation where one variable decreases while the other variable increases(Zakaria Jaadi, 2019).

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Introduction

This research was conducted as a case study for rainfall and temperature trend analysis on the effects of rainfall and temperature variability on tomato production among smallholder farmers. A case study of Mpingu EPA in Lilongwe district. Monthly rainfall and temperature data for eleven years (2012 – 2023) for the district was collected from Chitedze Research Station. This data included Monthly rainfall, maximum and minimum temperature, and annual tomato production. The time series analysis of rainfall and temperature data was done every year.

4.2. Descriptive statistics

4.2.1. Rainfall Variations

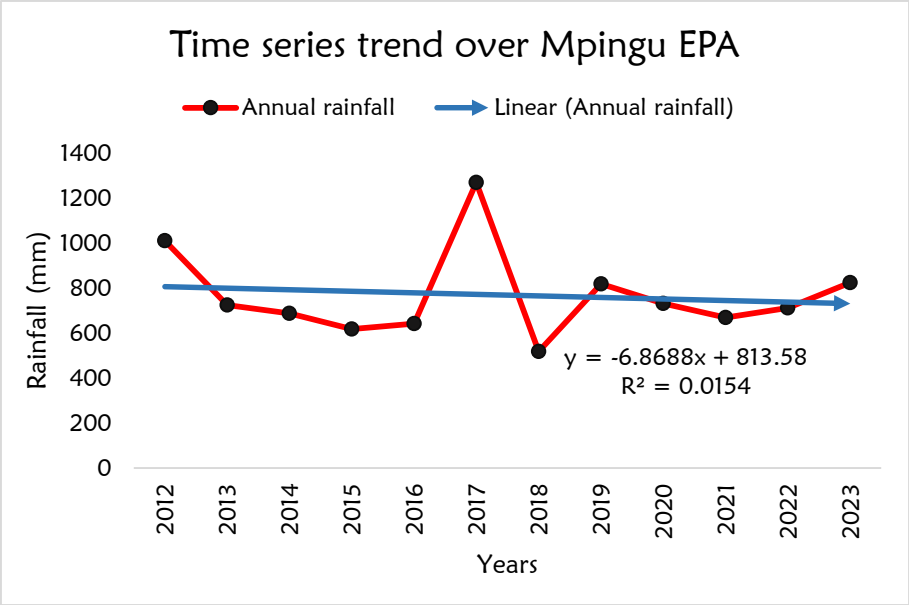
The analysis of the annual rainfall data for Mpingu EPA from 2012 to 2023 provides a compelling narrative of the region's climatic trends, revealing periods of both bounty and scarcity that have significant implications for the area's water resource management and agricultural planning. The following trends of patterns offer insights into the past and considerations for the future.

From the study, it was observed that the rainfall pattern over Mpingu EPA from 2012 to 2023 exhibited significant fluctuations, reflecting a dynamic and unpredictable climate. The rainfall amounts vary significantly from year to year. The year 2012 started with a high rainfall measurement of 1011.1 mm, suggesting a period of abundance in precipitation. This abundance, however, transitioned into a declining phase, with the lowest annual rainfall recorded in 2018 at 517.9 mm. Such a trend points to potential shifts in weather patterns, which could have implications for water resources and agricultural practices in the region.

The year 2017 was particularly noteworthy, as it marked an unexpected surge in rainfall, reaching an eleven-year high at 1269.4 mm. This sudden increase might be

attributed to specific atmospheric conditions or could represent a natural cyclical variation. Following this peak, the rainfall data from 2018 to 2023 showed a return to instability, with annual figures fluctuating without a discernible pattern. This erratic behavior underscores the complexity of predicting future rainfall trends.

Figure 2 Annual Rainfall Trends at Mpingu EPA (2012-2023)



A detailed account of the pattern of rainfall variability in the study area is shown in Figure 1 above. The trend equation and the annual rainfall trend line indicate a gradual decreasing (minus) trend (-6.8688x), which demonstrates that the average rainfall pattern has decreased at a steady rate over the years (2012-2023). The degree of variance indicates that the variability in the area's annual precipitation is less than 1% (R2 = 0.0154). In general, the total annual precipitation has decreased over the last 12 years as there was a decreasing trend for both rainfalls in the study area

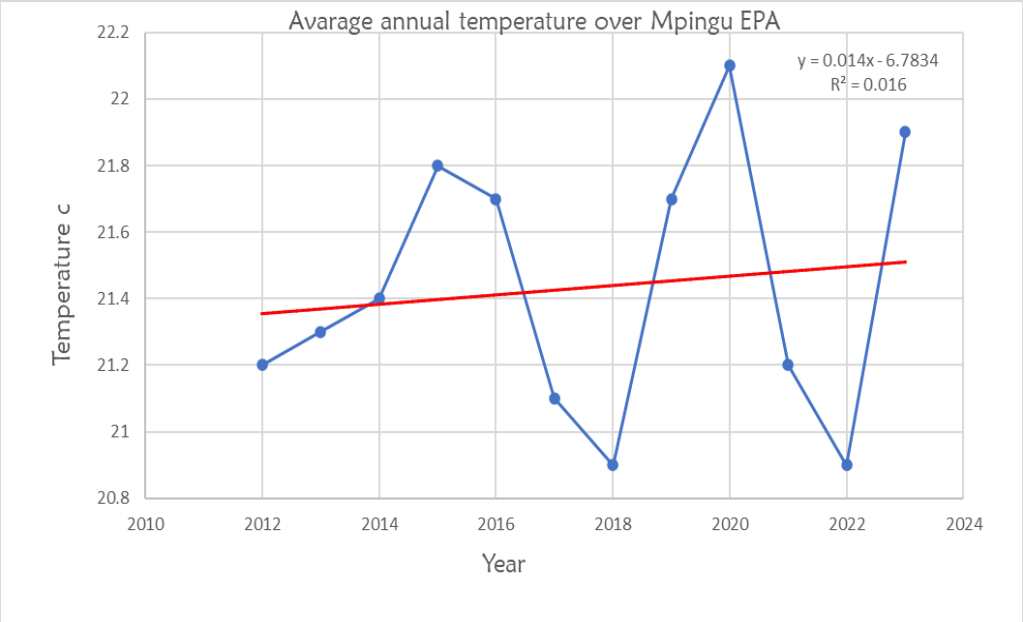
4.2.2. Average annual temperature

The trend in average annual temperatures across Mpingu EPA from 2012 to 2023 shows notable variations and a discernible pattern of change. From 2012 to 2015, the mean average temperatures increased rapidly, with minor fluctuations observed between

21.2°C and 21.7°C. The highest average annual temperature during this period was 22.1, which occurred in 2020. The lowest average annual temperature during this period was 20.9, which occurred in both 2018 and 2022. The overall trend shows fluctuations in the average annual temperature over the years with some years experiencing increase while others saw decreases.

The accompanying time series Figure 3 provides a visual representation of the temperature dynamics in Mpingu EPA. The inclusion of trend lines and equations offers a quantitative perspective, allowing us to discern the direction and rate of temperature changes over the observed period. This graphical analysis complements our statistical findings, presenting a clear and immediate depiction of the warming trend that could have profound implications for agricultural practices, particularly in tomato production.

Figure 3 Average Annual Temperature Trends over Mpingu EPA (2012-2023)



In 2012, the average annual temperature was 21.2˚c and in 2013, the average annual temperature increased to 21.3˚c. In 2014, there was a further increase to 21.4˚c. In 2015, the temperature rose to 21.8˚c. However, in 2016, there was a slight decrease to 21.7˚c. The trend continued with a drop in temperature in 2017 to 21.1˚c. In 2018, there was another decrease to 20.9˚c. The following year in 2019, there was an increase back up to 21.7˚c. Subsequently, in 2020 the temperature rose further to 22.1˚c. However, in 2021, there was a decline back down to 21.2˚c. In 2022, the temperature

remained at 20.9˚c, and finally, in 2023, there was an increase to 21.9˚c. The rising and decreasing of average annual temperature pattern in Mpingu EPA.

The average annual temperature variability in the study area is shown in Figure 4.4. The trend equation and the trend line indicate a gradual increase trend (0.0.14x), which demonstrates that the average annual temperature pattern has increased at a steady rate over the years (2012-2023). The degree of variance indicates that the variability in the area's average annual temperature is less than 1% (R2 = 0.016). In general, the annual temperature has increased over the last 12 years as there was an increasing trend and there exists a very weak positive linear relationship between x and y, indicated by the correlation coefficient being close to zero.

4.2.2. Production and Farm Size

Trend

The trend in tomato production over the years in Mpingu EPA shows a consistent upward trajectory. Both the area of land dedicated to tomato cultivation and the volume of production have increased steadily from 2012 to 2023. This trend indicates a positive growth pattern in the tomato industry within the region. However, there is a slight decrease in production observed in 2023 compared to the previous year, which may suggest a potential deviation from the established trend. Despite this minor fluctuation, the overall trend points towards continuous growth and expansion in tomato production over the analyzed period.

Variability

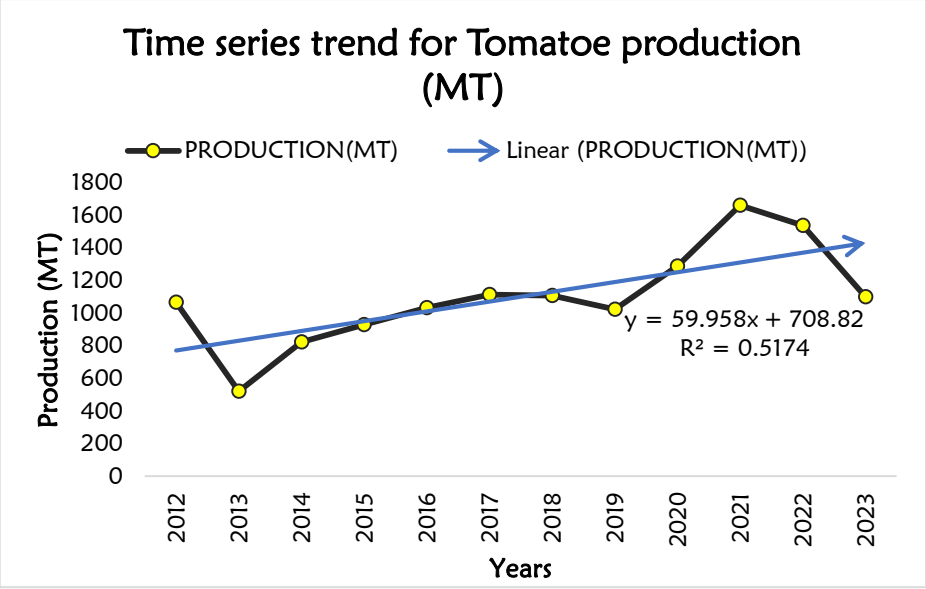
Variability is apparent in both the hectares of land cultivated for tomatoes and the production output across the years. While there is a general upward trend in production, there are fluctuations in production levels from one year to another. These fluctuations could be influenced by various factors such as weather conditions, pest outbreaks, and changes in agricultural practices. Notably, there is a significant increase in both the area cultivated and production output from 2019 to 2020, indicating a notable shift in tomato farming practices or environmental conditions during that period.

Comparison:

Comparing production figures across the years reveals significant differences in both the area of land cultivated and the volume of production. The highest production year is 2021, with 79 hectares cultivated and a production volume of 1659 metric tons, indicating substantial growth in the tomato industry. In contrast, the lowest production year is 2013, with only 26 hectares cultivated and a production volume of 519 metric tons, highlighting potential challenges or limitations faced by farmers during that period. Despite fluctuations, the overall trend shows consistent growth in tomato production in Mpingu EPA over the analyzed period, suggesting a positive outlook for the industry. Overall, comparing production figures provides valuable insights into the dynamic nature of tomato farming at Mpingu EPA, highlighting both successes and areas for improvement in agricultural practices and resource management.

The time series figure presented below illustrates the trajectory of tomato production in Mpingu EPA from 2012 to 2023. It includes a linear trend line and its corresponding equation, providing a mathematical representation of the production trend over time. This visual aid serves to enhance our understanding of the production dynamics by quantifying the rate of change and offering a predictive insight into future trends. The linear equation, in particular, allows us to estimate production levels at any given point within the timeframe, thus offering a valuable tool for strategic agricultural planning.

Figure 4 Annual tomato production trends over Mpingu (2012-2023)



The linear trend equation (Y = 59.958x + 708.5) and the R-squared value of (0.5174) from the graph provide insights into the trend of tomato production in Mpingu EPA. The slope of (59.958) indicates that for each year, the tomato production increases by approximately (59.958) metric tons. The intercept (708.5) represents the estimated production at the starting point of the analysis when (x) (the year) is zero. An R-squared of (0.5174) means that about (51.74%) of the variation in tomato production can be explained by year-to-year changes. This moderate value suggests that while time is a significant factor in production trends, other factors also play a role.

4.3. The rainfall and temperature trends during the years 2012 to 2023

4.3.1. Total annual rainfall

One of the objectives was to evaluate the rainfall trend during the years 2012 to 2023. In the historical record of rainfall over Mpingu EPA, a discernible pattern emerged over the years. Each year witnessed fluctuations in precipitation, with certain months experiencing notably higher rainfall compared to others. For instance, in 2012, January registered the highest rainfall at 268.5mm, marking it as the wettest month of the year. Subsequent months saw a gradual decline in precipitation, with no rainfall recorded from May to August. However, the year concluded with a resurgence in rainfall, with November emerging as the month with the highest recorded precipitation.

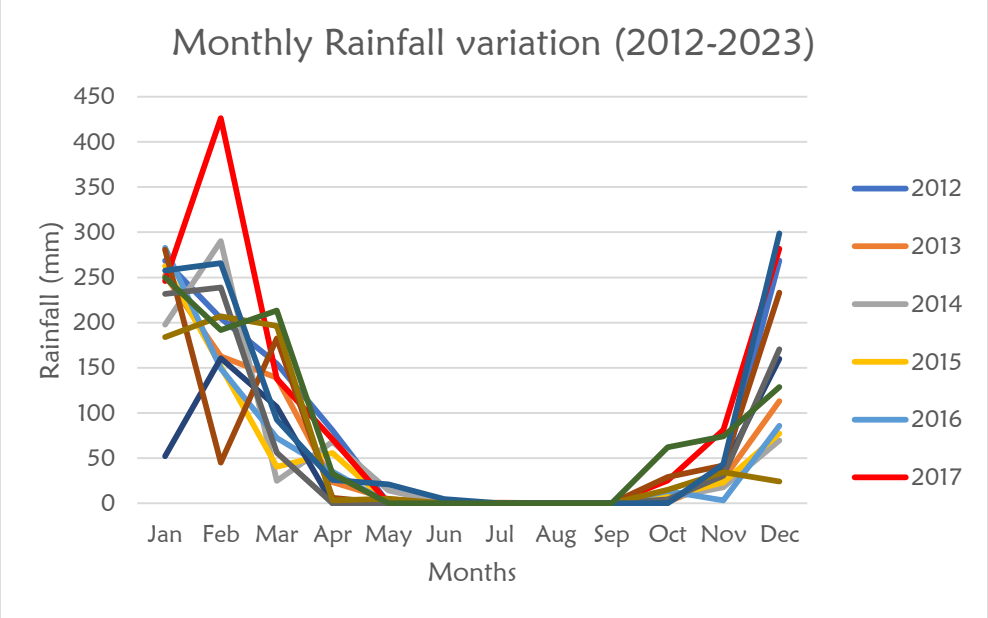
Similarly, 2013 followed a comparable trend, with January showcasing considerable rainfall at 252.3mm, making it the wettest month. While precipitation decreased in the succeeding months, a slight increase occurred in July before reaching its peak in November.

In 2014, The year began with moderate rainfall in January and February, followed by a significant decrease in March. Rainfall remained sporadic throughout the year, with notable peaks in August and December. In 2015, rainfall was relatively high in the first quarter, especially in January and February. However, there was a sharp decline in rainfall from March onwards, with sporadic showers in November and December. Similar to 2015, the year 2016 commenced with abundant rainfall in January and February. However, there was a noticeable decrease in March, with intermittent

showers in subsequent months. 2017 January started with moderate rainfall, followed by a substantial increase in February and March. Rainfall declined in April but spiked again in November and December. The year 2018 began with minimal rainfall, with notable spikes in February and March. There was a significant decrease in rainfall from April to July, followed by moderate precipitation in the latter months.

The years 2018 to 2023 displayed similar variations in rainfall patterns. Despite fluctuations in the intensity and distribution of precipitation, certain months consistently emerged as the wettest throughout this period. For instance, in 2020, January recorded the highest rainfall at 231.6mm, while in 2022, January again stood out with 257.8mm of rainfall.

Figure 5 Monthly rainfall variation over Mpingu



4.3.3. Mann- Kendall trend analysis.

4.3.3.1. Annual Rainfall

The Mann-Kendall trend test is a non-parametric test that looks for monotonic trends in time series data and was performed for each year separately, using the monthly rainfall data for that year from 2012 to 2023. The null hypothesis of the test is that there is no trend in the rainfall data, and the alternative hypothesis is that there is a trend (either positive or negative). The following results were obtained.

Table 1 Total annual rainfall trend test

Items	Rainfall
Kendall tau	0.071
S	6
Z	2
Var(S)	212.667
P-Value (two-tailed)	0.892
Alpha	0.05

***, **, * Significant at 1%, 5% and 10% respectively

Kendall's tau: A value of 0.071 suggests a very weak correlation between the ranks of the data points. In other words, there is no monotonic trend. The S statistic is also 6, which supports the lack of a significant trend, as a non-zero S and Kendall's tau would indicate a trend but it is not significant. The variance of S is 212.6667, which is used to test the significance of Kendall's tau. A value of 212.6667 indicates the spread of the S values in the dataset. A p-value of 0.892 is much higher than the typical alpha level of 0.05, meaning there is no statistically significant trend. The slope of 6 suggests that there is a very weak trend, in the variable of interest over time. Given the p-value, this slope is not statistically significant.

Overall, the Mann-Kendall trend test did not reveal any significant trend in the annual rainfall over Mpingu EPA for the period tested. The data does not show a statistically significant increase or decrease in rainfall amounts over the years. This could imply that the rainfall pattern is relatively stable, or that any changes are not consistent enough to form a trend over the period under study.

The results of this study are consistent with some of the previous studies that have investigated the rainfall trend pattern over similar regions. For example, a study by Mwale et al. (2017) found that the rainfall in Malawi decreased from 1971 to 2000, with significant negative trends in January, February, and March. Another study by Chavula et al. (2019) found that the rainfall over Malawi showed a weak positive trend from 1960 to 2006, with significant positive trends in October, November, and

December. These studies also used the Mann-Kendall trend test and Sen's slope estimate to analyze the rainfall data.

4.3.3.2. Average annual temperature

Following the analysis of annual rainfall trends in Mpingu EPA, it was well-established that temperature plays a significant role in agricultural outcomes, including cultivating tomatoes—a key crop in the region. Recognizing this critical relationship, a Mann-Kendall trend test was conducted to discern the patterns and significance of temperature fluctuations over the past decade. The results of this test, shed light on the temperature trends and their potential influence on agricultural productivity and practices in Mpingu EPA.

Table 2 Average annual temperature trend test

Items	Average annual Temperature
Kendall's Tau	0.0775
Z	0.276
Slope	5.000
Vars(S)	209.667
P-Value(two-tailed)	0.782
Alpha	0.05

***, **, * Significant at 1%, 5% and 10% respectively

Kendall's tau: A value of 0.0775 indicates a very weak positive correlation between time and average annual temperature, suggesting a rising trend in average annual temperatures. The Z-score of 0.276 indicates that the trend is not statistically significant. An S value of 5.00 supports the presence of an upward trend of 5 units per year. A p-value of 0.782 is much higher than the alpha level of 0.05, indicating that the trend is not statistically significant at the 5% level. The estimated slope of 5.00 suggests that the average annual temperature is increasing over time. The mann-kendall analysis results

indicate that there is no statically significant trend in average annual temperatures based on weak positive correlation (Kendall Tau), non-significant z value(z=0.276), and high p-value (0.782)

The average annual temperatures do not show a significant trend. This could imply that the region is experiencing a warmer day. The significance levels are denoted by asterisks, with ** indicating significance at the 5% level for average annual temperatures. The average annual temperatures, however, do not reach a conventional level of statistical significance.

This could have implications for tomato production and overall agriculture in the area. Warmer temperatures, as indicated by the increasing trend in average annual temperature, may potentially lead to changes in growing conditions for tomatoes and other crops. These changes could include alterations in crop growth patterns, flowering, and ripening periods. While not directly addressed in the analysis, the observed trend in average annual temperature may not have contributed to variations in tomato production over the years, potentially influencing yields and overall agricultural productivity in the region.

4.4. Assessing the tomato production trend between the years 2012 and 2023.

This section of the study presents the empirical evaluation of tomato production in Mpingu EPA from 2012 to 2023. The objective was to assess the production data to examine any observable patterns or trends that have emerged over these years. By applying statistical analyses aimed to understand the extent to which climatic factors, such as the temperature variations and rainfall patterns previously discussed, may have influenced the productivity of tomato crops.

4.4.1. Mann Kendall analysis Using total annual tomato production in Metric tons

The Mann-Kendall test was conducted to assess whether there was a significant trend in total annual tomato production in Mpingu between the years 2012 and 2023. The Mann-Kendall test revealed compelling evidence of a significant trend in total annual tomato production in Mpingu EPA from 2012 to 2023. The following key results were obtained from the analysis.

Table 3 Annual tomato production trend test

Items	Rainfall
Kendall's tau	0.54
S	2.4
Z	36.00
Var(S)	212.67
P-value (two-tailed)	0.02
Alpha	0.05

***, **, * Significant at 1%, 5% and 10% respectively

The Mann-Kendall test results for total annual tomato production in Mpingu EPA from 2012 to 2023 indicate a significant upward trend. A value of 0.54 suggests a moderate to strong positive correlation, indicating that tomato production has been increasing over the years. The Z-score of 2.4 exceeds the critical value of approximately 1.96 for a two-tailed test at the 5% significance level, confirming that the trend is statistically significant. The S statistic/slope of 36.00 is positive, which further supports the presence of an upward trend in production. With a p-value of 0.02, the trend is statistically significant at the 5% level (**), meaning there is only a 2% probability that the observed trend is due to random chance.

The Mann-Kendall test suggests that there has been a statistically significant increase in total annual tomato production in Mpingu EPA over the specified period. This positive trend is likely to have implications for local agriculture, economy, and food security. Knowing the fact that the annual production of tomatoes depends also on irrigation and not only rainfed water, it is imperative to consider a range of factors that could

have influenced and coincided with the observed upward trend in tomato production. These factors encompass various aspects of agricultural management, technological advancements, market dynamics, and environmental conditions.

4.5. Correlating total annual rainfall, average annual temperatures, and tomato production data of the Mpingu EPA.

In the quest to understand the dynamics between climatic variables and agricultural output, this section of the research focused on the correlation between total annual rainfall, average annual temperatures, and tomato production data plus the cultivated area within the Mpingu Extension Planning Area (EPA). The objective was to employ statistical methods to explore the relationships between these variables and determine the extent to which they interact and influence one another. By establishing the strength and direction of these correlations.

Table 4. below of the Pearson correlation coefficient shows the linear correlation coefficients between two variables: average annual temperature or total annual rainfall, and tomato production in metric tons. The correlation coefficient is a measure of the linear relationship between two variables, ranging from -1 (perfect negative correlation) to 1 (perfect positive correlation). A correlation coefficient of 0 indicates no linear relationship.

Table 4 Pearson correlation coefficient

Climatic variables	Tomato production(r)	T value	p-value	remarks
Rainfall	0.1708	0.5200	0.6922	No Significant
Average Annual Temperature	-0.2062	-0.6323	0.2715	No significant

***, **, * Significant at 1%, 5% and 10% respectively

Figure 6 Correlation between total annual rainfall and tomato production.

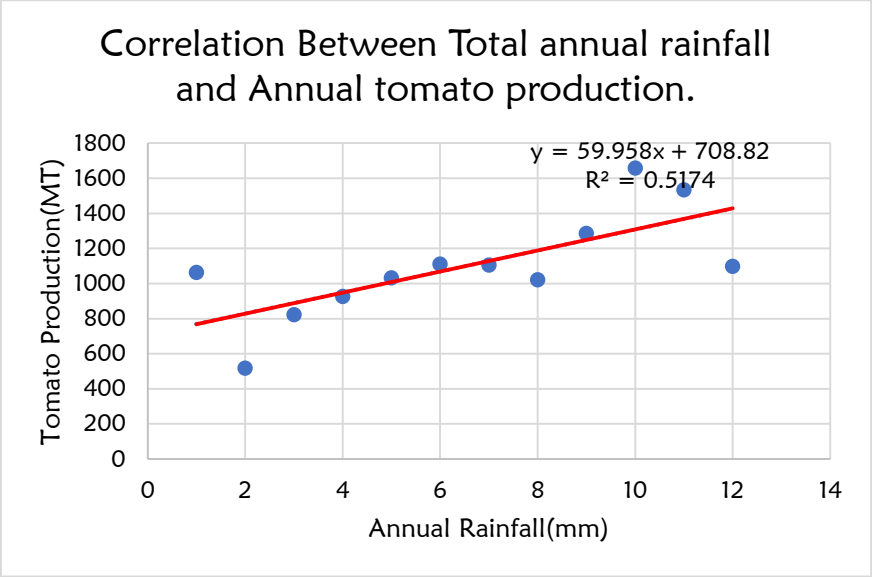
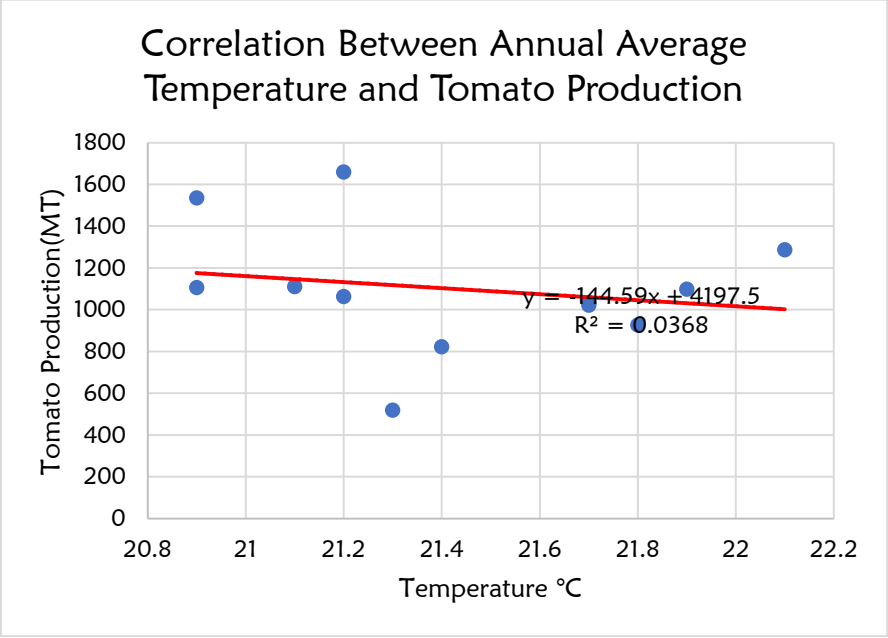


Figure 7 Correlation between average annual temperature and annual tomato production



The focus of the question was the relationship between total annual rainfall, average annual temperature, and tomato production in metric tons. The correlation coefficient between average annual temperature and tomato production, for these two variables

is -0.2062, which suggests that there is a negative correlation between the two variables. This suggests a weak negative linear relationship, implying that as average annual temperatures increase, there might be a tendency for tomato production to decrease as an inverse relationship. However, the coefficient's proximity to zero indicates that this relationship is very weak and not statistically significant. It implies that other factors may have a more significant influence on tomato production. Nonetheless, this negative correlation could be due to tomatoes generally favoring warmer growing conditions up to an optimal point, beyond which excessive heat may be detrimental.

Moving on to the correlation coefficient for annual total rainfall and tomato production, a positive coefficient of 0.1708 was found. This implies a weak positive linear relationship between the variables. A correlation coefficient close to zero suggests that there is almost no linear relationship between the two variables. Consequently, changes in rainfall do not appear to significantly influence tomato production in Mpingu EPA.

This implies that tomato production is not sensitive to changes in rainfall simply and directly. For example, if the rainfall increases by 10%, the tomato production does not necessarily increase or decrease by a proportional amount. This also suggests that rainfall is not the main determinant of tomato production in the study area. Rainfall is still an essential input for plant growth and survival, and it may have indirect or conditional effects on tomato production that are not captured by the correlation coefficient.

However, this does not mean that rainfall is irrelevant for tomato production. There may be other factors that mediate or moderate the effect of rainfall, such as soil quality, irrigation, and pest control. Also, the relationship between rainfall and tomato production may not be linear, but rather nonlinear or complex. For example, there may be a threshold or optimal level of rainfall for tomato production, beyond which too much or too little rain may be detrimental.

This means that the effect of rainfall on tomato production may depend on other factors that interact with rainfall. For example, soil quality may affect the water retention and drainage capacity of the soil, which may influence how much water is

available for the plants. Irrigation may supplement or substitute the natural rainfall, which may affect the water stress or excess of the plants. Pest control may affect the susceptibility or resistance of the plants to diseases or insects, which may affect the quality and quantity of the harvest.

This also means that the relationship between rainfall and tomato production may not be constant or proportional across different levels of rainfall. For example, there may be a threshold level of rainfall below which tomato production is severely reduced due to water scarcity. There may also be an optimal level of rainfall that maximizes tomato production by providing sufficient water without causing waterlogging or flooding. There may also be a saturation level of rainfall above which tomato production is negatively affected by water excess or damage. An assessment of tomato production practices among rural farmers in Malawi highlighted by Eviness P. et al., (2022) emphasized the importance of tomatoes as a year-round crop for both cash and food. While the study's focus was on production practices, it implicitly suggests that climatic variables such as temperature and rainfall are crucial factors that farmers need to consider for successful tomato cultivation, found out that rainfall had different effects on tomato yield and quality depending on the growth stage, and that excess rainfall reduced the yield and quality of tomato significantly.

Furthermore, in South Africa, A study titled "Influence of climate on tomato yield and quality in South Africa" by Stephanus Malherbe, published in 2012 investigated the climatic factors associated with reduced yields in a high-yielding farm in the Limpopo province. It found that humidity, moisture, and temperature during the first 10 weeks after planting had a significant impact on tomato quality. This study emphasizes the importance of optimizing planting times according to local climate conditions to avoid compromising yield and quality.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The rainfall trend pattern over Mpingu EPA for the years 2012-2023 varies by month, season, and year. The results of the Mann-Kendall trend test indicate no statistically significant trend in total annual rainfall over the Mpingu EPA for the period examined. This indicates that the rainfall variability over Mpingu is influenced by multiple factors, such as local and regional climate, topography, land use, and human activities. Both Kendall's tau and the S statistic suggest a weak correlation between the ranks of data points and support the absence of a monotonic trend. The high p-value further confirms the lack of statistical significance in trend detection. Consequently, it appears that the rainfall pattern in the area remains relatively stable over the studied years, with no consistent increase or decrease in rainfall amounts observed. This finding is crucial for understanding regional climate dynamics and can inform local water resource management strategies.

The analysis of average annual temperature trends in Mpingu EPA reveals no significant and consistent increase in average annual temperatures over the past decade, as indicated by Kendall's tau, the Z-score, and the statistically significant p-value. The average annual temperatures show a slight negative correlation, it lacks statistical significance, suggesting a less pronounced trend. The graphical representation further illustrates the steady rise in temperatures, emphasizing the need for adaptation strategies in agriculture to mitigate the impacts of climate change.

The empirical evaluation of tomato production in Mpingu EPA from 2012 to 2023 reveals a significant and consistent upward trend in total annual tomato production, as evidenced by the Mann-Kendall analysis. The statistically significant positive correlation, supported by the Z-score and p-value, indicates a substantial increase in tomato production over the specified period. This trend is likely to have profound implications for local agriculture, economy, and food security, suggesting potential improvements in agricultural practices, market dynamics, and technological advancements. While

climatic factors such as temperature and rainfall patterns are crucial considerations in understanding agricultural productivity, the observed increase in tomato production underscores the multifaceted nature of influences on crop yields.

The correlation results for temperature, rainfall, and tomato production reveal interesting insights into the relationships between these variables in Mpingu EPA. Firstly, the weak correlation coefficients between average annual temperature, total annual rainfall, and tomato production suggest that there is no significant linear relationship between these factors. While there might be slight tendencies for tomato production to increase with higher temperatures and decrease with higher rainfall, these associations are very weak and not statistically significant. This implies that other factors beyond temperature and rainfall, such as soil quality, pest control measures, and crop management practices, likely have more substantial influences on tomato production in the region. Furthermore, the lack of a significant correlation between rainfall and tomato production highlights the complexity of agricultural systems, where various interacting factors contribute to crop yields.

5.2. Recommendations

1. Promotion of Climate-Smart Agriculture, implement policies to promote climate-smart agricultural techniques such as improved water management, drought-resistant crop varieties, and sustainable irrigation practices. These measures can help farmers adapt to changing climatic conditions and minimize the negative impacts of erratic rainfall patterns on crop yields.

2. Investment in Irrigation Infrastructure, increase investment in irrigation infrastructure and technologies to mitigate the risks associated with erratic rainfall patterns and ensure reliable access to water resources for agricultural purposes. This includes both large-scale irrigation schemes and small-scale water harvesting and conservation initiatives tailored to local needs and conditions.

3. Enhanced Weather Monitoring and Early Warning Systems, strengthen weather monitoring and early warning systems to provide farmers with timely and

accurate information on climate variability and extreme weather events. This includes the development of localized weather forecasting tools and the dissemination of weather-related advisories and alerts to support informed decision-making and adaptive management practices.

4. The government should collaborate and coordinate with other stakeholders, such as farmers, researchers, NGOs, or international organizations, to share information and experiences, foster innovation and learning, and address the challenges and opportunities of tomato production and consumption.

5. Diversification of Agricultural Practices, encourages farmers to diversify their agricultural practices by exploring alternative crops that are less sensitive to variations in rainfall. This strategy would help reduce dependency on rainfall-dependent crops like tomatoes and mitigate the risks associated with fluctuations in precipitation.

APPENDIX

Limitations

1. Data availability and accuracy, Access to reliable and accurate data on rainfall, temperature, and tomato production can be challenging, especially in Malawi where agricultural data collection and reporting systems may be less developed or inconsistent. This could limit the ability to draw definitive conclusions from the study.

2. Other environmental factors, while rainfall and temperature are important determinants of tomato production, other environmental factors such as soil quality, water availability, pests, diseases, and management practices can also significantly impact yields. These factors were not explicitly considered in the study, which could limit its scope and applicability.

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