Assessing climatic and non-climatic impacts on smallholder maize production in Tshimapha Irrigation Scheme, Limpopo Province.

by

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DECLARATION

I, **Ntsemeni Rainah Mudzanani [17000165],** declare that this dissertation is my original work, and it has not been submitted for any degree at any other university or institution. All reference material contained therein has been duly acknowledged and referenced accordingly.

21 February 2024

Ntsemeni Rainah Mudzanani Date

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I am immensely grateful to my family, especially my Mother. Thank you for your support and encouragement to keep going. Thank you for being the best mother any daughter could ever ask for. I love and appreciate you always.

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DEDICATION

To my parents,

Thinavhuyo Jeremiah Mudzanani

Muhali Muthaphuli Mudzanani

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ABSTRACT

Globally, climatic extremes and non-climatic factors are a major concern due to their emerging and expected impacts on maize production. Climatic extremes come through drought and floods, whilst non-climatic factors include lack of education, poor management, and lack of support. The study evaluated the impacts of climatic extremes and non-climatic factors on the production of maize yield and further examined measures for sustainable production of maize yield in Tshimapha Irrigation Scheme, Limpopo Province of South Africa. The irrigation scheme was established in the 1960s, and today has 115 smallholder farmers, each having 1.5 hectares. Climate data was obtained from the Agricultural Research Council (ARC), South African Weather Services (SAWS) and from literature. Questionnaires were administered among the 115 smallholder farmers. The key informant interviews were conducted among the farmer's leaders, community leaders and extension officers. The extension officer and smallholder farmers assisted with generating maize yield data. For the first objective, rainfall data was analysed using *Mann-Kendall* test analysis in R-Studio. Furthermore, Sen's slope was also done to determine the magnitude of the trend of the rainfall, monthly, seasonal, and yearly and questionnaires were analysed using Microsoft Excel Version 2310. For the second objective, the Standardized Precipitation Index (SPI) was analysed using rainfall data in Microsoft Excel, and the last objectives were analysed using Statistical Package for the Social Sciences (SPSS) by looking at the percentage distribution. The findings of this study indicated an increase in the intensity and amount of rainfall received during flood years, with floods peaking in January and February. The SPI indicated that the area is not prone to severe drought as it is mountainous. The highest production of maize yield was 3.4 tons, with the least being 1 ton per year (based on the available data). Water and land for farming in the scheme were sufficient before the establishment of the Mutshedzi dam, which restricts access to dam water, and the land taken for some of the farmers during the establishment of the dam. This study is in response to national, regional, and global demand for knowledge on how smallholder farmers can adapt to erratic climates and in support of achieving the Sustainable Development Goal (SDG) Number 2. This study can be useful the in working towards alleviating challenges experienced by smallholder farmers in South Africa to ensure sustainability in smallholder production.

Keywords: Climatic extremes, Drought, Flood, SDGs, Smallholder farmers.

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TABLE OF CONTENTS

DECLARATION i

DEDICATION iii

ABSTRACT iv

LIST OF FIGURES viii

LIST OF TABLES x

LIST OF ACRONYMS xi

LIST OF APPENDICES xii

CHAPTER 1: INTRODUCTION 1

1.1. Background 1

1.2. Conceptual framework 3

1.3. Problem statement 4

1.4. Aim of the study 4

1.4.1. Study objectives 5

1.4.2. Research questions 5

1.5. Relevance of the study 5

1.6. Assumptions of the study 6

1.7. Summary 6

CHAPTER 2: LITERATURE REVIEW 7

2.1. Introduction 7

2.2. Impact of climatic extremes 7

2.3. Non-climatic impacts on maize yield production 8

2.4. Adaptation to climatic extremes 9

2.5. Drought 9

2.6. Flooding 12

2.7. Maize yield estimation 12

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2.8. Summary 14

CHAPTER 3: MATERIALS AND METHODS......15

3.1. Introduction......15

3.2. Study area map 15

3.3. The study area characteristics 16

3.3.1. Description of the study area......16

3.3.2. Climate 16

3.3.3 Soil 17

3.3.4 Elevation......17

3.4. Research design......17

3.5. Methods of data collection 18

3.5.1. Secondary data 18

3.5.2. Primary data......18

3.6. Population sampling 19

3.7. Data presentation and analysis......19

3.7.1. *Mann-Kendall test* 19

3.7.2. Sen's slope estimator......20

3.7.3. Standardized Precipitation Index (SPI)......21

3.8. Research approach 23

3.9. Summary 24

CHAPTER 4: RESULTS AND DISCUSSION 25

4.1. Introduction......25

4.2 Drought and floods impacts on maize production 26

4.2.1. Drought occurrence between 1970 and 2021......27

4.2.2. Standardised Precipitation Index Analysis......29

4.2.3 Flood occurrence 30

4.2.4 Rainfall trend analysis using Mann-Kendall......32

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4.2.5. Maize production between 1970 and 2021 34
4.2.6. The Standardized Precipitation Index (SPI) and Maize yield production 35
4.2.7. Flood impacts on maize yield 36
4.3. Non-climatic factors hindering maize yield production 37
4.3.1. Lack and high cost of farm inputs 38
4.3.2. Provision of business advice and services 39
4.3.3. Limited Access to Modern Agricultural Technology 39
4.3.4. Poor management of the schemes 40
4.3.5. Insufficient education 41
4.3.6. Lack of support 42
4.4. The maize yield production before and after the Mutshedzi dam 45
4.4.1. Maize production before the dam 45
4.4.2. Maize production after the dam 48
4.4.3. The climatic variabilities 49
4.4.4. The seasonality shifts 50
4.5. Summary 50
CHAPTER 5: SUMMARY, RECOMMENDATIONS AND CONCLUSION 52
5.1. Summary 52
5.2. Recommendations 52
5.3. Conclusion 53
REFERENCES 54
APPENDICES 69

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LIST OF FIGURES

Figure 1: Conceptual Framework showing the linkage between climatic extremes, non-climatic factors, and maize production. 4

Figure 2: Maize Yield in Africa (these are the findings of the study by (Epule et al., 2022)). 13

Figure 3*: Study area map showing Mutshedzi Dam and Tshimapha Irrigation Scheme (Phadzima Madzuwa and Tshitavha) Makhado Local Municipality.* 15

Figure 4: Research approach. 23

Figure 5: The rainfall pattern from 1979 to 2016 in Tshimapha Irrigation Scheme. 26

Figure 6: SPI during drought years from 1970 to 2021 in Tshimapha Irrigation Scheme 28

Figure 7: Average monthly rainfall during flood years in rainfall season (October to March).....30

Figure 8: The rainfall received monthly during the flood years in the rainfall season. 31

Figure 9: Maize yield in tons during the drought years for the ten farmers...............................34

Figure 10: Standardised Precipitation Index and maize yield during drought...........................36

Figure 11: Maize yield produced by Ten farmers for the year 2021 during floods. 36

Figure 12: Percentage distribution of the non-climatic challenges in Tshimapha Irrigation Scheme..38

Figure 13: Percentage distribution on how often the department officials visit the Tshimapha Irrigation Scheme for monitoring 40

Figure 14: Education level of farmers in Tshimapha Irrigation Scheme. 41

Figure 15: Percentage distribution of age...42

Figure 16: Percentage distribution of 'Where farmers get information regarding the upcoming drought and floods'...43

Figure 17: Percentage distribution of the number of years in the farming sector. 43

Figure 18: Employment status of farmers in Tshimapha irrigation scheme. 44

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Figure 19: Percentage distribution of 'where farmer was getting water for irrigation before the dam..46
Figure 20: Percentage distribution on how the maize production was before Mutshedzi Dam. .46
Figure 21: Percentage distribution of current maize production. 47
Figure 22: Percentage distribution on means of land ownership' of farmers in Tshimapha Irrigation Scheme. 47
Figure 23: Percentage distribution of 'Do you think you have enough space for your maize production? 49

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LIST OF TABLES

Table 1: Drought categories using Standardised Precipitation Index values of McKee et al. (1993). 22

Table 2: Drought events classification using SPI-6 in Tshimapha Irrigation Scheme 27

Table 3: Rainfall analysis using *Mann-Kendall* and *Sen's slope* during rainfall season for the year, 1972, 1975, 1977, 1981, 2000 and 2021 (Appendix 6 and 7). 32

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LIST OF ACRONYMS

ARC: Agricultural Research Council
Ha: Hectare
IFAD: International Fund for Agricultural Development
IPCC: Intergovernmental Panel on Climate Change
LIM 344: Makhado Local Municipality
***MK*:** Mann Kendall
SAWS: South African Weather Services
SDG: Sustainable Development Goal
SPI: Standardized Precipitation Index
SPSS: Statistical Package for the Social Sciences
SSA: Sub-Sahara Africa
UN: United Nations

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LIST OF APPENDICES

Appendix 1: Recommendation letter
Appendix 2: Climate data from South African Weather Services
Appendix 3: Farmers questionnaires
Appendix 4: Key informant's interview
Appendix 5: Standardized Precipitation Index analysis on Excel
Appendix 6: Mann-Kendal test in RStudio
Appendix 7: Sen's slope test in RStudio
Appendix 8: During data collection in Tshimapha Irrigation Scheme
Appendix 9: Template of the register used data collection and meetings with farmers
Appendix 10: Furrow irrigation system in Tshimapha Irrigation Scheme
Appendix 11: Questionnaire tool used for smallholder farmers
Appendix 12: Questionnaire tool used for key informants
Appendix 13: Ethical clearance certificate

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CHAPTER 1: INTRODUCTION

1.1. Background

Climate change has increased the severity of climatic extremes such as droughts, floods, and heatwaves, with severe impacts on the production of maize in the Tshimapha Irrigation Scheme, Vhembe District of Limpopo Province in South Africa, and the world at large. Climate extremes are explained as the occurrence of a hydro-climatic variables value being higher (or lower) than a defined extremely high (or low) threshold value (Tan et al., 2020). Different types of climate extremes are projected to intensify and become more frequent in several regions worldwide due to climate change, negatively impacting maize production and has implications on the livelihoods and food security in communities (Vogel et al., 2019). Floods, drought, heatwaves, and cyclones are posing significant impacts on the production of maize in the smallholder farmers of Vhembe District and the world at large (Mpandeli et al., 2019). Climate change is a threat that further worsens the already precarious production of maize by smallholder farmers. Not only are regions directly experiencing the extreme event affected, but also regions in other parts of the world suffer from indirect consequences such as higher food prices, among other challenges (Vogel et al., 2019).

Education (formal and non-formal) plays a crucial role in the development process through its effect on agricultural productivity (Ahmad Yahaya et al., 2022). Education is essential for agricultural production in a rapidly changing technological or economic environment. According to (Gowda & Dixit, 2015); Aldosari et al. (2019) the basic idea is that an adequate response to technological change in agriculture requires collecting and processing new information, and thus educated farmers respond more quickly than others. In developing countries, technological change has largely involved the distribution of new crop varieties and the use of artificial fertilizers (Paltasingh & Goyari, 2018). Under such circumstances, education influences agricultural productivity by first boosting farmers' adoption of these technologies and then boosting farmers' capacity to increase production from specific resources by making effective use of the newly introduced technology. While education exposes farmers to a more dynamic and systematic production system, it is anticipated that agricultural productivity will increase faster as a result (Myeni et al., 2019). This illustrates the need for further research on the effects of farmer education on agricultural productivity in Africa.

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Even though the world's climate varies from decade to decade, a changing climate is natural and expected (Kephe, 2013). Climate change is the natural cycle through which the earth and its atmosphere will accommodate the change in the amount of energy received from the sun (Beillouin et al., 2020). The climate goes through warm and cold periods, taking hundreds of years to complete one cycle. Temperature changes also influence rainfall, but the biosphere can adapt to a changing climate if these changes take centuries (Fagariba et al., 2018). Unfortunately, human interventions are currently causing the climate to change too fast, with climate models predicting that the mean air temperature over South Africa will increase by an estimated 2°C over the next century (Kolstad & Johansson, 2011). Crops do not adapt as quickly to this rapid climate change and extremes as humans (Keshavarz & Moqadas, 2021).

The shortage of knowledge about how smallholder farmers are coping with and adapting to climate change and climatic extremes impedes attempts to help farmer adaptation, despite being one of the most susceptible groups to climate change. Additional research is required to understand how different smallholder farmers view and react to climate change. (Harvey et al., 2018). While broad adaptation strategies exist, there is a need to contextualize them on a local scale. According to Tun Oo et al. (2020), agriculture is one of the most climate-dependent human activities, as it is susceptible to different climatic conditions, such as rising temperatures and changes in rainfall. Furthermore, global historical climatic data show that temperatures are increasing, while rainfall has also become more erratic (Miranda et al., 2023). Climate variability has destructive impacts on agricultural systems because of the drying up of temporary water bodies and the reduced groundwater resources to a critical level by extreme droughts (Keshavarz & Moqadas, 2021).

According to Kori et al. (2012), climate change poses a threat to crop production in the semi-arid zones of South Africa and several semi-arid areas at large. Rainfall variability in such areas makes smallholder farmers more susceptible to climatic shocks and uncertainties since rainfall has resulted in droughts or floods that have significantly impacted the rural and poor smallholder farmers who rely on natural rainfall for maize production. Moreover, climate models predict an increase in the frequency and intensity of extreme weather events, which can be partially attributable to modifications in land use and anthropogenic emissions, among other things (AghaKouchak et al., 2020).

AghaKouchak et al. (2020) indicate that droughts and floods often result from interactions between various physical processes that might not be considered extreme, but they result in

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significant impacts when combined. A study conducted by Fagariba et al. (2018) suggested that the majority of African nations are susceptible to climate change due to issues including extreme weather, poverty, and inadequate government support for agriculture to lessen the effects of extremes (Teshome & Zhang, 2019). According to Feng and Hao (2020), droughts are among the most catastrophic natural hazards to crop production. Numerous studies have recognised the damages of these extremes to crop yields at regional and global scales. Mpandeli et al. (2019) agree that long-term climatic changes are a basis for developing tailor-made adaptation strategies.

Keshavarz and Moqadas (2021) indicate that some major adaptation strategies to these climatic extremes by smallholder farmers include reducing cultivation areas and changing cropping patterns. Beillouin et al. (2020) argue that extreme weather increases the risk of large-scale crop failure. Vogel et al. (2019) concur that to secure and optimise yields in a changing climate is crucial to understand the impacts of climatic extremes on crop yields in the past and present climate to help predict the future. Yield, the mass of harvested crop product in a specific area, is influenced by several factors (Liliane & Charles, 2020). This study intends to assess the climatic factors (drought and floods) and non-climatic (agricultural practices and managerial decisions) factors influencing the maize yield production in the Tshimapha Irrigation Scheme.

1.2. Conceptual framework

The study's conceptual framework presented in Figure 1, shows the linkages between climatic extremes, non-climatic factors, and their impacts on maize yield production. Climatic extreme impacts are causing a decline in agricultural productivity due to extreme weather conditions experienced (Troy et al., 2015; Elahi et al., 2022). The reduction in crop production results in limited harvest for smallholder farmers. All these climatic extremes lead to the tremendous negative impacts that require intervention to help farmers sustain their farming activities. Therefore, to avoid smallholder farmers' vulnerability due to climate change, interventions and support systems should be available, accessible, and useful to smallholder farmers. As a result, agricultural production would significantly contribute towards improved food security and maximised livelihood options for improved well-being of smallholder farmers.

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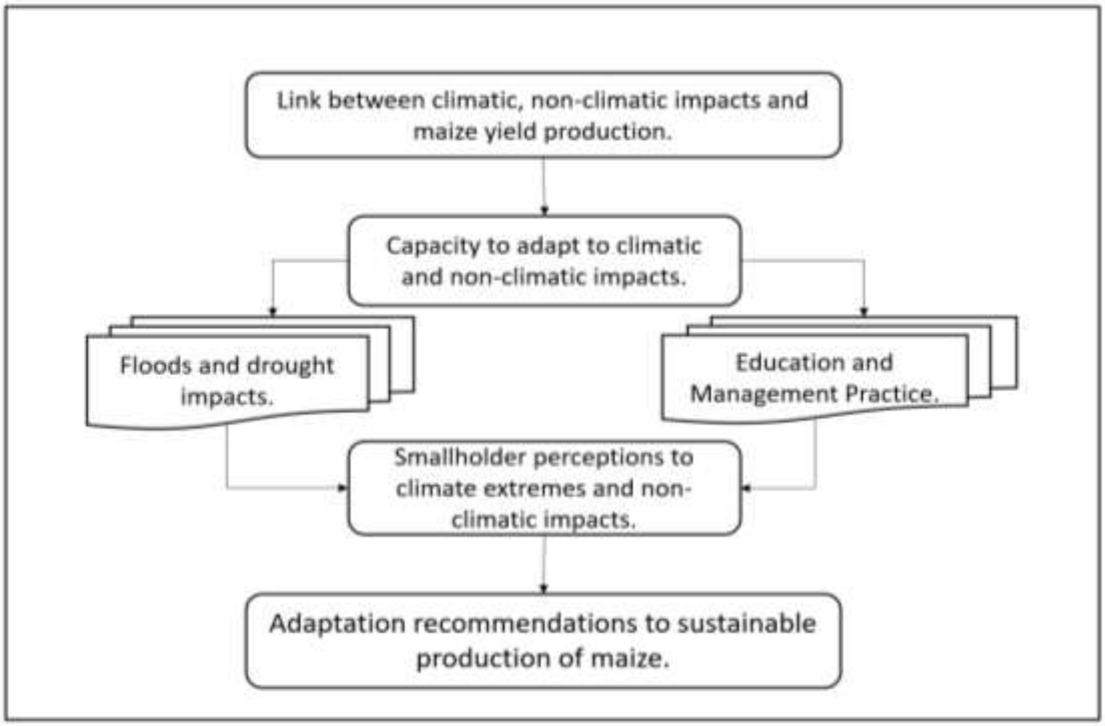

Figure 1: Conceptual Framework showing the linkage between climatic extremes, non-climatic factors, and maize production.

1.3. Problem statement

There is a projected trend for the continuation of the reduction in maize yield production in the Tshimapha Irrigation Scheme due to climatic extremes and non-climatic variables. Non-climatic factors such as insufficient education, agricultural practice, and management decisions are among the challenges smallholder farmers face. Climate extremes, such as drought and flooding, are leading to harvest failures and threatening the food security of rural communities worldwide. Farmers in Tshimapha Irrigation Scheme continue to report increasing stress due to climatic extremes and non-climatic factors.

1.4. Aim of the study

The aim of the study was to evaluate the influence of climatic extremes and non-climatic factors on the production of maize and further examine measures for sustainable maize production in Tshimapha Irrigation Scheme, Vhulaudzi Village, Makhado Local Municipality, Limpopo Province of South Africa.

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1.4.1. Study objectives

- To analyse drought and flood impacts on maize production between 1970 and 2021 Tshimapha Irrigation Scheme.
- To unpack the non-climatic factors hindering the maize yield production in Tshimapha Irrigation Scheme.
- To analyse the maize yield production before and after the establishment of Mutshedzi dam.

1.4.2. Research questions

- How did the droughts and floods between 1970 and 2021 affect maize production in Tshimapha Irrigation Scheme?
- What are the non-climatic factors hindering the maize yield production in Tshimapha Irrigation Scheme?
- How was the maize production before the dam's construction compared to the maize production after the dam?

1.5. Relevance of the study

Rain-fed crop production is a dominant mode of food production in most of the rural areas in Limpopo Province. Therefore, it is important to study rainfall patterns, variabilities, and climatic extremes in line with the production of maize. The reliance of the agricultural sector on natural rainfall places this sector at serious risk of shrinkage (Kori et al., 2012). For every 1% rise in agricultural yield, the proportion of absolute poor households worldwide decreases by 0.61–1.2% (Liliane & Charles, 2020). Academics and researchers have expressed concern over the growing impact of climate change in journal articles and researchers (Dube, 2018; Ojala et al., 2021; Von Uexkull & Buhaug, 2021; Abbass et al., 2022). The ever-changing climate makes it more interesting for researchers to find more concerning aspects of climatic extremes. This study supports Sustainable Development Goal (SDG) Number 2, 'End hunger, achieve food security and improved nutrition and promote sustainable agriculture (Sachs, 2015; Gil et al., 2019; Nugraha & Priyambodo, 2021). A good understanding of the dynamics involved in food production is critical for improving food security.

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1.6. Assumptions of the study

Climate is a primary determinant of agricultural productivity, especially in the case of developing countries like South Africa, where agriculture is dependent on natural circumstances. Climate change influences crop production to a greater extent in developing countries. According to Maharjan and Joshi (2013), plausible scenarios in climate, including increasing temperature, changes in precipitation, and climate extremes like drought and flood, will directly affect crop yields. An increase in the climatic extremes is likely to reduce yields and quality of food crops, thereby exacerbating vulnerability in the food supply. Similarly, changes in precipitation patterns and intensive rain concentration can also have a devastating effect on maize production.

1.7. Summary

This chapter provided background information about the study and an overview of the aim of the study. The aim of the research, as well as the research objectives and questions, are well explained. Knowledge is the best method to deal with climate extremes to succeed in the field of smallholder farming or irrigation schemes and the challenges faced by the sector. Climate change and climate variability appear to be the dominant climatic challenges faced by smallholder farmers. The necessity to adapt to these climate extremes and changes has prompted decision-makers in South Africa and other countries worldwide.

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CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

Throughout farming history, climate extremes have threatened human health and economic growth with non-climatic factors also having greater impacts posed to the sector of agriculture (Derbile et al., 2022). The observed increase in the effects of extreme events directly reflects an increase in exposure to natural hazards, climate change, and climatic variabilities (AghaKouchak et al., 2020). Climatic extremes severely impact agricultural production, which jeopardises food security worldwide making it crucial to look at the aspects of climatic extremes (Kogo et al., 2021). Natural resource-based activities such as agriculture are key to the livelihoods of the communities in Limpopo province, with over a million people engaging in small-scale agriculture to secure food (Louis & Mathew, 2020). The impacts of climate change on maize yield differ spatially; therefore, it becomes essential to look at the impacts posed to maize yield production in different regions (Segnon et al., 2021). In agricultural production, the climate is among the crucial factors which significantly affect production and the dependence on the climatic factor makes agricultural activities vulnerable to climate variability and change (Gwambene et al., 2023).

Phuong et al. (2018) indicated that the link among farmers perceptions, learning processes, and their decisions to adopt adaptation strategies in agriculture remains a contested issue in the literature. This chapter reviews the literature from around the world, downscaling it to Tshimapha Irrigation Scheme on the impact of climatic and non-climatic factors on maize yield production. Comprehending the current adaptation methods implemented at the farm level and the perspectives of farmers on potential future adaptation strategies is crucial for creating new adaptation efforts and bolstering farmers' productivity (Aryal, Sapkota, Khurana, et al., 2020).

2.2. Impact of climatic extremes

Region-specific explorations of agricultural drought are critical for effective and efficient drought monitoring and adaptation strategies (Hamal et al., 2020; Hermans & McLeman, 2021). The ongoing climate change has accelerated and increased extreme weather events, such as drought and floods, with substantial regional variations (Crocetti et al., 2020). Climatic extremes affect many aspects of society and the environment globally with widespread consequences (Ault, 2020). The impacts of climatic extremes such as drought are notably higher in rain-fed agricultural countries such as South Africa, among other developing countries (Mangani et al., 2018; Meza et al., 2020). Among extreme events, drought and excessive rainfall are ranked as the first and

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second most significant cause of maize production loss (Li et al., 2019). In 2015 to 2018 South Africa experienced a prolonged drought that has affected agricultural production and water resources, with the impact already propagating into socio-economic (Matikinca et al., 2020; Dube et al., 2022). Due to the country's persistent and widespread severe drought impacts, robust emphasis on understanding the effects of this natural hazard on vital economic sectors is warranted (Adisa et al., 2019).

Pörtner, Roberts, Tignor, et al. (2022) assert that as global warming increases, societies will face more restrictions on their ability to adapt and make decisions and prospects for sustainable development will be restricted. The potential of both rapid and chronic onset development issues, like food insecurity and poverty traps, has grown due to climate change. To minimise loss and harm from climate change, adaptation interventions and transformative solutions that prioritise inclusive and wide-ranging climate-resilient development, as well as the eradication of poverty and inequality are required. The Sustainable Development Goals (SDGs) set forth by the United Nations (UN) are under jeopardy due to both climate change and vulnerability. This impedes the advancement of several objectives, including eradicating hunger and poverty (SDGs 1 and 2) (Gil et al., 2019).

2.3. Non-climatic impacts on maize yield production

With so much interest paid to the impacts of climatic events hindering crop production and making it more difficult to sustainably continue with maize production by smallholder farmers, numerous non-climatic impacts inhibit crop production and require as much attention as climatic impacts (Adeagbo et al., 2021; Khanal et al., 2021). Among many non-climatic conditions, awareness and education is one of the crucial aspects that demand attention toward sustained crop production. Kabiru (2020) found that there is a significant and positive relationship between education and agricultural productivity, indicating that education affects agricultural productivity in several ways. Education can boost agricultural productivity by increasing smallholder farmers productive capacities, exposing them to a more dynamic and systematic production system, and improving their capacity to select the ideal ratios of inputs to outputs, (Reimers & Klasen, 2013). Productivity growth and transformation involve the adoption of better technology and a more efficient allocation of resources, often through better management, which smallholder farmers lack (Pörtner, Roberts, Adams, et al., 2022).

Pittock et al. (2020) indicated that smallholder irrigation schemes in sub-Saharan Africa (SSA) have performed badly and failed to lift farmers out of poverty, enhance food security or improve

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local or national economies. At the same time, limited land and water resources have been used inefficiently and contributed to environmental degradation and detracted from other opportunities for sustainable development. Farmers across SSA have used agricultural production systems adapted to local biophysical and socio-economic conditions and have used agricultural water management (Aryal, Sapkota, Rahut, et al., 2020).

2.4. Adaptation to climatic extremes

Adaptation is defined as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2014; Kom, 2020; Pörtner, Roberts, Tignor, et al., 2022). According to this definition, the term 'adaptation' involves financial adaptation, socioeconomic and institutional adjustment. Hence, adaptation to climate change has been identified as a set of activities with which a population responds to various pressures resulting from a changing climate. Phuong et al. (2018) suggested that farmers' perceptions and contextual factors like culture, education, and resource endowment influence their decisions about climate change adaptation. Recent literature on smallholder farmers' decisions to adapt to climate change indicates that adaptation is driven by multiple stressors (Singh et al., 2020; Bedeke, 2023; Leroy et al., 2023). According to Kephe et al. (2020), the question of what to produce cannot be divorced from the farmers' overarching management goals when examining agricultural production and management. According to Phuong et al. (2018) even in cases where farmers perceive high risks, their ability to make adaptation decisions may be hampered by a lack of resources and socioeconomic constraints.

2.5. Drought

Drought is defined as an unpredictable natural phenomenon aggravated by the changing climate and anthropogenic drivers (IUCN, 2017; FAO, 2018; Haile et al., 2020). Agriculture sectors face many risks, such as climate and market volatility, pests and diseases, extreme weather events (FAO, 2018). The Intergovernmental Panel on Climate Change IPCC (2014) AR4 (Fourth Assessment Report) has mentioned that, in general terms, drought is a prolonged absence or marked deficiency of precipitation, a deficiency of precipitation that results in water shortage for some activity or for some group or a period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance. According to the study by Mazibuko et al. (2021), droughts are destructive, resulting in devastating impacts on crop production. For instance, across Southern Africa, smallholder farmers with limited access to irrigation systems struggle to maintain crop production during drought. Ngcamu and Chari (2020)

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define drought as a deficiency of precipitation over an extended period usually a season or more, which results in a water shortage for some activity, group, or environmental sector. Frequent drought events with increasing severity can substantially impact agricultural productivity and food security in the regions with semi-arid hot climate (Organization, 2020; Oecd, 2022).

Since the 1970s, there has been a notable increase in the frequency and intensity of extreme climate events such as drought (Lin et al., 2020). The earth system model predicts that the danger of global drought will rise further in the 21st century (Liu et al., 2016; Sydney Shikwambana et al., 2021). Drought is still a common occurrence in African nations, primarily due to unfavourable weather patterns and climate fluctuations that negatively affect rural households and agricultural productivity (Ngcamu & Chari, 2020).

According to AghaKouchak et al. (2020), it has been difficult to ascribe a standard definition to drought, with different drought indices serving to represent various aspects of water availability and thus, studies that improve understanding of droughts and natural variability would increase knowledge of historical and projected drought trends. AghaKouchak et al. (2020) highlight the lack of studies researching the impacts of human activities on water stress and emphasised the importance of understanding the roles that human activities play in determining water availability. AghaKouchak et al. (2020) also called attention to the need to incorporate the role of humans in exacerbating and alleviating drought conditions. To improve regional and global drought management, it is vital to improve understanding of the relative contributions of natural variability and climate change on droughts (Cohen et al., 2021). The occurrence of drought coupled with high temperatures and late rainfall onset often forces farmers to reduce the size of the area planted, therefore resulting in low yields (Mazibuko et al., 2021). Thus, several studies conducted in the Vhembe District have shown that commercial farmers have a wider choice during prolonged drought than Smallholder farmers (Maponya, 2021; Kom et al., 2022; Shikwambana et al., 2022). However, farmers with good financial backups, good irrigation systems, and commercial farmers can easily switch their business to a suitable location easy for adaptation (Nabhan, 2013). However, Smallholder farmers are most affected due to their high dependency on the climate-sensitive rainfed agriculture sector, limited options, and lack of financial resources (Kom et al., 2020).

2.5.1. Types of droughts

There are numerous categories for droughts. For example, hydrologic droughts are caused by shortfalls in streamflow, meteorological droughts are based on precipitation deficits, agricultural

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droughts are based on soil moisture deficits, and socio-economic droughts arise when the demand for various commodities that require water exceeds the supply (Dai et al., 2020). The severity of drought determines the impacts and expected impacts to be posed to the maize production. In this study, four types of droughts were identified and studied. For maize production in this area depends on more than just rainfall but also on the stream flow during season on little to no rainfall. To facilitate communication, management, and response, drought often is categorised into four general types, (1) meteorological or climatological, (2) agricultural, (3) hydrological, and (4) socioeconomic (Wang et al., 2016).

i. Meteorological

Lack of precipitation during rainfall season is the first indicator of meteorological drought (Jasim & Awchi, 2020). A meteorological drought can be seen because of a precipitation shortage, or lack of precipitation during rainfall season (Torabi Haghighi et al., 2020). It is usually region-specific because the atmospheric conditions in different areas are highly variable in space and time. Depending on the duration of the meteorological drought, the soil humidity will be reduced (shorter term), and the groundwater table can be dropped (longer term). There are different indices for monitoring and assessing the extent of meteorological droughts, e.g. Standardized precipitation index (SPI), Standard stream flow index (SSI) and Standardized precipitation–evapotranspiration index (SPEI) (Spinoni et al., 2019; Salimi et al., 2021).

ii. Agricultural

Droughts are frequently characterised by a lack of rainfall and high temperatures (Orimoloye et al., 2022) and generally originates as a meteorological phenomenon, in which periods of low precipitation may produce water scarcity in various parts or the whole of the hydrological cycle (Tramblay et al., 2020). The hydrological cycle is primarily driven by these two climate parameters (Mukherjee et al., 2018). Insufficient and unevenly distributed rainfall has led to a decrease in crop production in Vhembe District (Mazibuko et al., 2021).

iii. Hydrological

Van Loon (2015) explains hydrological drought as a lack of water in the hydrological system, manifesting abnormally low streamflow in rivers and abnormally low levels in lakes, reservoirs, and groundwater. It is part of the bigger drought phenomenon that denotes a recurrent natural hazard. Hydrological extremes, which include floods and droughts, are global natural disasters that affect a vast number of people (Forootan et al., 2019). Smallholder farmers in Tshimapha

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Irrigation Scheme do not only rely on rainfed maize production but also rely on the supply of water from Mutshedzi and Tshiluvhadi rivers. Therefore the hydrological drought also affects them in a challenging manner.

iv. Socioeconomic

Socio-economic drought, or the lack of water available for socio-economic purposes, considers how the supply and demand of certain economic items, such as fruits, vegetables, cereals, and meat, are affected by drought circumstances, whether meteorological, agricultural, or hydrological in nature (van Ginkel & Biradar, 2021). A socioeconomic drought happens when there is a weather-related shortfall in water supplies, which causes demand for an economic good to outpace supply (Shikwambana et al., 2022).

2.6. Flooding

Smallholder farmers incur considerable losses during floods due to the destruction of crop after heavy rainfall (Mamun et al., 2021). Due to rapid increases in greenhouse gas emissions over the past century, precipitation patterns are changing, and extreme weather events such as floods are becoming more frequent and intense (McCarthy et al., 2021). Several studies have shown a possible increase in flood hazard for different regions of the globe based on both observations and future climate driven (Devitt et al., 2023; Edamo et al., 2023; Liu et al., 2023; Mashao et al., 2023). However, there is also significant regional variability and the attribution of these changes. Even though there are continental-scale analyses to document long-term trends in floods and their potential driving mechanisms, very little is known at the African region scale (Mavhura, 2019).

2.7. Maize yield estimation

There is a significant increase in the production of maize in South Africa and globally, and it is thus considered key in supporting global food security with most of the maize produced in the developing world coming from rural communities with the livelihoods of the most vulnerable populations strongly dependent on maize production (Leroux et al., 2019). With climate change, a significant decline in maize yield is foreseen for most parts of Africa (Akanbi et al., 2021; Degife et al., 2021). In addition, the population is expected to outgrow yield improvement, portending a decline in per capita food production in the coming years (Ibrahim et al., 2023). Among the current and future societal challenges brought by climate change, food security in regions with dominant smallholder farming systems remains a pressing priority, whereby timely and reliable information

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on maize crop yields and their inter-annual variability is urgently needed for effective decision-making (Matimolane, 2018).

According to the study by Epule et al. (2022), Africa's maize yields have assumed an overall rising trend between 1961 and 2019. They have increased from 499,210 hg/ha in 1961 to 855,422 hg/ha in 2019. Overall, there has been a 71.35% increase in maize yield across Africa. Figure 2 demonstrates some of the findings.

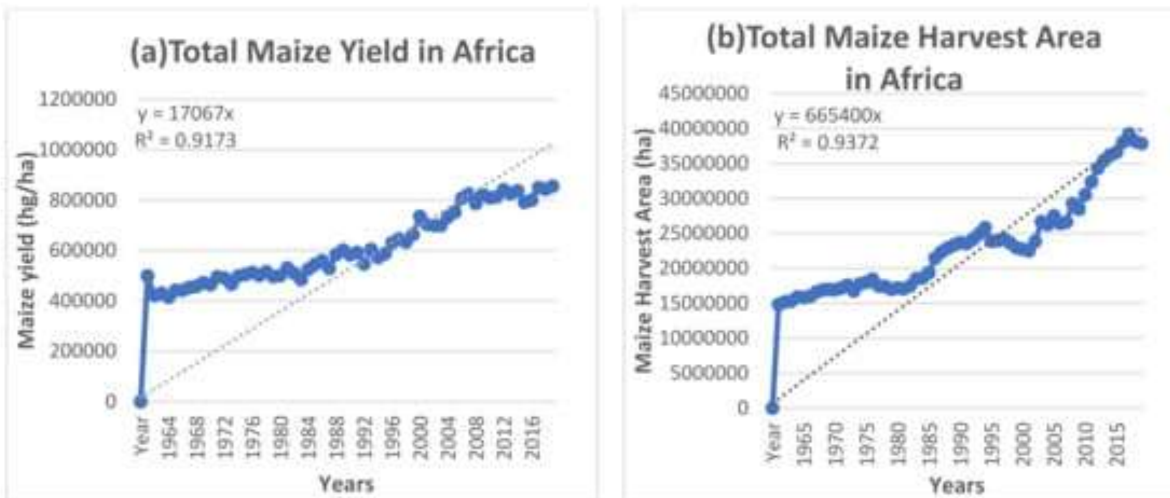

Figure 2: Maize Yield in Africa (these are the findings of the study by (Epule et al., 2022)).

There are several ways of estimating crop yields, from a plot to a continent scale (Sagan et al., 2021). Direct methods based on field surveys are expected to give reliable yield estimates, but they have significant weaknesses, including the cost in terms of time and labor and the difficulty of upscaling to large areas (Sakamoto, 2020; Rattalino Edreira et al., 2021). Another way of estimating crop yields is to use crop growth models that incorporate eco-physiological processes to simulate crop growth, development and yields according to soil characteristics, agricultural practices, and meteorological data (Fernandez-Ordoñez & Soria-Ruiz, 2017). Recent studies on rainfall patterns reveal that the frequency of extreme events is increasing while the frequency of moderate events is declining (Makungo et al., 2019). Understanding rainfall trends is critical in projecting future crop productivity under climate change, variability, and the world of climatic extremes. Past studies have demonstrated that the changing climate has already impacted farming and food systems, as evidenced by shifts in the rainy season and modifications in the environment (Sydney Shikwambana et al., 2021). Climatic extremes are causing agriculture to struggle to meet the growing food demands of an increasing population as the world faces water deficits and, consequently, low crop production. Changes in rainfall lead to changes in the amount

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of water available for farming activities, among other activities, which seriously impacts human life. The earth's climate has changed over the past centuries in terms of variations in rainfall, and one of the main impacts of climate change is the changing precipitation patterns. The amount of rainfall received in an area is an important factor in determining the amount of water available to meet various demands, such as agricultural, industrial, domestic water supply and hydroelectric power generation. The heavy rainfall leads to flood, and the other season exhibits an insufficiency of water to fulfil the irrigation requirements (Brema & Anie, 2018).

2.8. Summary

Climatic extremes and non-climatic factors threaten maize production and agricultural production at large. The spreading of early warning information to alert smallholder farmers and advise them on lowering the risks associated with high crop failure is fundamental. Agricultural policy development and implementation require an understanding of the causes and incentives that influence farmers' decisions. Numerous research in Africa, particularly in South Africa, are currently focusing on the agricultural production activities of farmers, particularly smallholder and subsistence farmers. Nevertheless, smallholder farmers in South Africa face numerous challenges that hinder their crop production.

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CHAPTER 3: MATERIALS AND METHODS

3.1. Introduction

This chapter outlines all the rational procedures taken in response to the research objectives through data collection and analysis. The methods utilised to gather the data to satisfy the study's objectives are represented in this chapter. The study utilised primary and secondary data sources that provided comprehensive information. A comprehensive discussion of the sample, analysis procedures, and research design is also provided.

3.2. Study area map

The Figure 3 shows the location of Tshimapha Irrigation Scheme within the Makhado Local Municipality (LIM 344) in Limpopo, South Africa.

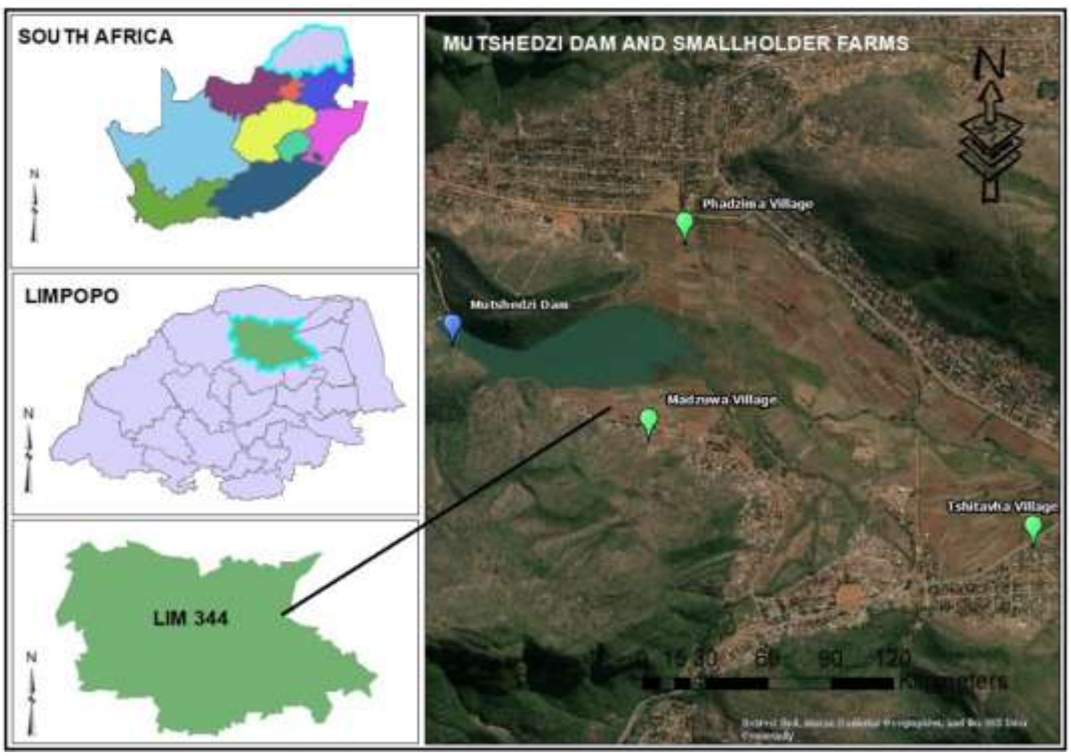

Figure 3*: Study area map showing Mutshedzi Dam and Tshimapha Irrigation Scheme (Phadzima Madzuwa and Tshitavha) Makhado Local Municipality.*

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3.3. The study area characteristics

3.3.1. Description of the study area

This study looked at the smallholder farming in Tshimapha Irrigation Scheme, which is found in Makhado Local Municipality. Although the scheme uses the furrow irrigation system (Appendix 10), it also relies on rainfall during the rainfall season (October-March). Rainfall is largely seasonal and mostly occurs during summer months, between October and March (Mazibuko et al., 2021). Mutshedzi Dam is located on the Mutshedzi River, a tributary of the Nzhelele River and located 40 km west of Thohoyandou, Limpopo, South Africa. The scheme was established back in the 1960s, and the dam was established in 1990, and serves mainly for consumption. Furthermore, this dam is located within the Vhembe District, Limpopo, in South Africa. The scheme is under performing and with the dam in the vicinity, it was interesting to understand the underlying challenges behind the under performance of the scheme.

3.3.2. Climate

This area has a semi-arid climate prevailing. It is warm to hot all year round. The average annual temperature ranges from 9° to 17° C during winter and 22° to 37° C during summer season and it receives about 544 mm of rain in a year (Ziervogel et al., 2006; Kom et al., 2022). Recent climate change models indicate that Vhembe District will face a warmer future, with temperatures predicted to increase by as much as 2°C by 2035, by 1-2°C between 2040 and 2060 (or between 2-5°C in the high-end scenarios), and by 3-6°C between 2080 and 2100 (or 4-7°C in the high-end scenarios) (Ncube et al., 2016; Kubayi, 2022). There is less certainty with regard to rainfall forecasts in Limpopo, with some climate models projecting decreases in rainfall, and others suggesting increases in rainfall in the province. Limpopo will experience greater variability in rainfall (Mpandeli, 2014).

Limpopo accounts for almost 60% of all fruit, vegetables, maize, wheat, and cotton produced in South Africa (Municipality, 2016). Livestock farming is also a significant contributor in the province. It is estimated that 33% of households in Limpopo are agricultural households with a large rural population that depends on agriculture as a means of livelihood and food security (Kativhu et al., 2020). Increasing temperatures and increasing variability in rainfall are predicted to result in a shifting of areas in the province that are suitable for certain crops, such as maize, with certain crops such as lemons, no longer becoming viable. Increases in temperatures will also result in the need for increased irrigation and cooling. Limpopo has been identified as the most

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vulnerable province in South Africa and is particularly vulnerable to the effects of climate change on agriculture because of the large proportion of smallholder farmers there (Municipality, 2016).

3.3.3 Soil

According to A. A. Mufungizi et al. (2020), the aim of SDGs launched by the United Nations in 2015 include ending poverty, protecting the planet and ensuring prosperity for all. Such a bold aim calls for action in understanding the relationships between the condition of the land, environmental factors that determine the productivity of land and the subsequent agricultural productivity of land in regions of the world that have long been known for agricultural activity. This is important because ending poverty cannot be considered in isolation from food security.

3.3.4 Elevation

Tshimapha Irrigation Scheme is surrounded by mountains, and according to farmers experience in the area they indicate that this also plays a role in ensuring that the scheme gets sufficient rainfall during rainfall season which also allows for their dam to remain in existence. The altitude ranges from 850 m to 910 m above mean sea. With an understanding that high temperatures enhance evaporation, which reduces surface water and dries out soils and crop or vegetation, and if this persists it result into drought. This area does not experience very high temperatures, the location of this scheme ensures that this scheme is not always susceptible to extreme drought ,thus the geographic location of Tshimapha Irrigation Scheme is suitable for maize production (A. A. Mufungizi et al., 2020).

3.4. Research design

For this study, integrated approaches using qualitative and quantitative methods were used (Clark & Vealé, 2018). Qualitative research was used to understand the perspective by looking at first-hand experience (Maxwell, 2021). Data on farmers' awareness and comprehension of climate change interventions and support systems, as well as on maize production, was gathered through focus groups with smallholder farmers. Individual farmers were given questionnaires to provide information on their perceptions of climate change support systems available to them to deal with climatic and non-climatic challenges (Appendix 11). For example, climate adaptation measures they have used, crops they cultivate, and what influences their decision. Key informants such as the extension officer, farmers leader, and community leader were interviewed to understand their role and the support they offer to the irrigation scheme.

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3.5. Methods of data collection

The collection of data serves as a crucial aspect of a research project as the collected data contributes to understanding the theoretical framework better. For this study, different methods were implemented depending on the intended output, and thus include primary and secondary data collection methods as explained in the following section.

3.5.1. Secondary data

Climate data, providing minimum and maximum temperatures and rainfall used in this study, were obtained from the Agricultural Research Council and South African Weather Service from 1970 to 2021. Maize yield data was obtained from smallholder farmers that keep a record of their maize yield production.

3.5.2. Primary data

3.5.2.1. Smallholder farmers questionnaires

A hundred and fifteen questionnaires were distributed to all smallholder farmers in Tshimapha Irrigation Scheme. The first part of the questionnaire captured the demographic information of the farmers and the second part of the questionnaire looked at the climatic impacts, a non-climatic impact assessment followed by the SDG 2 assessment of the adaptation to the sustainable production of maize. The questionnaire used closed and open-ended questions to allow farmers to provide additional information about climatic and non-climatic impacts on maize yield production. Google forms were used to distribute the questionnaires to the smallholder farmers (Appendix three and four). Questionnaires for both smallholder farmers and key informants are attached in (Appendix eleven and twelve). The qualitative data of this study included questionnaires and all data gathered from the focus group discussion were analysed using Microsoft Excel were used in data analysis to show the findings through graph representations.

3.5.2.2. Key informant interviews

Key informants included the Community Leader, the Department of Agriculture representative and the Farmers leaders at the Tshimapha Irrigation Scheme. These were interviewed face to face, which allowed for additional information. See Appendix twelve for interview schedule and guiding questions. The interview explored the views of respondents in dealing with climatic and non-climatic impacts to understand what needs to be balanced or supported. These interviews

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examined the understanding of the relationship between climatic extremes, non-climatic factors impact, and maize yield production, Appendix 11.

3.5.2.3. Maize yield data

The extension officer working with Tshimapha Irrigation Scheme assisted with providing the information of farmers that record their maize yield production data and using questionnaires, farmers assisted by giving their maize yield production data. Farmers helped in understanding the yield produced through questionnaires and interviews. During the interviews farmers were asked if the department officials would come to collect yield data, whilst extension officers were asked if such data is available on the record. Maize yield data was used to look at how these non-climatic factors are affecting their production to understand the non-climatic factors hindering the production of maize.

3.6. Population sampling

This study assessed smallholder farming in Tshimapha Irrigation Scheme, Vhulaudzi Village. A set of 115 questionnaires was sent out, and only 60 farmers responded. Purposive sampling criteria was used to choose the participating sample: the respondents were individual smallholder farmers engaged in the production of crops (maize), to provide both excess for sale and sustenance.

3.7. Data presentation and analysis

For the first objective, rainfall data was analysed using *Mann-Kendall* test analysis in R-Studio. Furthermore, Sen's slope was also used to calculate the rainfall trend's magnitude, monthly, seasonal, and yearly and questionnaires were analysed using Microsoft Excel Version 2310. For the second objective, Standardized Precipitation Index (SPI) was analysed using rainfall data in Microsoft Excel and the last objectives were analysed using SPSS by looking at the percentage distribution. Several methods were used to analyse and present data in this study. SPSS was used to analyse and presents qualitative data in form of tables and graphs (Smit & Scherman, 2021).

3.7.1. *Mann-Kendall test*

A non-parametric test called the Mann-Kendall test was used to identify trends in data by comparing ranks across a specified period. In this test, the data did not have to meet normality assumptions (Aditya et al., 2021). The World Meteorological Organization recommends this test

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to detect trends in a set of hydrological data (Brema & Anie, 2018; Sayyad et al., 2019). The Mann-Kendall test statistic is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign\left(x_j - x_i\right)$$

$$sign\left(x_j - x_i\right) = \begin{cases} +1\left(x_j - x_i\right) > 0 \\ 0\left(x_j - x_i\right) = 0 \\ -1\left(x_j - x_i\right) < 0 \end{cases}$$ [Equation 1]

A positive S value indicates an upward trend, while a negative value indicates a downward trend and *x* represent the sequential data value for runoff. The variance of the rainfall is calculated to obtain the Z value. Variance (S) is computed as:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i-1}^{m} t_i(t_i-1)(2t_i+5)}{18}$$ [Equation 2]

A tied group (m) is a rainfall data set with the same value when the sample size is n>10. The normal Z test statistic is calculated by the equation:

$$Z = \frac{S \pm 1}{Var(S)^{1/2}}$$ [Equation 3]

This equation uses S-1 if S>0, S+1 if S<0, and Z is 0 if S=0. A positive value of Z indicates an increasing trend. Otherwise, it indicates a downward trend.

3.7.2. Sen's slope estimator

The World Meteorological Organization recommends this test as part of the trend detection in hydrometeorological data (Ali et al., 2019; Nisansala et al., 2020; Nyikadzino et al., 2020). In this test, the trend is assumed to be linear and represents the quantification of the time change. Sen's Slope has an advantage compared to the linear regression where the test is not affected by the number of outliers and data errors (Aditya et al., 2021). (Ali & Abubaker, 2019; Murungweni et al., 2020) also employed a non-parametric MK test and Sen's slope estimates to test the trend of each extreme rainfall and temperature indices as well as their statistical significance. The Sen's Slope equation for a number of N data sample pairs is written as:

$$Q_i = \frac{(x_j - x_i)}{j - i}, i = 1,2,3,3, \ldots, N$$ [Equation 4]

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x_j and x_i are data values at time j and i (j > i), respectively. If there are n values of x_j in the time series, there will be N = n(n-1)/2 slope estimates. The N value of Q_i is sorted from smallest to largest, then Sen's Slope used median Q_i (Q_{med}). A two-tailed test estimated the value of Q_{med} at a confidence interval of 90% and 95%, which is calculated as:

$$Q_{med} = \begin{cases} Q_{\left[\frac{N+1}{2}\right]} & if\ N = odd \\ \frac{Q_{\left[\frac{N}{2}\right]}+Q_{\left[\frac{N+1}{2}\right]}}{2} & if\ N = even \end{cases}$$ [Equation 5]

3.7.3. Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is a widely accepted index for the quantification of drought. SPI was recommended through the Lincoln Declaration on Drought as the internationally preferred index for meteorological drought (Docheshmeh Gorgij et al., 2022). The SPI has become more significant in recent years as a potential drought indicator that enables comparisons across space and time because it expresses actual rainfall as a standardised departure from the rainfall probability distribution function (Naresh Kumar et al., 2009; Karavitis et al., 2011). To calculate the SPI, long-term precipitation data must be obtained to calculate the probability distribution function, which is then converted to a normal distribution with a mean of zero and a standard deviation of one. As a result, SPI values are given as standard deviations, where positive values denote precipitation above the median and negative values less than the median (Das et al., 2020; Alawsi et al., 2022).

$$S = \frac{X - X_m}{S_x}$$ [Equation 6]

Where:

s= Standardised Precipitation Index

x = Precipitation

xm = Mean

sx = Standard deviation

The Standardized Precipitation Index (SPI) is a widely accepted index for the quantification of drought, and Hayes et al. (2011) recommended it through the Lincoln Declaration on Drought as

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the internationally preferred index for meteorological drought. The only input variable for SPI is precipitation, so an increase or decrease in precipitation is very likely to result in, respectively, a wetting or drying tendency for SPI (Spinoni et al., 2019). The Standardised Precipitation Index (SPI) has proved to be one of the most competitive tools for assessing drought, and it is used nowadays for operational and research activities in more than 70 countries (Cheval et al., 2014). The Inter-Regional Workshop on Indices and Early Warning Systems for Drought Participants' pool agreed that the SPI is a universal meteorological drought index and that it should be used by all national meteorological and hydrological services (Hayes et al., 2011). SPI was proposed by (McKee et al., 1993), and many scholars have addressed the concept and methods, despite the main criticisms regarding the use of a single meteorological element for describing a complex event like drought. Through the rain-based meteorological drought, one can track the amount of drought just by the precipitation's value.

Table 1: Drought categories using Standardised Precipitation Index values of McKee et al. (1993).

Drought category	**SPI Values**
Extreme wet	2.0+
Very wet	1.5 to 1.99
Moderate wet	1.0 to 1.49
Near normal	-0.99 to 0.99
Moderate drought	-1.0 to -1.49
Severely dry	-1.5 to -1.99
Extremely dry	-2.0 and less

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3.8. Research approach

Figure four demonstrates the research approach used in this study, from setting objectives to collecting and analysing data.

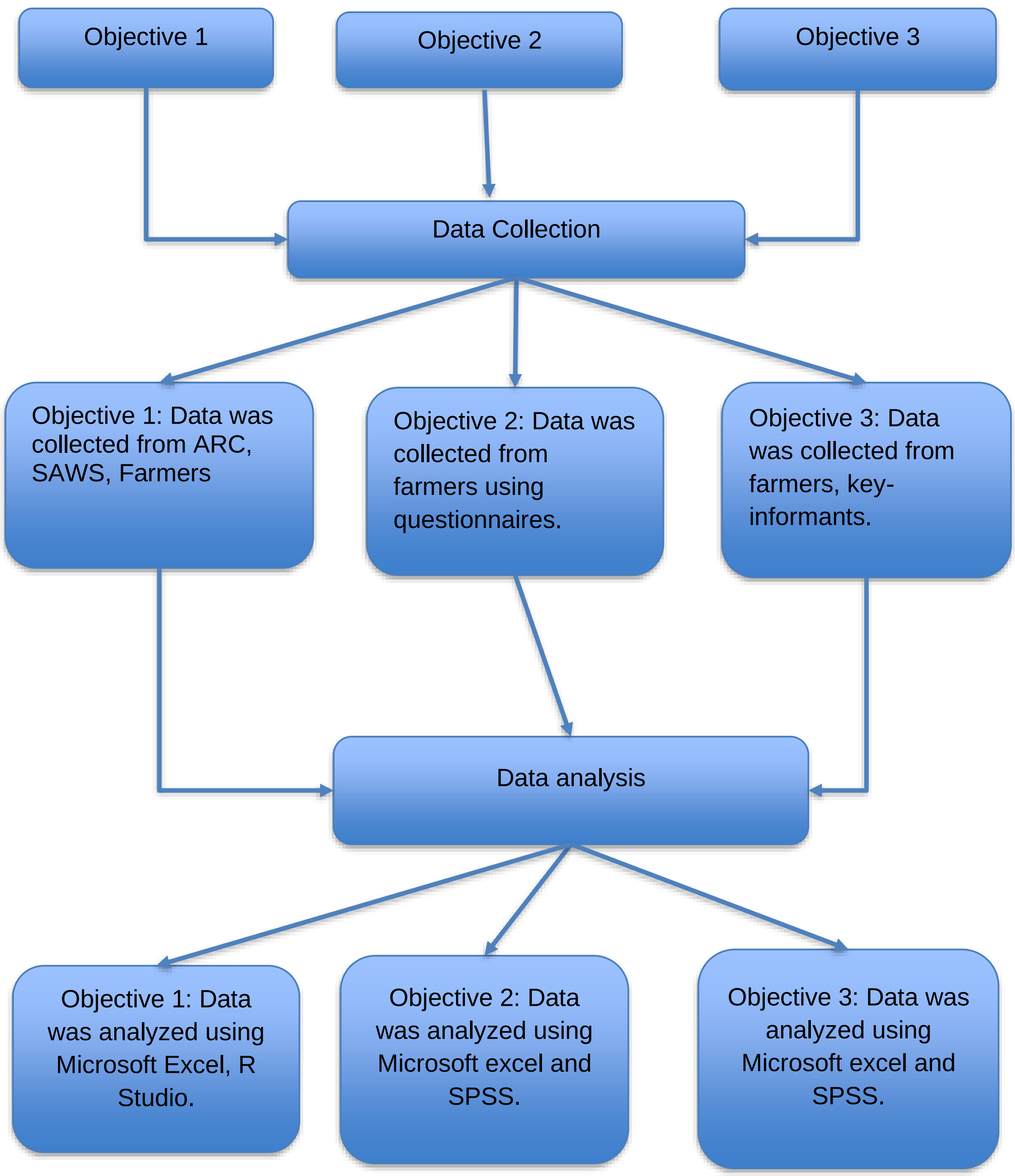

Figure 4: Research approach.

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3.9. Summary

This chapter introduced and justified the methods that were used to collect and analyse the data in this study. There was usage of both main and secondary data types. The primary data came from questionnaires and key informants' interviews, the secondary data was obtained from literature, SAWS, ARC, and Scientific journals. Smallholder farmers assisted with providing the maize yield production data. Purposive sampling was used to sample smallholder farmers and key informants.

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CHAPTER 4: RESULTS AND DISCUSSION

4.1. Introduction

This chapter present the research findings and discussion that respond to all the study's objectives. All the outcomes from the methods used were examined and presented. The first objective of this study is to present the findings and analysis of drought and flood occurrence between 1970 and 2021 in Tshimapha Irrigation Scheme and further look at the impacts posed on maize production. For the past years, Vhembe District has been one of the regions highly impacted by drought and floods with current and developing evidence that this might continue with severe impacts if the strategies put in place are not effective (Arunrat et al., 2022). The Vhembe District is dominated by stallholder farmers producing maize for substance and sale. In this chapter, drought and flood years were identified through literature, climate data and questionnaires, thereafter, the researcher looked at the impacts posed on maize production by assessing maize yield produced. The erratic climate conditions are exacerbating the challenges that hinder maize production in and around areas in Vhulaudzi Village. This chapter present the finding from the assessment of drought and flood trends between 1970 and 2021 and their impacts on maize yield production in Tshimapha Irrigation Scheme. Drought and floods in sub-Saharan Africa increase food insecurity, water scarcity, and famine, reflecting the region's vulnerability to climate change. Warning signals of the adverse effects of climate change in sub-Saharan Africa are manifest in higher food prices (Msowoya et al., 2016).

The second objective presents the findings and analysis of the non-climatic impacts hindering maize production in Tshimapha Irrigation Scheme. The need to understand the impact of non-climatic factors on agricultural crop production varies from place to place, as other areas are well developed than the other. Long-term implications of crop yield reduction are significant for food security and socioeconomic stability. These risks are particularly high for the less resilient, impoverished countries. Lastly, in the findings of the last objective, this chapter presented and analysed the findings that depict the maize production before the dam was established in 1990 and after the dam's establishment. Although the Mutshedzi Dam does not supply the Tshimapha Irrigation Scheme with water for irrigation, its establishment has impacted the production of the Scheme. The impact of the dam was indicated by some of the smallholder farmers in the Scheme, indicating that a significant part of their land for farming was taken during the establishment of the dam and they were left with little space for farming with other left with no space of land.

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4.2 Drought and floods impacts on maize production

Figure five demonstrates the rainfall pattern, with positive values (blue) representing the average and above average rainfall, the negative values representing the below average rainfall which can also symbolise the years of little to no rainfall in the Vhembe District.

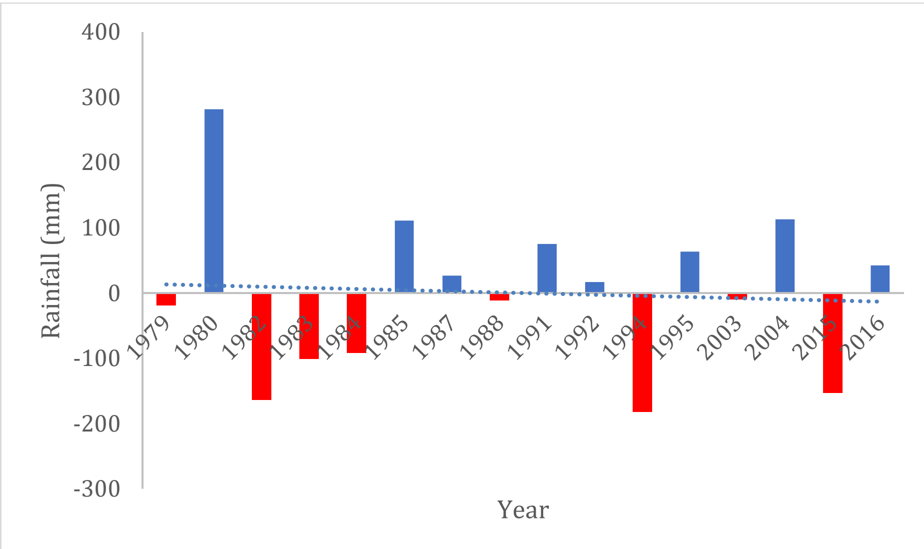

Figure 5: The rainfall pattern from 1979 to 2016 in Tshimapha Irrigation Scheme.

The severity of drought occurrence is identified to have been observed in the years 1982, 1983, 1984, 1994 and 2015. This can be seen through the severe shortage of rainfall in the period of six rainfall months (October to March).

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4.2.1. Drought occurrence between 1970 and 2021

Table 2: Drought events classification using SPI-6 in Tshimapha Irrigation Scheme

Year	January	February	March	October	November	December
1979	0,145	-0,098	-0,025	-0,010	-0,073	0,061
1980	0,034	0,027	-0,026	-0,021	0,010	-0,023
1982	0,071	-0,059	-0,296	0,096	0,031	0,156
1983	-0,092	0,012	0,101	-0,122	0,089	0,012
1984	-0,036	-0,069	0,043	0,017	0,099	-0,054
1985	0,012	0,047	-0,048	-0,011	-0,051	0,051
1987	0,042	-0,122	0,028	-0,072	0,007	0,117
1988	-0,026	-0,010	-0,008	0,111	-0,069	0,002
1991	0,079	-0,004	-0,003	-0,073	0,023	-0,022
1992	0,006	-0,020	-0,029	-0,023	-0,004	0,070
1994	0,088	-0,179	-0,095	0,041	-0,122	0,267
1995	-0,031	0,006	0,083	-0,040	-0,018	-0,001
2003	0,088	-0,128	-0,194	0,123	-0,028	0,139
2004	-0,048	0,045	0,056	-0,033	-0,022	0,003
2015	-0,037	0,050	-0,047	-0,168	0,205	-0,003
2016	-0,010	-0,058	0,049	-0,051	-0,033	0,102

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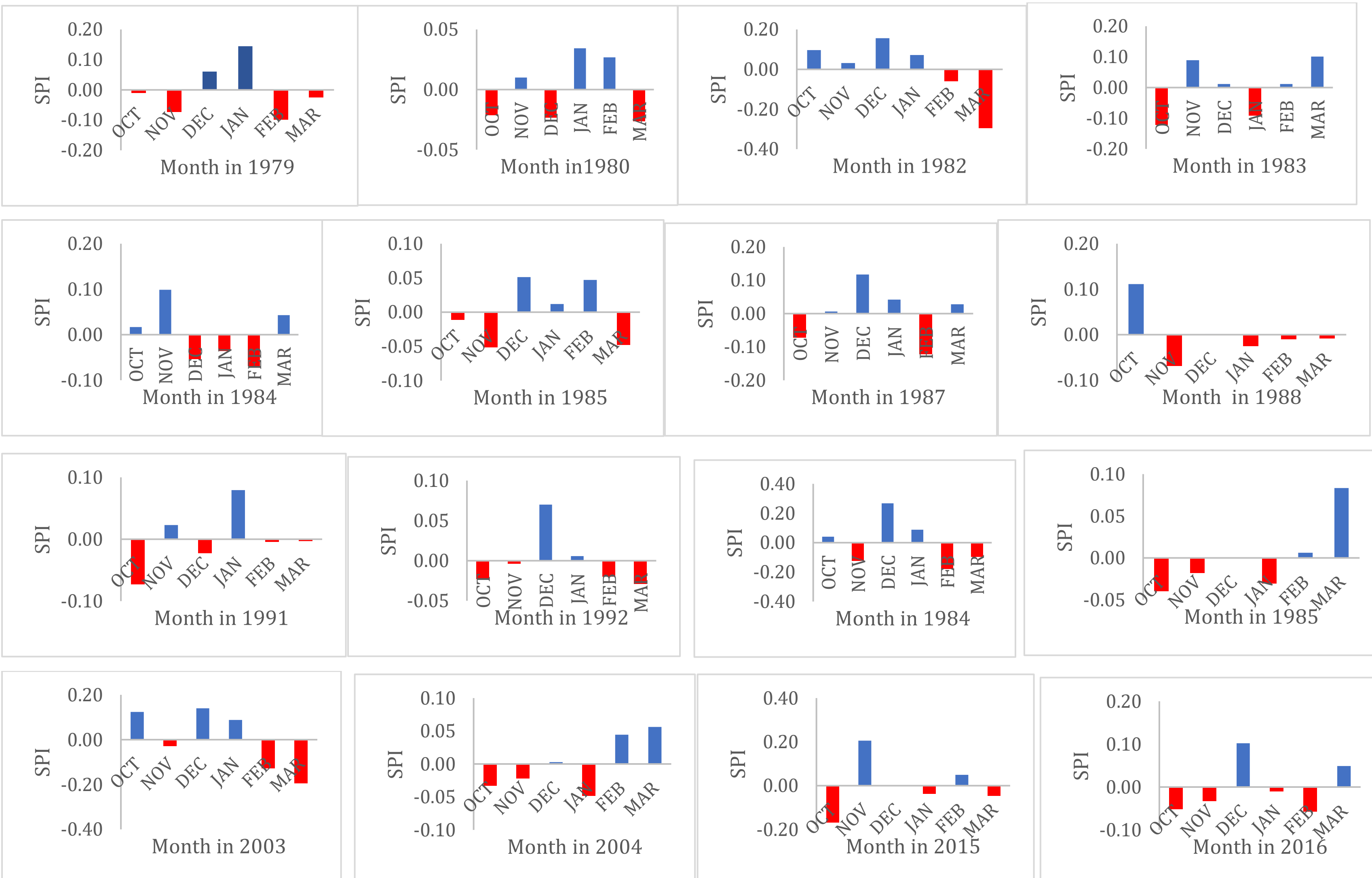

Figure 6: SPI during drought years from 1970 to 2021 in Tshimapha Irrigation Scheme

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Unlike floods, drought lasts longer and covers a larger area when occurring. Vhembe District had drought in 1979/1980, 1982/83, 1984/1985, 1987/1988, 1991/92, 1994/1995, 2003/2004 and 2015/16 (Mazibuko et al., 2021). Throughout the 20th century, severe droughts have occurred over South Africa (Makungo et al., 2019). The SPI values during drought years are shown in Table two; positive numbers indicate more precipitation than the median amount, while negative values indicate less precipitation than the median amount. Any time the SPI is consistently negative and reaches an intensity of –1.0 or below, it is considered a drought event. Wetter and drier climates can be depicted similarly because the SPI is normalised and can also be used to track wet seasons (Azimi & Azhdary Moghaddam, 2020; Moccia et al., 2022). The worst droughts experienced during 1982/83, 1991/92, and 2015/16 seasons, when compared with other droughts periods (S Shikwambana et al., 2021; Shikwambana & Malaza, 2022). At the global level, the average surface temperature has risen by 0.6 °C over the last century with the impacts posed to the smallholder farmers expected to increase (Ullah et al., 2020; Mondal et al., 2022).

Globally, traditional enhanced maize that is, non-genetically modified, or non-GM maize is planted on more than 66% of the total area of maize, according to a study by Erenstein et al. (2022). After rice and wheat, maize is the third most popular cereal consumed by humans (direct channel, processed or unprocessed). In Southern Africa, rain-fed agriculture is the predominant method of producing crops for the majority of rural inhabitants, who depend on natural rainfall for their crops, further indicating that Africa is characterised by only two seasons, which are dry and wet season (Gumbo et al., 2021). During the dry season smallholder farmers in Tshimapha Irrigation Scheme rely on river flow for their maize production. The erratic rainfall during rainy seasons, and very little to no rainfall during winter places the maize production by smallholder farmers at a serious risk of shrinkage.

4.2.2. Standardised Precipitation Index Analysis

Table 2 demonstrates the SPI-6 for the rainfall season in Tshimapha Irrigation Scheme and the SPI was calculated monthly in excel. Figure six are SPI graphs showing the severity of drought monthly. This is with the understanding that in Tshimapha Irrigation Scheme, rainfall usually peaks in February, and thus, the negative SPI values during this month signify drought occurrence in 1979, 1984, 1987, 1992, and 2016. The SPI were for the years that the scheme experienced drought between 1979 and 2021.

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4.2.3 Flood occurrence

Vhembe District experienced floods in the year 1972, 1975, 1977, 1981, 2000 and 2021 (Mazibuko et al., 2021). Figure seven demonstrates the amount of rainfall received during flood episodes in Tshimapha Irrigation Scheme.

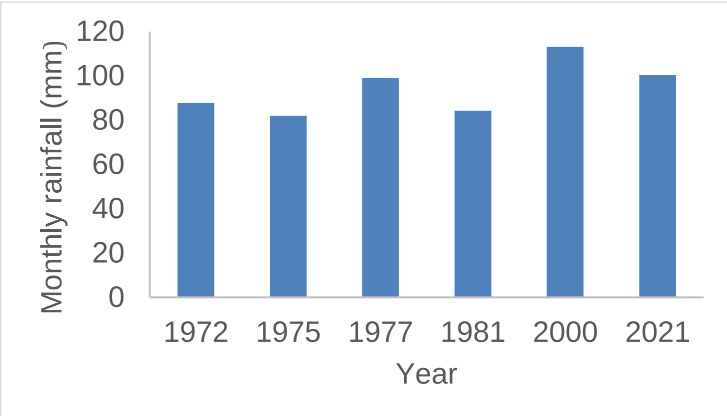

Figure 7: Average monthly rainfall during flood years in rainfall season (October to March)

Figure seven demonstrates the monthly rainfall during the years of floods in Tshimapha Irrigation Scheme between 1970 and 2021. With the graphic representation in Figure eight rainfall predominantly peaks in January, with floods episodes happening in February and January leading to increased impacts posed on maize production for the farmers in the scheme.

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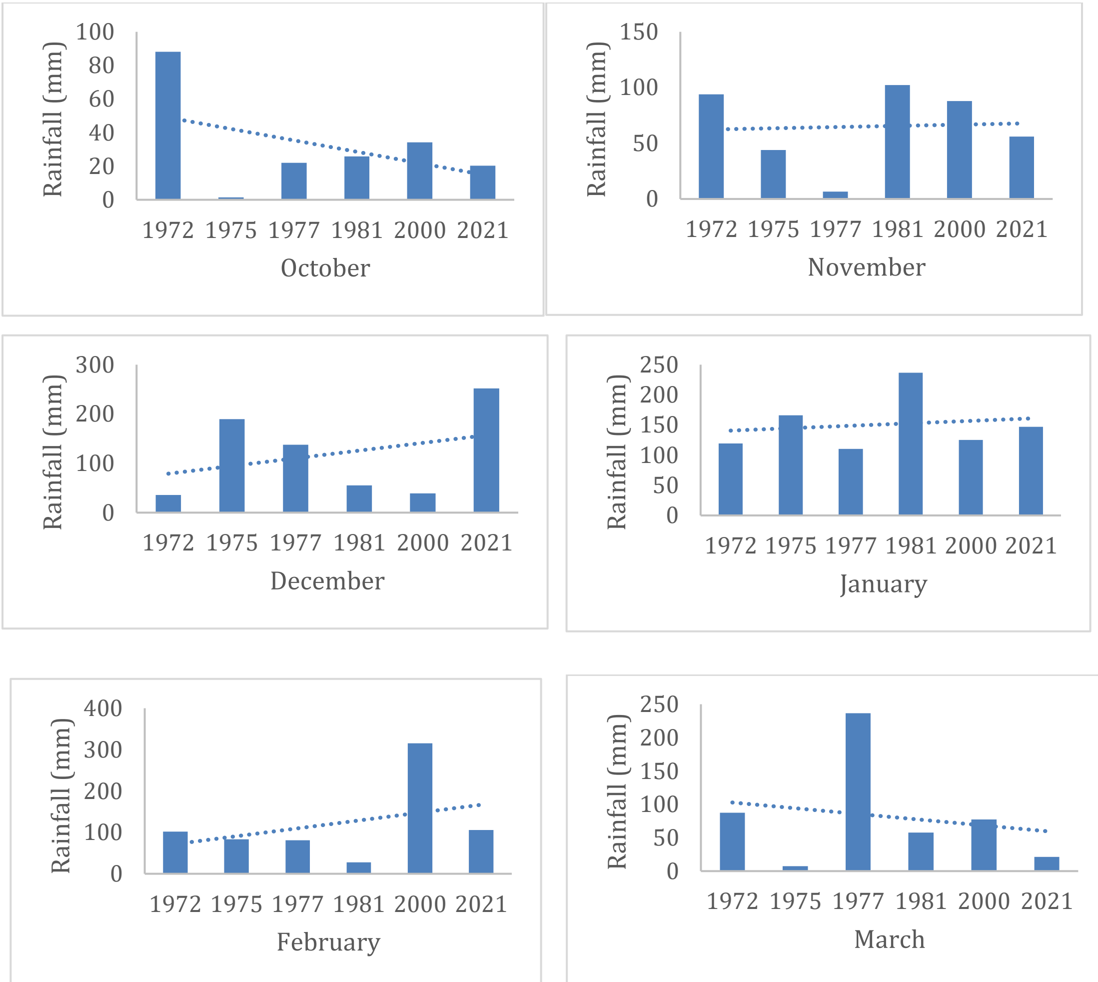

Figure 8: The rainfall received monthly during the flood years in the rainfall season.

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Table 3: Rainfall analysis using *Mann-Kendall* and *Sen's slope* during rainfall season for the year, 1972, 1975, 1977, 1981, 2000 and 2021 (Appendix 6 and 7).

		P-Value	**Mk-Statistic (S)**	**z-value**	**Sen's slope (mm)**	**Trend direction**
Monthly	October	1	-1	0	-1.5	Decreasing
	November	1	-1	0	-0.6	Decreasing
	December	0.71	3	0.38	6.57	Increasing
	January	0.71	3	0.38	5.5	Increasing
	February	1	1	0	0.82	Increasing
	March	0.71	-3	-0.38	-9.87	Decreasing
Seasonal average rainfall.		0.26	7	1.13	4.59	Increasing

4.2.4 Rainfall trend analysis using Mann-Kendall

Vhembe District experienced floods in 1972, 1975, 1977, 1981, 2000 and 2021 (Mazibuko et al., 2021). Recent studies on rainfall patterns reveal that the frequency of extreme events is increasing while the frequency of moderate events is declining (Makungo et al., 2019). Understanding rainfall trends is critical in projecting future crop productivity under climate change, variability, and the world of climatic extremes. Past studies have demonstrated that the changing climate has already impacted farming and food systems, as evidenced by shifts in the rainy season and modifications in the environment (Sydney Shikwambana et al., 2021). Climatic extremes are causing agriculture to struggle to meet the growing food demands of an increasing population as the world is faced with water deficits and, consequently, low crop production. Changes in rainfall lead to changes in the amount of water available for farming activities, among other activities, and this brings on a serious impact on human life. The earth's climate has changed over the past century in terms of variations of rainfall, and one of the main impacts of

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climate change is the changing precipitation patterns. The amount of rainfall received in an area is an important factor in determining the amount of water available to meet various demands, such as agricultural, industrial, domestic water supply and hydroelectric power generation. The heavy rainfall leads to floods, and the other season exhibits an insufficiency of water to fulfil the requirement especially irrigation requirement (Brema & Anie, 2018). Table three shows the monthly and seasonal rainfall trend during the flood years as well as the direction.

Mann Kendall and Sen's Slope tests were conducted on average monthly rainfall in Tshimapha Irrigation Scheme. The Seasonal *Kendall* test statistic involved computing the *Mann Kendall* for each month before combining the results for the whole rainfall season (October, November, December, January, February, and March) at the end (Nyikadzino et al., 2020). The monthly *Kendall* Test was ideal for testing the direction of change in rainfall data over years during floods years in Tshimapha Irrigation Scheme, and in the case of monthly seasons, comparisons were made only against the same months (Nyikadzino et al., 2020). Mean monthly rainfall data was used in the analysis. Table three presents the basic statistical properties that best describe the data set. The highest amount of rainfall, 315,6 mm, was recorded during the month of February. There is a notable increase in the amount of rainfall received during rainfall season and flood episodes. The *Mann Kendall* test ($p < 0.05$) ran across the six rainfall months of the flooding years showed that *p*-values were above the significant level of alpha of 0.05 in all six months, as shown in Table three.

The Tshimapha Irrigation Scheme's seasonal rainfall data showed a growing, noteworthy pattern throughout the six rainy months. Sen Slope recorded positive values in December, January, and February, corresponding to 6.57, 5.5, and 0.82; negative values were recorded in October, November, and March, with a positive value of 4.59 indicated by the overall rainy season. A positive S-value means that the trend is increasing, and the negative S-value means the trend is decreasing. The positive S value in the annual average indicates a significant increase in the amount of rain received during rainfall months. This can lead to future predictions of increasing amounts of rainfall during rainfall season. Thus, the increase in the severity or amount of rainfall received during flood episodes. December, January, and February are months that are predominately receiving the highest amount of rainfall or said to be flooding months. The knowledge of when the area is more likely to experience heavy rain can be used when advising farmers on what and what not to plant whenever there are predictions of floods. The Sen's Slope estimator test has been used to determine rainfall variability and long-term monotonic trends (Aditya et al., 2021). This trend indicates that Tshimapha Irrigation Scheme will experience heavy

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flood episodes in the future. The results of the monthly rainfall analysis showed significant upward and downward trends. Rainfall trends indicate that this area has experienced climatic extremes (Figure 8).

4.2.5. Maize production between 1970 and 2021

Figure 10 demonstrates the maize production in tons during the years of drought in Tshimapha Irrigation Scheme.

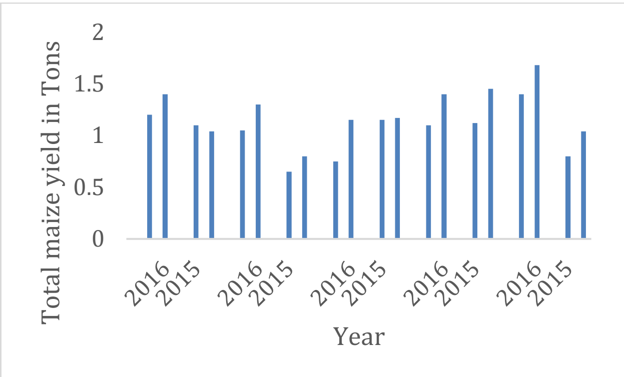

Figure 9: Maize yield in tons during the drought years for the ten farmers.

Although the relationship between maize yield and flooding could not be significantly tested due to inadequate maize yield data, the observation indicated that farmers reported a decrease in their maize production. Although farmers describe the impacts of floods as being severe compared to the effects of drought, both drought and floods have negative impacts on maize yield production. According to farmers from Tshimapha Irrigation Scheme, floods affect production more than drought because the scheme is surrounded by the Mutshedzi and Tshiluvhadi rivers, as well as the Mutshedzi dam. Excessive rainfall wipes away the crops in the scheme, leading to no harvest and very low harvest in some other years. Tshimapha Irrigation Scheme has 115 farmers, and each one of them has 1.5 hectares (ha) of land for their production. Between the period of 51 years from 1970 to 2021, Tshimapha Irrigation Scheme experienced eight drought episodes (Mukwada et al., 2021). In this irrigation scheme, farmers only had data from recent years, which is 2015 and 2016. The findings demonstrating the maize yield data in Tons from the Ten (10) farmers who had maize yield data available indicated the variability of the production, with others having a great production whilst others had the least (Figure 9). The available data from farmers included a maximum of 13 years, from 2008 to 2021, with other farmers having less than that. Although the Department of Agriculture in Makhado Local Municipality did not have the maize yield data recorded for Tshimapha Irrigation Scheme, ten farmers who are producing maize

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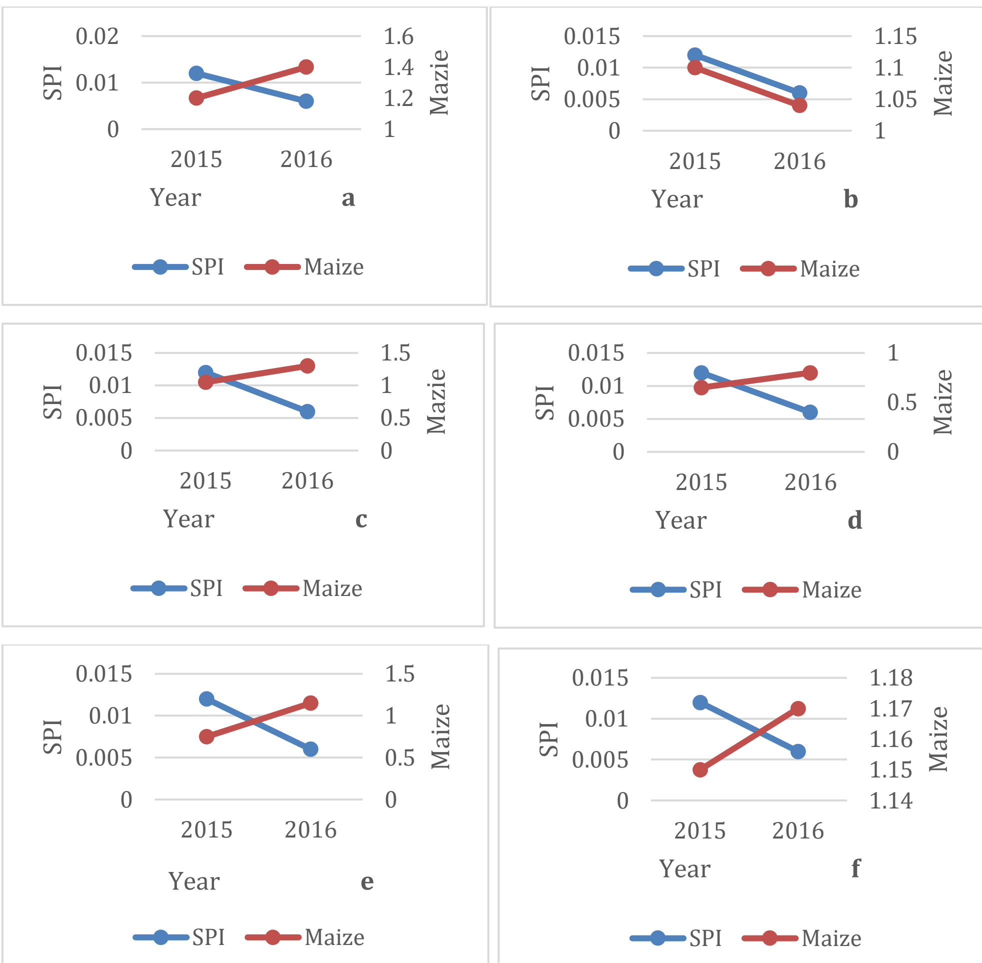
helped in generating the maize yield data. With 1.5 hectare (ha) allocated to each farmer in Tshimapha Irrigation Scheme. Maize yield data was used to understand the amount of harvest produced by each smallholder. Questionnaires responses from farmers indicated that department officials do not collect yield data as all farmers responded with 'no'. Extension officers were also asked if such data is available on the record, but nothing remains. Only ten out of the 115 smallholder farmers have their maize yield production record and have the data recorded in monetary values.

4.2.6. The Standardized Precipitation Index (SPI) and Maize yield production



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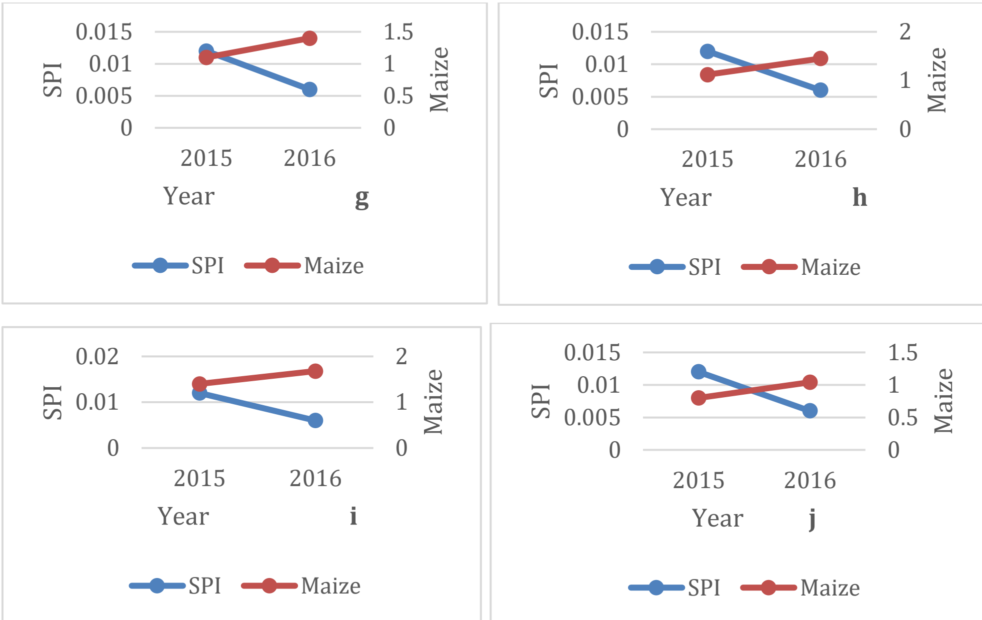

Figure 10: Standardised Precipitation Index and maize yield during drought.

Maize is the most important food crop in Africa whose availability equates to food security, hence smallholder farmers producing maize yield are faced with different climatic conditions that hinder their production (Katengeza & Holden, 2021). Figure 10 demonstrates the relationship between SPI and maize yield in hectares (Ha) produced during drought years in Tshimapha Irrigation Scheme. The graphs (Figure 11 a to j) present the production of ten farmers in the scheme which indicate the decrease in maize yield with the decrease in the SPI value.

4.2.7. Flood impacts on maize yield

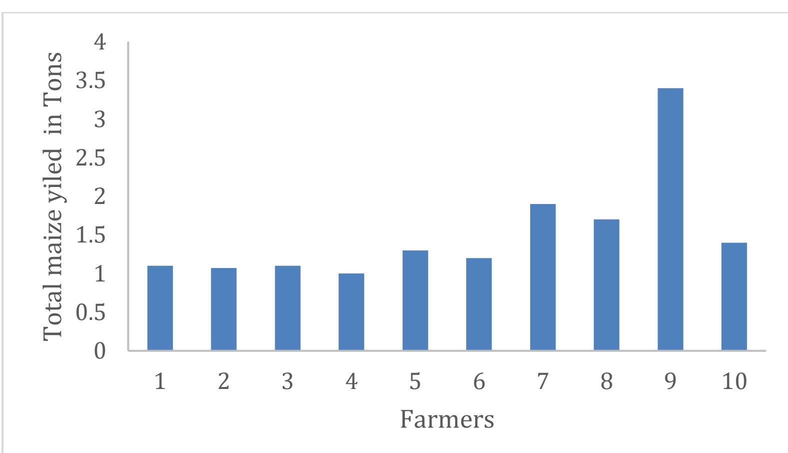

Figure 11: Maize yield produced by Ten farmers for the year 2021 during floods.

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Although the relationship between maize yield and flooding could not be significantly tested due to inadequate maize yield data, the observation indicated that farmers reported a decrease in their maize production. Although farmers describe the impacts of floods as being severe compared to the impact of drought, both drought and floods have negative impacts on maize yield production. According to farmers from Tshimapha Irrigation Scheme, floods affect production more than drought because the scheme is surrounded by the rivers, Mutshedzi and Tshiluvhadi rivers, as well as the Mutshedzi dam. Excessive rainfall wipes away the crops in the scheme, leading to no harvest and very low harvest in some other years. The growing maize crops planted after the summer harvest were planted in January for what is considered winter harvest, as the harvest does not merely depend on rainfall, and it was after what is considered summer harvest. As farmers harvest the maize yield for the summer production, they begin with planting for Winter harvest, and these are the maize crops that are negatively affected by the flood, which normally occurs in February around this area.

4.3. Non-climatic factors hindering maize yield production

Tshimapha Irrigation Scheme has several challenges that hinder maize yield production. Although there are climatic factors hindering the production in the scheme, several non-climatic are also worsening the existing natural challenges. By international standards, a farm that is less than 10 hectares is classified as small-scale (Mgbenka et al., 2016), and in a study conducted by Stuch et al. (2021), the definition of 'smallholding farm' varies from publication to publication and authors use various criteria, but however, definitions based on land holding area have typical thresholds of 1–2 ha. Smallholder farmers depend on their efficiency in utilising basic production resources available to them. Over the years, thoughtful efforts have been made to improve agricultural production, but these efforts have not yielded the expected results. Research has confirmed that smallholder farmers play a particularly important role in food security in SSA. During the meeting, some farmers expressed how they perceive their scheme as quoted below:

Farmer: *"Here we are on our own, we support ourselves, the production here was good way back when we were still young and not anymore, we struggle with almost everything, the fertilizers, the tractors are expensive, seed and fertilizers makes it worse with very high prices"*

Farmer: *" There is a tree that whenever there is going to be floods there will be water falling in a form of rain coming out from the leaves of that particular tree, and that helps me to know if we are going to have heavy rainfall so I know what to do in terms of planting my maize but this is not*

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what everyone believes that it is true, so we need someone who can help us with the information about these climatic extremes"

Figure 13 illustrates the non-climatic factors affecting the maize yield production in Tshimapha Irrigation Scheme.

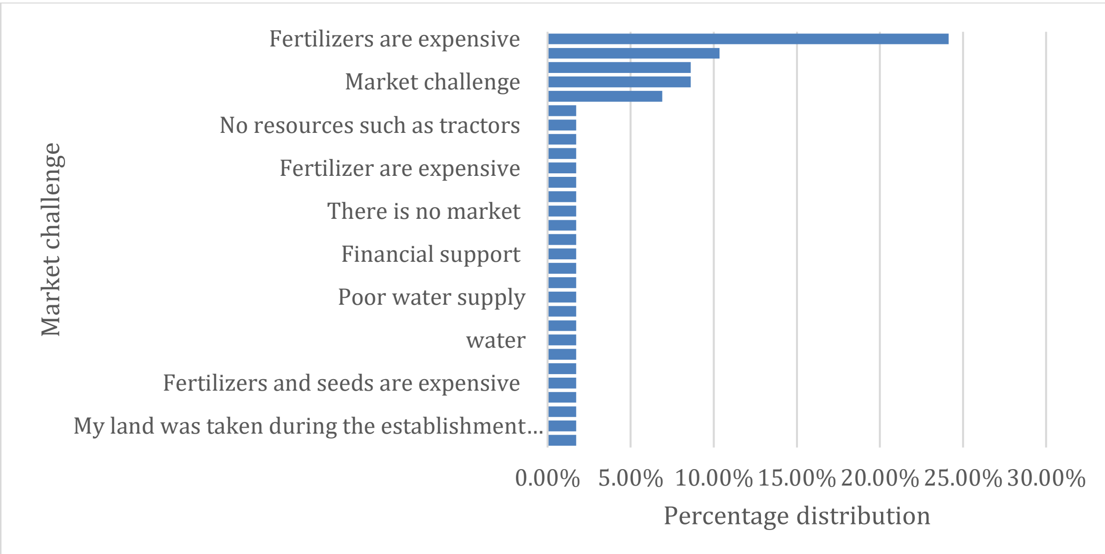

Figure 12: Percentage distribution of the non-climatic challenges in Tshimapha Irrigation Scheme.

4.3.1. Lack and high cost of farm inputs

Similar findings were found when smallholder farmers in the Tshimapha Irrigation Scheme claimed they struggle to afford enough fertiliser for one hectare. According to Mgbenka et al. (2016) the average Nigerian small-holder farmer struggle to afford enough fertiliser for one hectare, according to the International Food Policy Research Institute's Nigeria Strategy Support Programmer document. These findings are consistent with those of the farmers in the Tshimapha Irrigation Scheme. A mix of knowledge through extension services, timely and adequate input availability, and financial resources to buy inputs are needed to achieve yields.

The International Fund for Agricultural Development (IFAD) notes that a number of unfavorable factors work against high productivity in small-scale farming, including: (i) a significant portion of small-scale agriculture is uncompetitive and neither profit- or business-oriented nor sustainable; (ii) there is a vicious cycle of low productivity and income, complete cash shortages, and limited investments or input availability/use; and (iii) it is difficult to expand or improve production due to a lack of reliable processing and trading outlets and markets. For instance, an efficient distribution

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infrastructure is required to assist smallholders, stay competitive and provide them with affordable fertiliser. According to Mgbenka et al. (2016), the seed and planting material businesses are currently underdeveloped, and the quality of the supply is frequently subpar.

4.3.2. Provision of business advice and services

The lack of reliable access to credit is a major impediment to improving small farm operations and enhancing the livelihoods of rural households. Priority attention should be given to resolving the problem of microfinance in much greater depth across Nigeria. The National Agricultural Research Institutes are potential sources of much more practical advice and services, particularly if they are better resourced and their operating paradigms are oriented to the commercial, rather than just the technical/scientific, aspects of agriculture. International Fund for Agricultural Development (IFAD) support is required for commodity-based marketing groups and marketing information systems. Finally, in its efforts to support the renewed focus on small farmers, IFAD is in a strong position to take advantage of its experience in West Africa, other parts of the continent and elsewhere. This implies proactive and strategic use of knowledge management and policy dialogue.

4.3.3. Limited Access to Modern Agricultural Technology

Access to contemporary, upgraded technology is severely restricted, and their overall situation does not always call for outright expenditures of labour, capital, or inputs. For smallholder farmers, agricultural technology needs to reduce the tediousness and irritation of farm work. It ought to be expanding, improving, and saving labour. A farmer needs to know about production techniques, which include weeding, insect control, fertiliser application, cultivating, and harvesting. Extension agents, other farmers, government parastatals, and dealers in agricultural equipment are now disseminating this kind of knowledge, although the effects have not yet been felt (Mgbenka et al., 2016).

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4.3.4. Poor management of the schemes

Figure 13 indicates the responds from smallholder farmers in Tshimapha Irrigation Scheme. Responding to a question on how often do the department officials come to monitor your production?

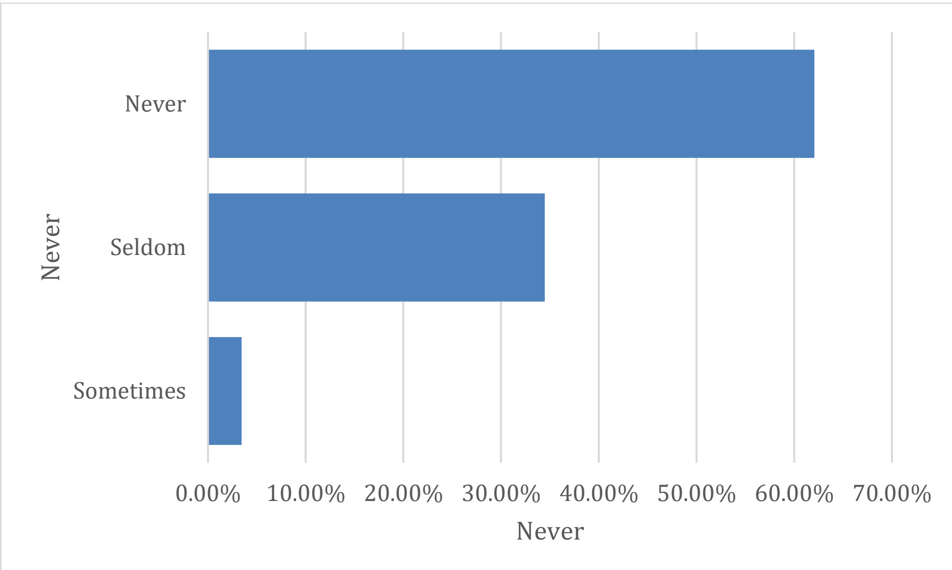

Figure 13: Percentage distribution on how often the department officials visit the Tshimapha Irrigation Scheme for monitoring

The Tshimapha Irrigation Scheme is dominated by the elderly group of farmers. Throughout the process of understanding the impacts they are faced with, farmers indicated that shortage of support is one the challenges they face daily. Farmers indicated that there is no active management of the scheme form the department. With the dominance of the elders in this scheme, several farmers indicated that Tshimapha Irrigation Scheme was well and better managed in the olden days as compared to how the scheme is managed currently. Farmers were asked how often the extension officer visited the scheme to monitor their production, and that was done to understand the extent of the support offered to the farmers by the department.

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4.3.5. Insufficient education

Education can either be formal or informal education Myeni et al. (2019) for this study. The male percentage of farmers in Tshimapha Irrigation Scheme is 53,3%, and the female percentage is 46,7%. The age distribution indicated that the scheme is dominated by elders of 66 years and above with 38,3%, followed by the age group of 56 to 65 with 31,7%, then 46 to 55 years with 16,7%, then 21 to 35 years with 11,7% and the least group of 36 to 45 years with 1,7%. Figure 15 shows the education level of farmers in Tshimapha Irrigation Scheme.

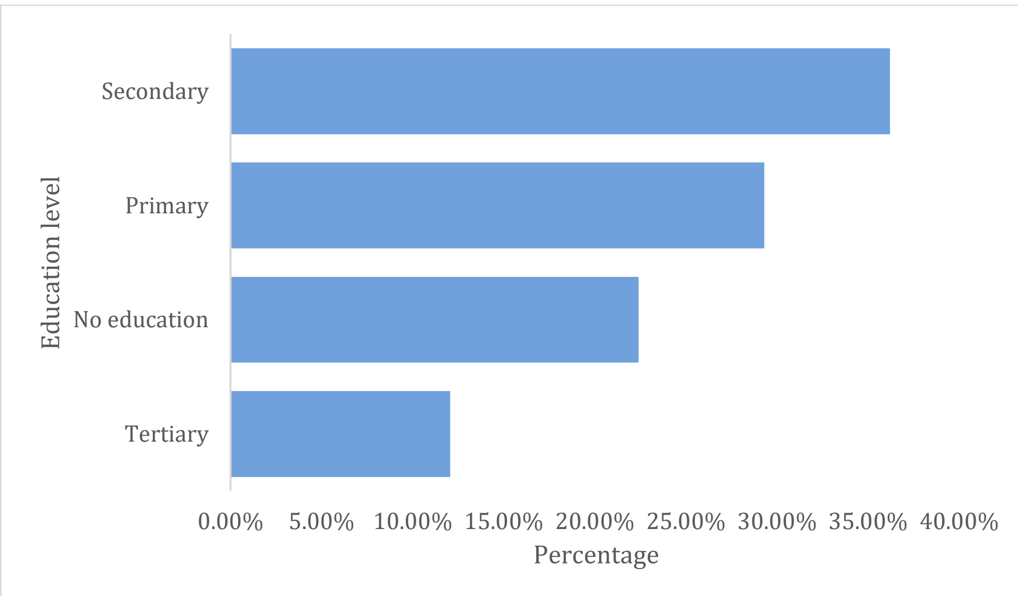

Figure 14: Education level of farmers in Tshimapha Irrigation Scheme.

In Tshimapha Irrigation Scheme, about 38,3% of farmers had completed secondary school, 28,3% had completed basic education, 21,7% had no formal education, and 11,7% had completed university education, according to the study's findings. These results supported the hypothesis that most smallholder farmers in South Africa have only a high school education (Myeni et al., 2019; Shikwambana & Malaza, 2022). The region's low literacy rates have an indirect effect on agricultural output because new knowledge and technology demand a certain amount of formal education and training. As a result, compared to their counterparts with no formal education or training, farmers with higher levels of formal education are more likely to adopt new sustainable agricultural management practices because they are better able to find, process, interpret, and react to new information about the challenges and changes they face. However,

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higher levels of formal education and training increase the likelihood that farmers will use these techniques (Smidt & Jokonya, 2022).

4.3.6. Lack of support

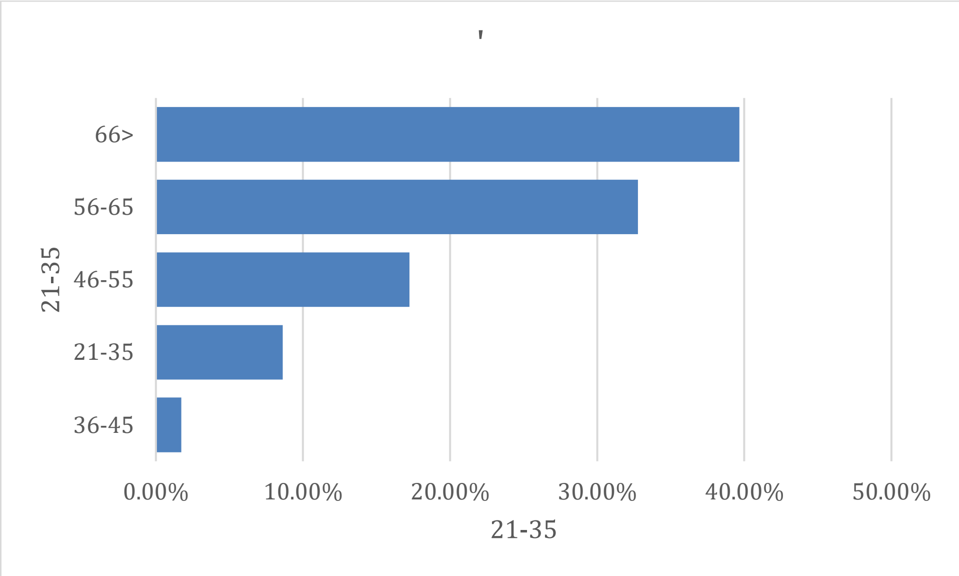

Figure 15: Percentage distribution of age

With the majority of farmers in Tshimapha Irrigation Scheme being the elderly group (Figure 15), it would be vital for them to be supported, but little is done in this scheme in terms of helping them. Literature suggests that smallholder farmers in South Africa have received little attention since the transfer of the farms in 1994; in fact, despite numerous policy interventions and programs meant to address the farmers' challenges, the reality is that these farmers still face several problems (Sikwela & Mushunje, 2013). Smallholder farming provides most of the food in sub-Saharan Africa. Utilising extensive datasets from household surveys conducted in many different countries, we discover that most farms are less than ONE hectare (ha), which is significantly smaller than previously thought (Giller et al., 2021) and thus a smaller area such as a hectare might require greater support of both education and financial assistance to obtain a significant production.

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Figure 17 shows the source of information about upcoming climatic extremes in Tshimapha Irrigation Scheme.

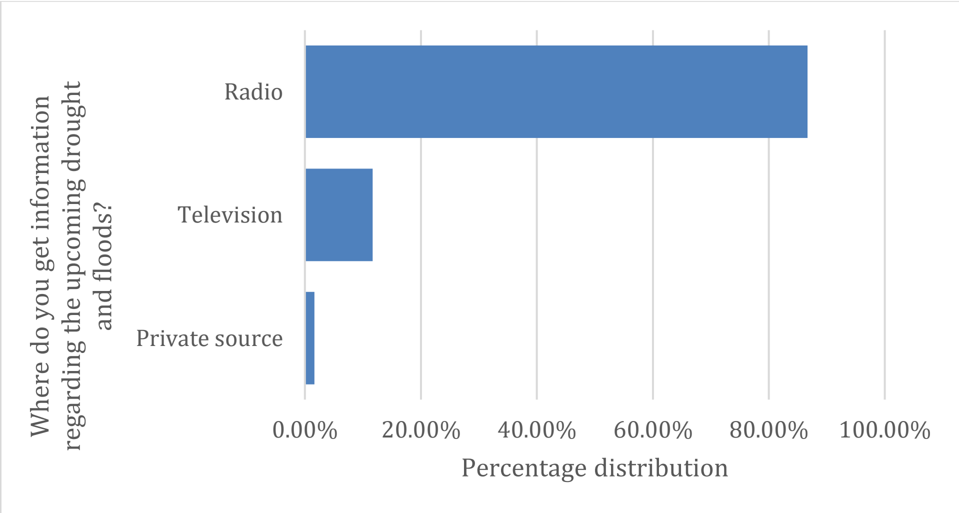

Figure 16: Percentage distribution of 'Where farmers get information regarding the upcoming drought and floods'.

Figure 17 highlights the number of years that farmers have in the sector of smallholder farming, with Figure 19 indicating the employment status of farmers in the scheme. These findings account for the amount of support that they should be getting.

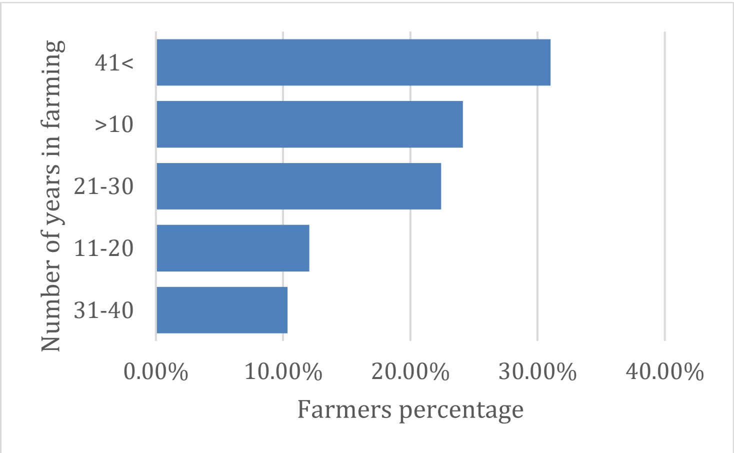

Figure 17: Percentage distribution of the number of years in the farming sector.

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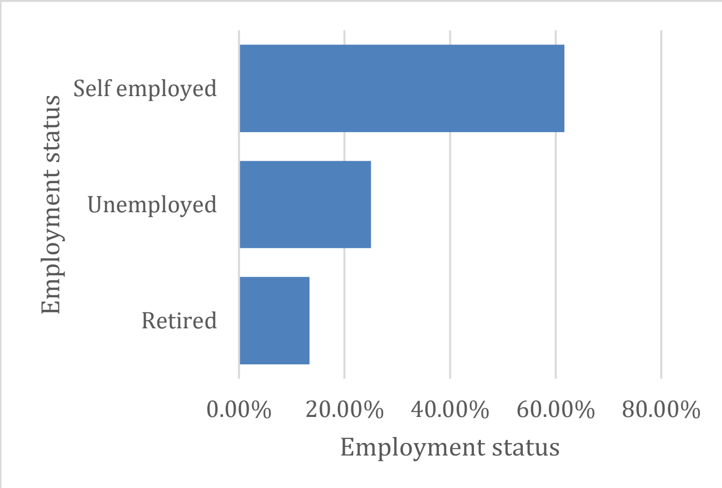

Figure 18: Employment status of farmers in Tshimapha irrigation scheme.

Most farmers in Tshimapha Irrigation Scheme are elderly (38,3% being elders of 66 year and above, 31,7 % being of the age between 56 and 65) people, and very few young people are in the sector with the dominance of elderly people in the Tshimapha Irrigation Scheme, the sustainability aspects become questionable (Figure 15). With some Irrigation Scheme in the Vhembe District no longer operating, this might lead to a similar dilemma in the Tshimapha Irrigation Scheme. While these elders embark on their daily activities of maize production, among other crops, they continue without assistance from their growing children as they attend their schools, nor do they have sufficient support from the department with an understanding that achieving sustainability in smallholder production or scheme contributes not only to farmers' livelihoods but also to the economy of the country and the SDGs (Bizikova et al., 2020; Musa & Basir, 2021). It is fundamental that smallholder farmers are supported and not only by those who are directly benefiting from the production such as family members. Smallholder farmers in South Africa lack institutional support, and they do not receive adequate support they need from extension officers, hence, it is difficult for them to adapt to the challenges that the industry is faced

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with (Muroyiwa et al., 2022). Therefore, smallholder farmers may be at a disadvantage, with more exposure to climatic shocks aggravating their vulnerability.

4.4. The maize yield production before and after the Mutshedzi dam

4.4.1. Maize production before the dam

Maize production has been a dominant crop production in the Vhembe region, with smallholder farmers doing it to feed their families and others doing it for sales. In Tshimapha Irrigation Scheme, maize production has been happening for decades since the establishment of this farming schemes around the Mutshedzi dam. According to farmers in Tshimapha Irrigation Scheme, the scheme had an effective extension officer who worked effectively with smallholders farmers to ensure that the production was sustainable and achieved.

4.4.1.1. Water availability

According to farmers who were producing maize in Tshimapha Irrigation Scheme before the establishment of the dam, the extraction of water directly from Mutshedzi and Tshiluvhadi rivers using pumps or by means of weir diversion were the two most common ways in which smallholder schemes sourced their irrigation water. Generally, irrigation water availability was reasonably adequate before the establishment of the dam because there was no restriction to access water from all the available sources as compared to the current situation with the Mutshedzi dam. Although sometimes there were seasonal water availability limitations due to the insufficient amount of rainfall received, the other sources were always available. Figure 13 illustrates the most pressing non-climatic factors in the scheme, as mentioned by the farmers, and Figure 21 shows how farmers perceive the production before the Mutshedzi dam was established. Figure 22 shows the current perception of the production.

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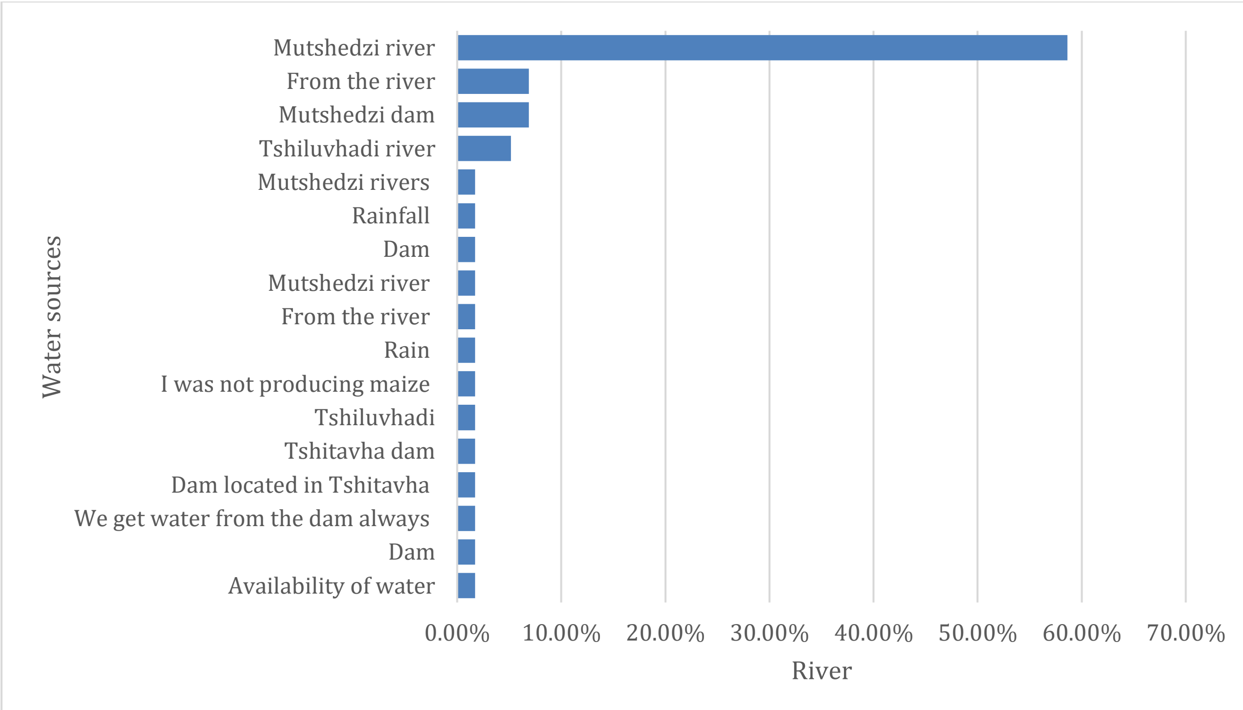

Figure 19: Percentage distribution of 'where farmer was getting water for irrigation before the dam.

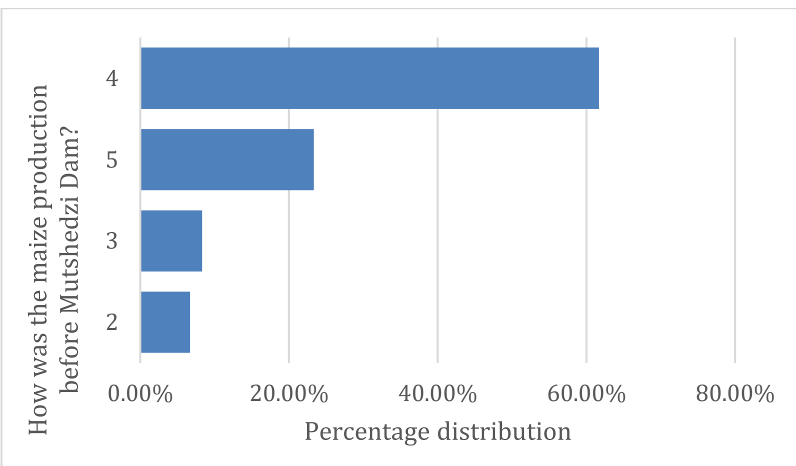

Figure 20: Percentage distribution on how the maize production was before Mutshedzi Dam.

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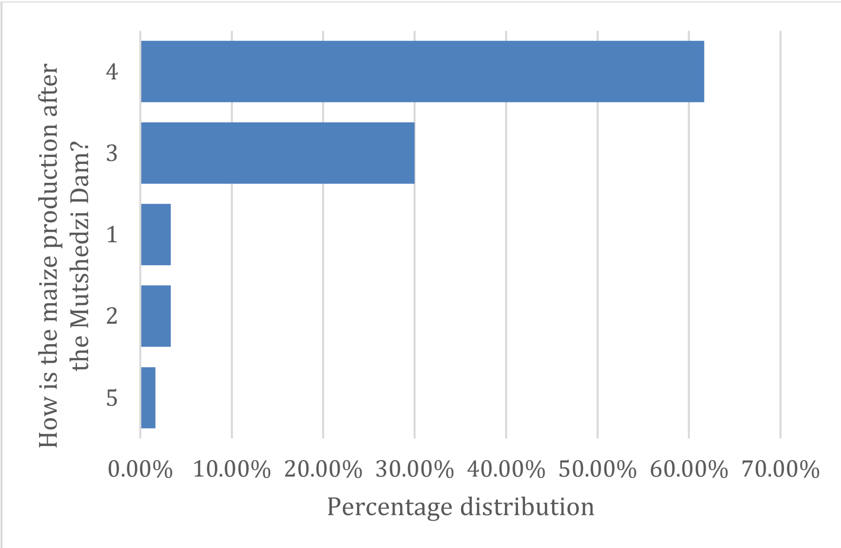

Figure 21: Percentage distribution of current maize production.

4.4.1.2. Land for farming

Production in developing countries also depends on the available land, unlike in developed countries where small space can be used with technological advancements to produce any desired outcome of production as possible. Expanding agricultural lands is one of the most common land management practices to increase crop production in smallholder crop farming in Sub-Saharan Africa (Kim et al., 2021). Figure 22 demonstrates the state of land ownership in Tshimapha Irrigation Scheme.

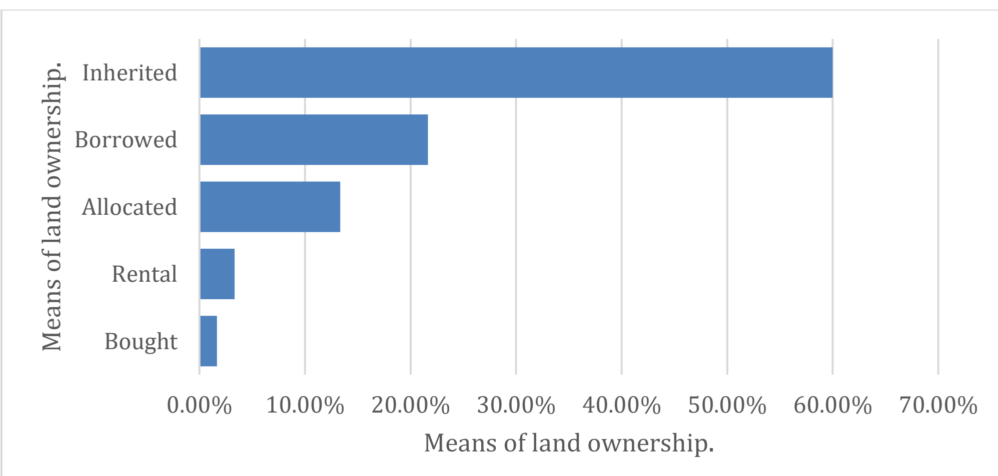

Figure 22: Percentage distribution on means of land ownership' of farmers in Tshimapha Irrigation Scheme.

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The highest percentage of 60% of farmers indicated that the land that they are producing maize on is the land that was allocated to their family member. Now they have inherited it, 21,67% indicated that they land they are using is borrowed, while 13,33% indicated that the was allocated to them, 3,33% are renting the land and 1,67% bought the land. This accounts for the need to give the land to people who can use the land.

4.4.2. Maize production after the dam

4.4.2.1. Water availability

According to farmers who participated in responding to the questionnaires that were distributed, Tshimapha Irrigation Scheme was established more than five decades ago. It is one of the fortunate schemes that is situated and surrounded by the Mutshedzi and Tshiluvhadi rivers. The scheme has been using water for irrigation from the balancing dam that is situated in the mountains surrounding the scheme in the Tshitavha area with Vhulaudzi Village. The growing population in the area has led to several residents in the village also wanting to use the same water from this balancing dam for domestic purposes and not for the Irrigation Scheme. The high demand for water has now led to a significant shortage of water for the irrigation scheme.

4.4.2.2. Land for farming

Although there are currently abandoned spaces in the Tshimapha Irrigation, there are farmers who do not have enough space for farming as they indicate that a hug part of the initial space was taken for the Mutshedzi dam, with that reducing farmer's land for maize production. While other farmers had to completely stop farming as they no longer had space, the establishment of the dam has negatively affected their production; others indicate that the space was reduced and formed part of the dam area. According to a study by Zerssa et al. (2021), farming systems are limited by small land size, a lack of resources, and a growing rate of soil quality degradation, which make it difficult to produce crops sustainably and provide food security. A dynamic and complex social-ecological system, agricultural land systems are a major study priority for global development and farming sustainability because they depend on several environmental and socioeconomic aspects that interact in space and time. According to Viana et al. (2022), a dynamic and complex social-ecological system, agricultural land systems are a major study priority for global development and farming sustainability because they depend on several environmental and socioeconomic aspects that interact in space and time. Figure 23 indicates what farmers say about the land they have for their production.

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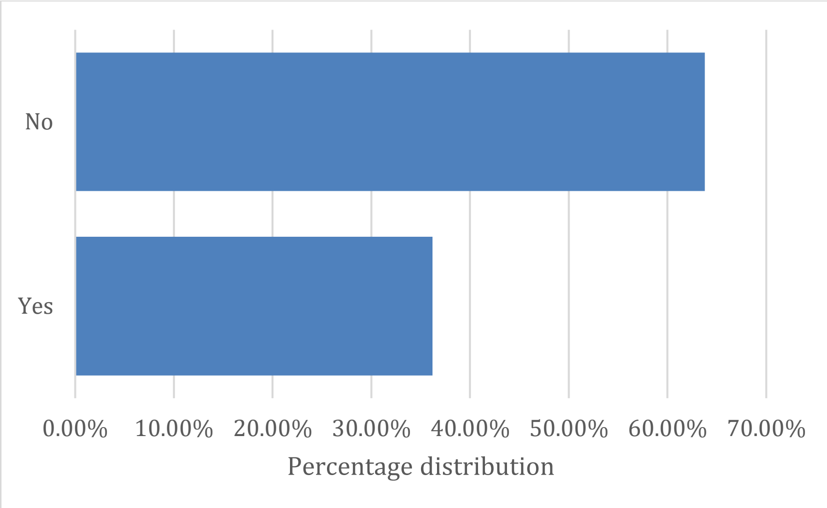

Figure 23: Percentage distribution of 'Do you think you have enough space for your maize production?

4.4.3. The climatic variabilities

Climate is never steady, and changes in average rainfall are observed every year. Interestingly, some years have average rain, and others have lower or higher than average rainfall (Mzezewa et al., 2010). For example, Vhembe District is usually expected to experience normal rainfall during the summer months (October to March), but due to climatic variabilities average summer rain falls are no longer easily predictable. As a result of these climatic variables, there have been changes from high rainfall to extreme temperatures in recent times, with heavy rainfall and extreme temperatures experienced when least expected (Mpandeli et al., 2019).

The swiftly changing climate is supported by evidence (Tshamano & Shopola, 2021). Farmers in the Tshimapha Irrigation Scheme said that climate variability had the greatest detrimental effects on their maize yield when it increased over time. According to Robinson (2020), freshwater supplies, agriculture, people's means of subsistence, and other natural resources critical to human survival are all negatively impacted by climate change. Crop output is negatively affected by climate change, particularly for vulnerable rural populations like smallholder farmers who depend on rain-fed agriculture for a living. Climate change puts South African rural smallholder farmers at risk. Mpandeli and Maponya (2013) predict that this will lead to a rise in food insecurity and a worsening of poverty in rural communities, thereby impacting all four aspects of food security: availability, accessibility, utilisation, and stability of food.

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4.4.4. The seasonality shifts

According to (Nyoni et al., 2021), the climatic variations vary from season-to-season, or year-to-year and are not steady but may be predicted. Climatic variation is among the major environmental challenges faced by smallholder farmers in the Vhembe District and globally. This has been observed with below-average rainfall, above-average rainfall, extreme temperatures and sometimes no rainfall at all. There is further evidence from several industries, including the agricultural sector, which indicates a slight decrease in production due to these new climate patterns. According to (Nembambula, 2018), the considerable climate variability in the Vhembe District is a serious problem because the region is known for its inconsistent rainfall. For example, the rainfall distribution pattern in Limpopo is characterised by wet and dry seasons that vary based on the geographical area. Because when people do not have an immediate solution, almost everything becomes a problem, the impacts of climate variation in Vhembe District are determined by the lack of enough adaptive strategies to fight the changes and variation (A. Mufungizi et al., 2020).

4.5. Summary

This study's primary goal was to look at patterns in the frequency of droughts and floods and assess how they affected the production of maize crops between 1970 and 2021. The rainfall data from SAWS and ARC supplied the baseline data on drought and flood occurrences in this region. This explains these environmental extremes in more detail using information gathered from smallholder farmers through questionnaires. The degree of drought and flood effects on maize output was also examined through an analysis of farmer-generated data on maize yield. This objective entails information that can be used to forecast the future trend of expected climatic extremes and maize production in this area, as well as all other areas with similar climatic conditions and smallholder farming activities. The researcher looked at the fundamental areas needed for pathways that can lead towards achieving the SGDs, mainly goal two, in poor rural communities.

The second objective of this study was an analysis of the non-climatic factors affecting the maize production in Tshimapha Irrigation Scheme. Poor management of the scheme, insufficient education and shortage of support were identified as some of the challenges that smallholder farmers are faced with and are affecting or hindering the maize yield production in this scheme. It is important to understand the characteristics of historical droughts to determine their impacts on current and future production. In addition, 86% of the South African population depends on

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smallholder agriculture for livelihood and food security, and these farmers are producing below their capacity because of numerous challenges they experience. Different governments have had many programmers to solve some of the constraints that militate against the farmer's efficiency, but they are yet to help farmers. Many, authors have proposed many solutions to the problems, and if these proposals are implemented, smallholder production inefficiency could be overcome.

The finding of the last object discloses that although the dominant maize production in Tshimapha Irrigation Scheme is rainfed, several smallholder farmers produce maize all year round, depending on water from the Mutshedzi river and the supporting dam for the Furrow irrigation system. Based on the results, farmers indicated that the water from this river is not always sufficient during dry season and expressed the struggle of not having water for their maize while they have a dam within their vicinity. Not only was the availability of water pointed out as an issue, but the management of the scheme has also completely changed from what it used to be when Tshimapha Irrigation Scheme was established in the 1960s. This chapter looked at the maize yield production before and after the Mutshedzi Dam.

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CHAPTER 5: SUMMARY, RECOMMENDATIONS AND CONCLUSION

5.1. Summary

This study's primary objectives were to assess the impact of extreme weather events and non-climatic variables on maize output and investigate strategies for sustainable maize production in South Africa's Tshimapha Irrigation Scheme, Makhado Local Municipality, and Limpopo Province. This study found that, despite the presence of an extension officer in the Tshimapha Irrigation Scheme, farmers are not receiving departmental services because of the identification of some of the barriers affecting smallholder farmers' sustainable agricultural productivity. According to the study's findings, extension agents require training to guarantee that they can provide the services to farmers. Recognising that extension services, through capacity building, awareness raising, and the provision of current information, early warnings on climatic extremes, climate change adaptation strategies, weather forecasts, and market access, play a critical role in ensuring the sustainability of smallholder production in many irrigation schemes within the Vhembe District. A few difficulties faced during the study included the lack of sufficient maize yield data from smallholder farmers or the department's records. As a result, while the maize yield data used in this study can be used to make inferences about the actual production, it cannot be said to be a complete true reflection of the actual production.

5.2. Recommendations

Following the study's conclusion, the following recommendations were made:

- Tshimapha Irrigation Scheme is dominated by the elderly group of farmers who indicated the lack of support from the department, a great recommendation of encouraging young people to through provision of support to venture into the industry as they hope towards achieving future goals.
- The extension officers and the Department of Agriculture must play a significant role in assisting smallholder farmers with training and ideas on recording their production, among other challenges they encounter.
- To maintain agricultural sustainability, government policies should incentivise farmer groups to expand the reach of extension services and disseminate information more widely.
- Studies that will demonstrate and assist extension officers in establishing mechanisms that will help in the operation of smallholder farming of the schemes in Vhembe District and globally.

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- It is suggested that department or government policies should address the issue of land redistribution and ownership to enable poverty alleviation and rural development through sustainable agricultural productivity. Some smallholder farmers mentioned the issue of land no longer used by the people to whom the land was allocated due to their age, but the land is not given to others who want to use it.
- The study suggests that in order to enhance the quality of extension services that smallholder farmers in South Africa's Tshimapha Irrigation Scheme and other irrigation schemes get, the government should provide facilities and resources.

5.3. Conclusion

Enhancing the calibre and accessibility of extension services is crucial. Smallholder farmers in South Africa, mostly uneducated and unskilled, rely primarily on oral and firsthand knowledge. Consequently, it is advised that future interventions encouraging ways for sustainable farming are vital since smallholder farmers need to be exposed to field demonstration trials and training. Furthermore, in order to include and educate farmers, extension organisations must carry out farmer-led trials. One further method for achieving sustainable agricultural productivity in smallholder agriculture is through the services provided by extension officers. The response strategies developed by the South African Government departments aiming to address climatic extreme impacts (droughts and floods) have not been proactive or region-specific but always generalised, and the distribution of relief measures after the occurrence of natural hazards is delayed due to limited resources and thus, this calls for the development of specific measures.

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APPENDICES

Appendix 1: Recommendation letter

KHOSI
MUSANDA WA ZWOKUNDAVHALALA RADZILANI
TRADITIONAL AUTHORITY

Vhulaudzi Village

Khosi N.O. Radzilani
PO Box 1
Vhulaudzi 0926
Limpopo, South Africa

Cell:
Email:

DATE: 2023-05-04

TO WHOM IT MAY CONCERN

RE: Confermation / Recommendation

I, Khosi Radzilani N.O hereby Confirm/Recommend that Mudzanani Nisemoni Rainah of I.D.NO [redacted] Granted permission to conduct Research at Vhulaudzi Vilage.

You are Appreciated.

Yours Sincerely,

KHOSI RADZILANI N.O
(ZWOKUNDAVHALALA)
OFFICE STAMP
2023 -05- 04
Vhulaudzi Village, 0926

(JURISDICTION OF VHULAUDZI AREA)

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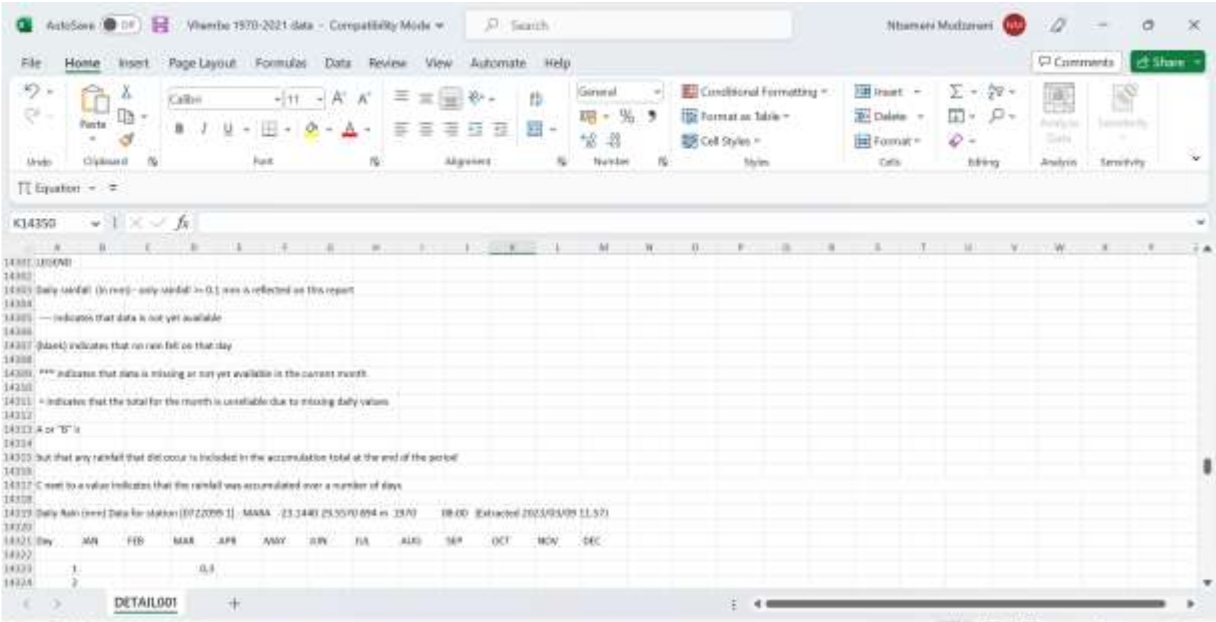
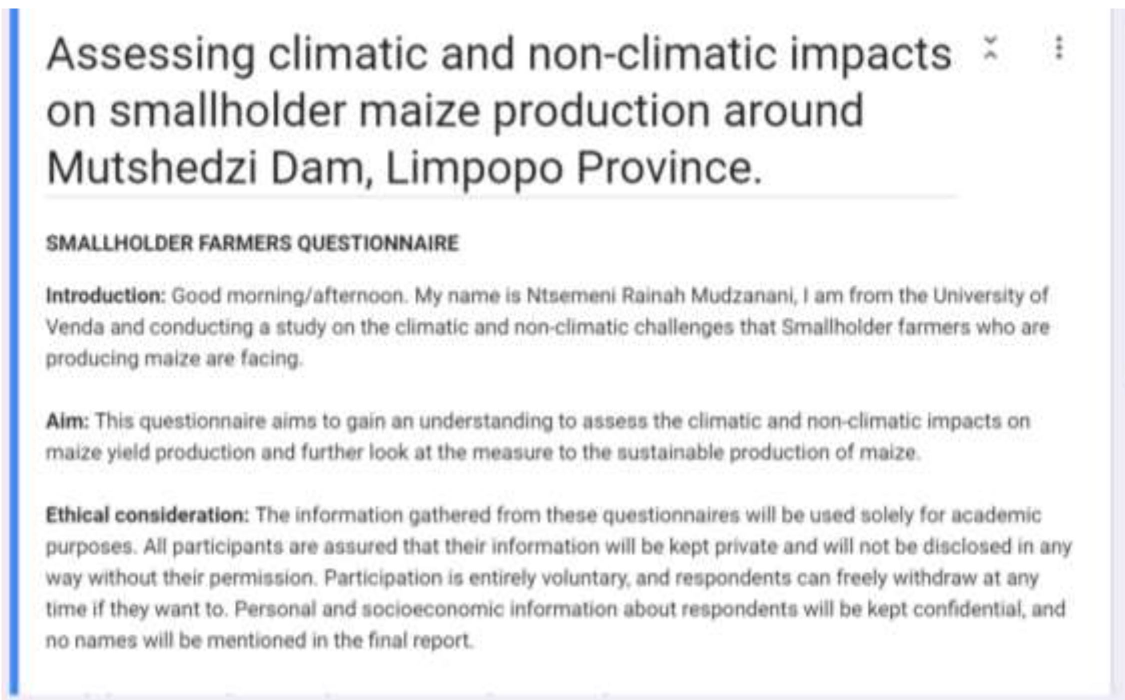
Appendix 2: Climate data from South African Weather Service (SAWS)



Appendix 3: Farmers questionnaires



Assessing climatic and non-climatic impacts on smallholder maize production around Mutshedzi Dam, Limpopo Province.

SMALLHOLDER FARMERS QUESTIONNAIRE

Introduction: Good morning/afternoon. My name is Ntsemeni Rainah Mudzanani, I am from the University of Venda and conducting a study on the climatic and non-climatic challenges that Smallholder farmers who are producing maize are facing.

Aim: This questionnaire aims to gain an understanding to assess the climatic and non-climatic impacts on maize yield production and further look at the measure to the sustainable production of maize.

Ethical consideration: The information gathered from these questionnaires will be used solely for academic purposes. All participants are assured that their information will be kept private and will not be disclosed in any way without their permission. Participation is entirely voluntary, and respondents can freely withdraw at any time if they want to. Personal and socioeconomic information about respondents will be kept confidential, and no names will be mentioned in the final report.

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Appendix 4: Key informants' interview

Assessing climatic and non-climatic impacts on smallholder maize production around Mutshedzi Dam, Limpopo Province

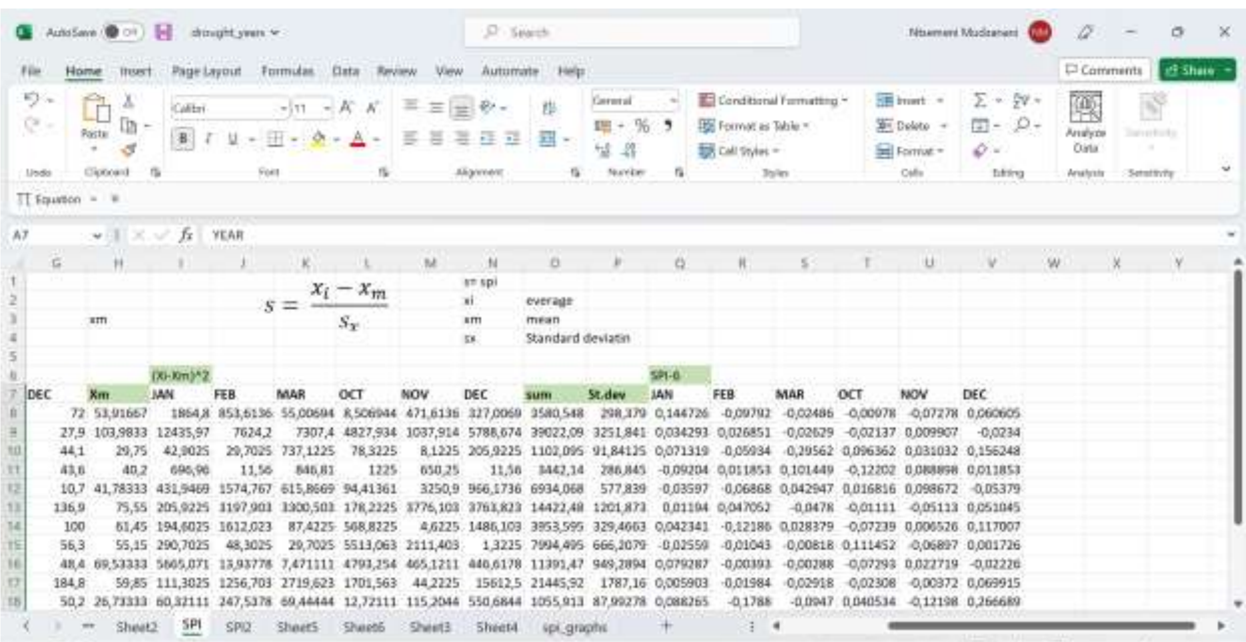
KEY INFORMANTS QUESTIONNAIRES

Introduction: Good morning/afternoon. My name is Ntsemeni Rainah Mudzanani, I am from the University of Venda and conducting a study on the climatic and non-climatic challenges that Smallholder farmers who are producing maize are facing.

Aim: The questionnaire aims to gain an understanding on how Community Leaders, Department officials, and NGOs are ensuring the sustainability of maize production in Phadzima, Madzuwa, and Tshitavha.

Ethical consideration: The information gathered from these questionnaires will be used solely for academic purposes. All participants are assured that their information will be kept private and will not be disclosed in any way without their permission. Participation is entirely voluntary, and respondents can freely withdraw at any time if they want to.

Appendix 5: Standardized Precipitation Index analysis on Excel



$$s = \frac{x_i - x_m}{s_x}$$

s= spi
xi everage
xm mean
sx Standard deviatin

DEC	Xm	JAN (Xi-Xm)^2	FEB	MAR	OCT	NOV	DEC	sum	St.dev	JAN (SPI-0)	FEB	MAR	OCT	NOV	DEC
72	53,91667	1864,8	853,6136	55,00694	8,506944	471,6136	327,0069	3580,548	298,379	0,144726	-0,09792	-0,02486	-0,00978	-0,07278	0,060605
27,9	103,9833	12435,97	7624,2	7307,4	4827,934	1037,914	5788,674	39022,09	3251,841	0,034293	0,026851	-0,02629	-0,02137	0,009907	-0,0234
44,1	29,75	42,9025	29,7025	737,1225	78,3225	8,1225	205,9225	1102,095	91,84125	0,071319	-0,05934	-0,29562	0,096362	0,031032	0,156248
43,6	40,2	696,96	11,56	846,81	1225	650,25	11,56	3442,14	286,845	-0,09204	0,011853	0,101449	-0,12202	0,088898	0,011853
10,7	41,78333	431,9469	1574,767	615,8669	94,41361	3250,9	966,1736	6934,068	577,839	-0,03597	-0,06868	0,042947	0,016816	0,098672	-0,05379
136,9	75,55	205,9225	3197,903	3300,503	178,2225	3776,103	3763,823	14422,48	1201,873	0,01194	0,047052	-0,0478	-0,01111	-0,05113	0,051045
100	61,45	194,6025	1612,023	87,4225	568,8225	4,6225	1486,103	3953,595	329,4663	0,042341	-0,12186	0,028379	-0,07239	0,006526	0,117007
56,3	55,15	290,7025	48,3025	29,7025	5513,063	2111,403	1,3225	7994,495	666,2079	-0,02559	-0,01043	-0,00818	0,111452	-0,06897	0,001726
48,4	69,53333	5665,071	13,93778	7,471111	4793,254	465,1211	446,6178	11391,47	949,2894	0,079287	-0,00393	-0,00288	-0,07293	0,022719	-0,02226
184,8	59,85	111,3025	1256,703	2719,623	1701,563	44,2225	15612,5	21445,92	1787,16	0,005903	-0,01984	-0,02918	-0,02308	-0,00372	0,069915
50,2	26,73333	60,32111	247,5378	69,44444	12,72111	115,2044	550,6844	1055,913	87,99278	0,088265	-0,1788	-0,0947	0,040534	-0,12198	0,266689

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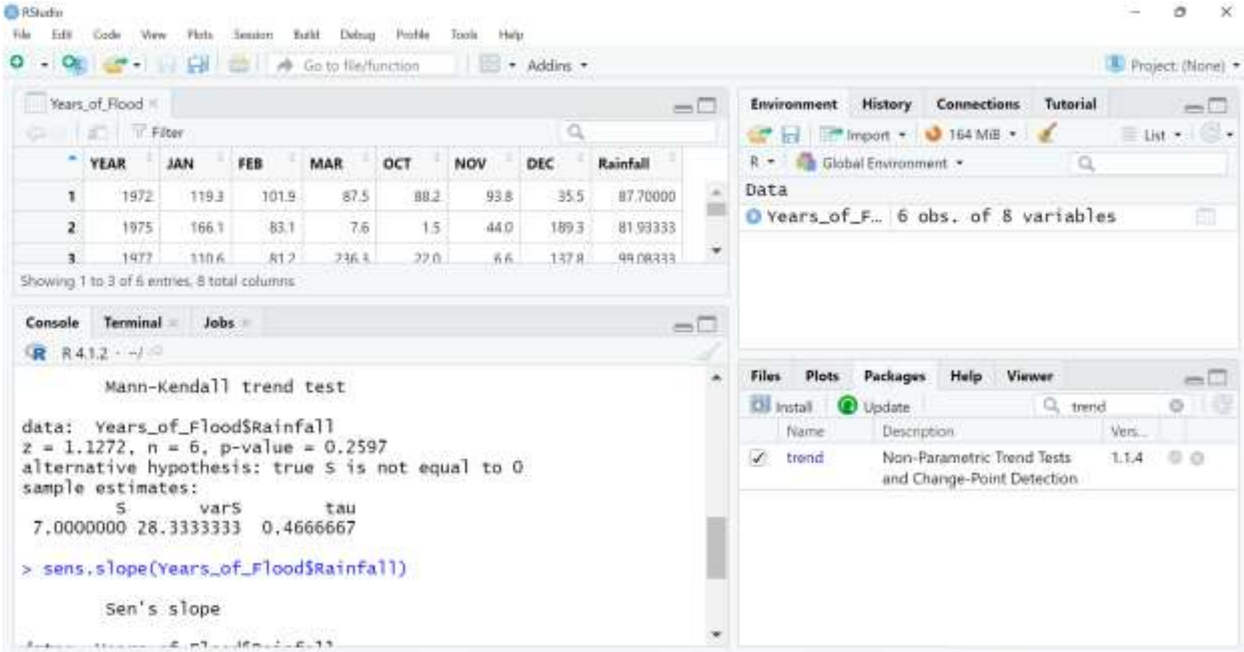
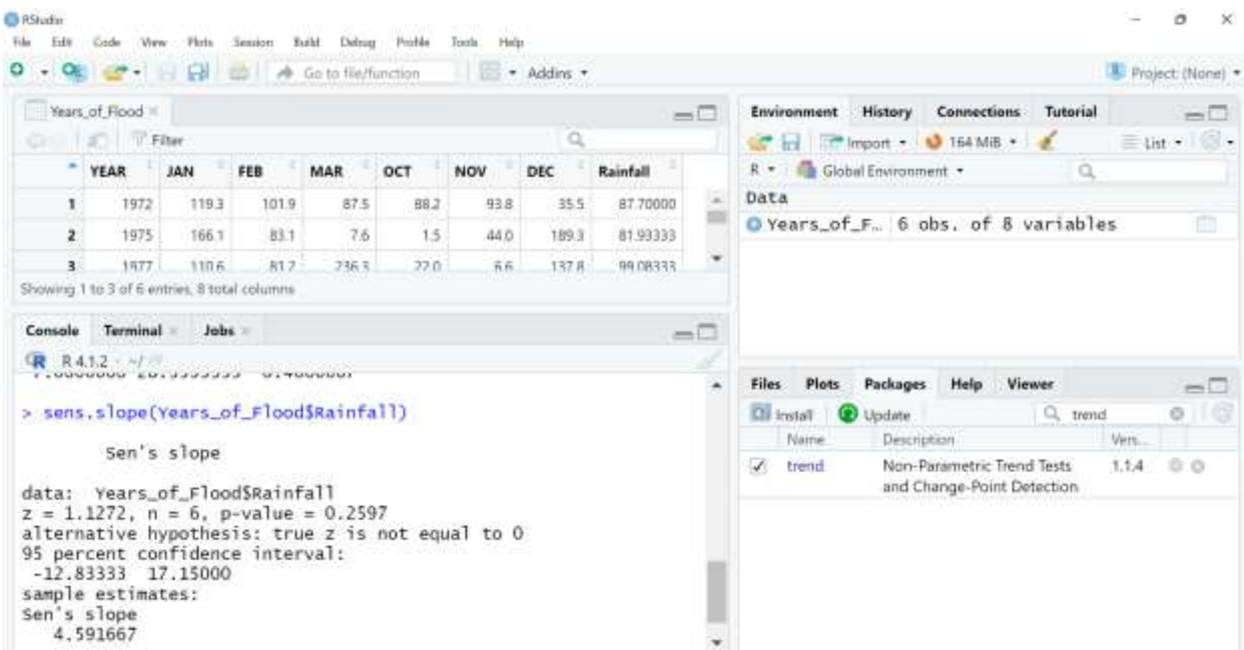
Appendix 6: Mann-Kendal test in RStudio



Appendix 7: Sen's slope test in RStudio



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Appendix 8: During data collection in Tshimapha Irrigation Scheme.

Appendix 9: Template of the register used during data collection and meetings with farmers.

University of Venda

Faculty of Science Engineering and Agriculture

Climatic and non-climatic impacts on Maize production around Mutshedzi Dam.
Date: 11 April 2023
Venue: Phadzima
Time: 08h00

Surname & Initials	Area	Contact	Signature
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			

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Appendix 10: Furrow Irrigation System in Tshimapha Irrigation Scheme

Appendix 11: Quesionnaire tool used for Smallholder farmers

	A	B	C	D	E	F	G	H
1	Would you like to take part in this survey?							
2	Sex							
3	Are you the head of the house?							
4	Employment status							
5	Education level							
6	Do you think you have enough space for your maize production?							
7	Age							
8	How much do you make from your maize production trade monthly?							
9	When did you start producing maize?							
10	How many years have you been producing maize?							
11	What is the number of your dependents?							
12	Means of land ownership.							
13	Where are you coming from?							
14	When do you remember having flood?							
15	How does flood affect (ed) your maize production?							
16	When do you remember having drought?							
17	How does drought affect (ed) your maize production?							
18	How would you describe the impacts of drought on your maize production in this area?							
19	How would you describe the impacts of floods on your maize production in this area?							
20	Where do you get information regarding the upcoming drought and floods?							
21	Have you been trained on climate change interventions							
22	How was the maize production before Mutshedzi Dam?							
23	How is the maize production after the Mutshedzi Dam?							

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24 Have you ever stopped producing maize ever since you started?
25 Have you ever experienced shortages of maize due to low production?
26 If yes, what were the reasons for the shortage of maize?
27 Do you get water for irrigation from the Mutshedzi dam?
28 What is your source of water for maize irrigation?
29 What is the maize produced used for from your land?
30 To whom do you sell your maize to?
31 What are the non-climatic challenges you face?
32 During which season(s) do you produce maize?
33 What influence your choice for the above-mentioned time frame?
34 Which season yield best maize production
35 Where were you getting water for irrigation before the dam?
36 How was the availability of water before the dam?
37 How is the current state of water supply for irrigation?
38 What adaptation measures have you used to deal with the climatic challenges?
39 Do you record your maize production data?
40 Do the department come to collect maize production data?
41 How often do the Department officials come to monitor your production?
42 Where do you get most of your financial support to fight challenges you are facing when producing maize?
43 What kind of support is lacking the most?
44 Do you understand the role of extension of officers?

Appendix 12: Quesionnaire tool used for key infomants

A B C D E F G H I J K L M N O P Q R
1 Would you like to take part in this survey?
2 What is your role/position in this area?
3 When was Tshimapha established?
4 How many farmers in record are around Mutshedzi dam?
5 How many farmers produce maize?
6 Do you collect/record maize yield production of smallholder farmers in this area?
7 When do you remember having drought in areas around Mutshedzi dam?
8 What are the impacts of drought on maize production?
9 When do you remember having floods in areas around Mutshedzi dam?
10 What are the impacts of floods on maize production?
11 What is the main purpose of Mutshedzi dam?
12 Do smallholder farmers around Mutshedzi dam come forward with challenges they face?
13 Of the challenges that smallholder farmers face or report, what are the non-climatic ones that you have seen/hear or know.
14 What kind of support system do you give smallholder farmers with regards to the challenges that they face?Mention them and describe their contribution and impact on maize production system.
15 Timeline of the services or information?
16 What are various organization that advise farmers with regard to the climatic extremes (floods and drought) support systems and challenges they face. (mention their names).
17 What climate services, interventions or support do they provide?
18 Timeline of receiving services/information?
19 What role do you play to ensure good maize production by smallholder farmers in this area?
20 Do you think you are doing enough to support smallholder with regard to the challenges they face?
21 Do you think the government is doing enough to support smallholder famers with regard to the challenges they face?
22 Given the climatic and non-climatic challenges, do you have enough resources to use in sharing the information with smallholder farmers?
23 If No for the above question, what are the shortages?

24 What are the short-term plans for combating the climatic and non-climatic impacts that smallholder farmers face?
25 What are the long-term plans for combating the climatic and non-climatic impacts that smallholder farmers face?
26 Do you have a good relationship with smallholder farmers in this area?
27 If No for the above question, why?
28 Have you ever heard of Sustainable Development Goal Number 2?
29 Do you think maize production in this area is helping to fight hunger?
30 In this area, can this goal be achieved?
31 Do you see maize production being sustained for the next 20 years in this area?

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Appendix 13: Ethical clearence certificate

ETHICS APPROVAL CERTIFICATE

ETHICS APPROVAL CERTIFICATE

**FACULTY OF SCIENCE, ENGINEERING AND AGRICULTURE
RESEARCH ETHICS COMMITTEE**

NAME OF RESEARCHER/INVESTIGATOR: NR MUDZANANI

Student No: 17000165

Project title:

Assessing climatic and non-climatic impacts on smallholder maize production around Mutshedzi Dam, Limpopo Province.

ETHICAL CLEARANCE No: FSEA/23/GES/12

SUPERVISORS/ CO-RESEARCHERS/ CO-INVESTIGATORS

NAME	INSTITUTION & DEPARTMENT	ROLE
FM Murungweni	University of Venda, Geography and Environmental Sciences	Supervisor
H Chikoore	University of Limpopo	Co-supervisor

Type: STUDENT RESEARCH

Risk: **Minimal risk to humans, animals, or environment (Category 1)**

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