Analysis of Level of Technical Efficiency of Water Use by Small-scale Irrigation Farmers in the Nwanedi Area of Limpopo Province: A case study of tomato farmers

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a) DECLARATION

I, **Masindi Lodric Mariba,** hereby declare that the dissertation for **Masters in Rural Development (AGMARD) Degree** submitted to the Institute for Rural Development (IRD) at the University of Venda, titled - **ANALYSIS OF LEVEL OF TECHNICAL EFFICIENCY OF WATER USE BY SMALL-SCALE IRRIGATION FARMERS IN THE NWANEDI AREA OF LIMPOPO PROVINCE: A CASE STUDY OF TOMATO FARMERS** - has not been submitted previously for any degree at this or another university. It is original in design and in execution, and all reference materials contained therein have been duly acknowledged.

Signature: ______________________ **Date:** 09 December 2024

b) ABSTRACT

Agricultural water-management practices are being promoted as a way to adapt to climate change, as well as to combat poverty and unemployment. Low-cost and water-efficient irrigation technologies, such as, drip irrigation are believed to have the potential to save water. This it is anticipated would lead to increased productivity and subsequently improved food and nutrition security for rural livelihoods, thus, lift small-scale farmers out of poverty. Inefficient and ineffective irrigation systems contribute to excessive wastage of available water resources. The purpose of this study was to analyse the level of technical efficiency in water use by small-scale irrigation farmers in Nwanedi. Specifically, the study aimed to (a) characterise tomato production under small-scale irrigation in Nwanedi, (b) analyse use of water against the yield of tomatoes produced in Nwanedi, as well as (c) evaluate the level of technical efficiency of water-use by small-scale tomato growers in Nwanedi. Data were gathered from 144 small-scale farmers from the Nwanedi irrigation system using a questionnaire with both open and closed-ended questions. Frequency distribution tables and graphs were utilised to describe and characterise small-scale tomato farmers. The Stochastic Frontiers model's Cobb-Douglas production function and a simple linear regression model were applied to address the second objective, which was to assess water use relative to tomato yield in Nwanedi. For the third objective, which aimed to evaluate the technical efficiency of water use by small-scale tomato growers in Nwanedi, the Cobb-Douglas production function, was employed. The findings of this study revealed that the efficiency levels of small-scale tomato farmers in Nwanedi ranged from 0.09 to 0.91, with an average of 0.59. This highlights the significant variability in tomato farming practices among Nwanedi farmers. Further, Stochastic Frontiers Analysis (SFA) results revealed that electricity as a proxy variable for water use was a significant predictor of farm income. In addition, the research findings revealed the significance of log(electricity)'s coefficient which suggests a meaningful impact on water use for tomato production's efficiency. This study's findings have both theoretical and practical implications. Theoretically, the findings contribute to the body of knowledge on water usage by small-scale farmers in irrigation farming environments. Practically, this study provides opportunities for improved monitoring and evaluation of small-scale farmers to address the inconsistencies identified in the findings. Overall, the results of the study would inform strategies for implementing effective and efficient water management practices, aimed at conserving water and increasing productivity, therefore, the findings it is anticipated, would be are valuable to farmers, extension workers, and policymakers.

Key words: analysis, efficiency, farm, Nwanedi, small-scale agriculture, stochastic frontiers regression techniques, technical efficiency, water-use efficiency

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i) LIST OF ABBREVIATIONS

ADB	African Development Bank
APRI	Alternate Partial Root-zone Irrigation
AU	African Union
DAFF	Department of Agriculture Forestry and Fisheries
DEA	Data Envelopment Analysis
FAO	Food and Agricultural Organisation
IPCC	Intergovernmental Panel on Climate Change
ITCE	Irrigation water technical cost efficiency
JF5	Jobs Fund Project 5
LDARD	Limpopo Department of Agriculture and Rural Development
NGO	Non-governmental Organisation
NPC	National Planning Commission
OECD	Organisation for Economic Co-operation and Development
SSA	Sub-Saharan Africa
UNSDGs	United Nations Sustainable Development Goals
WUE	Water-use Efficiency

j) CHAPTER 1

k) INTRODUCTION

a. 1.1 Background

Water for irrigation is becoming an increasingly scarce resource for agriculture in many regions of the world (Rosa, Chiarelli, Rulli and Dell'Angelo,2020), making it a global food and nutrition security concern, especially in the developing countries with South Africa included (Nhemachena et al, 2020). This scarcity has largely been compounded by the rapidly changing climate and increase in the number of small-scale irrigation schemes to meet the growing demand for food. According to Ochieng (2024), the past three decades have been the warmest in history, with each decade being warmer than the preceding one. Future impacts are projected to worsen as temperatures continue to rise and precipitation levels become more unreliable. Approximately 75% of the world's poor live in rural areas and rely on agriculture for at least part of their income (Thurlow, Dorosh & Davis, 2019). In South Africa, there has been a growing investment in the support of small irrigation schemes as a strategy to secure food and nutrition (Nyabvudzi & Nkwana,2019). This highlights the need for improved water management systems for agriculture.

The South African Irrigation Strategy which was adopted in 2015, for example, was designed as a response to the call for the irrigation sector to increase its contribution to agricultural production, thus ensuring food security, poverty alleviation and job creation (DAFF, 2015). At the continental level, the African Development Bank came up with the Ten-Year Strategy (2013-2022) in which the Bank assumes a more central role for Africa's development. It puts forward the Bank as a catalyst for transformation, especially, in the agricultural sector. The strategy focuses on achieving food security either through increased production, access or disposable income, for purchase of food (African Development Bank, 2018). The demand for water for irrigation is rising given that the agricultural sector competes with other sectors, such as energy, industry, environment and even domestic uses; since all these sectors are crucial, there is a need for finding ways of using water, efficiently (Rosa, 2022).

Efficient use of water for agricultural production can improve livelihoods of a great proportion of the rural communities through increased income from sale of agricultural products as well as cheaper food. Irrigation has been a cornerstone of agriculture for thousands of years and has helped food production to meet the global population growth (Asma, Subrahmanyam & Krishnaveni, 2023). Apart from promoting food and nutrition security, small scale irrigation has been cited as a strategy for reducing poverty through enhancing income generation (Mhembwe, Chiunya & Dube 2019). The irrigation sector's application of technology in areas, such as fertilisers and crop variation, enables year-round cultivation and promotes increased yields. This shows the potential that irrigation has in responding to multiple socio-economic challenges, especially in developing countries.

Small-scale irrigation systems have been found to have the potential to ensure food security, alleviate poverty and create employment, while at the same time saving water. A modelling study carried out by Akpoti *et al*. (2022) showed that small scale distributed irrigation had five times the expansion potential compared to centralised irrigation systems. In addition, the same authors noted other advantages of small-scale irrigation systems, such as reduced soil salinization, reduction of evaporation losses and their ability to be tailored to local water conditions to maximise usage of water from a variety of sources. These benefits are particularly essential for sub-Saharan African (SSA) countries, where climate change is greatly affecting rainfall patterns and amounts. Several policies and frameworks have been put in place to provide support to the agricultural sector in different ways, to increase productivity and ensure sustainability. These include - the National Development Plan of 2013, the National Policy on Comprehensive Producer Development Support of 2018, the Irrigation Strategy for South Africa of 2015 the National Water Resources Strategy of 2015 the Integrated Growth Development Plan of 2012, and the Draft Climate-smart Agricultural Strategic Framework for Agriculture, Forestry and Fisheries of 2018 – all aimed at a sustainable usage of water.

Drip irrigation in particular, has the potential to sustainably provide both small-scale and commercial farmers with improved yields and irrigation efficiency (Dawit, Dink & Leta 2020). According to Giller et al. (2021), improving farming technology, such as irrigation, has enabled African farmers to grow more and healthier food varieties. Drip irrigation is widely promoted as a way of improving water productivity (Yang et al., 2023). This is based on the assertion that drip irrigation is much more efficient than other techniques, such as furrow or sprinkler irrigation; this is because less water is lost in conveyance as most of the irrigation water is applied directly to the plant. Secondly, drip irrigation allows more uniform distribution of water across the field, such that all plants receive almost the same quantity of water (Yang et al., 2023), hence, according to Monaghan *et al.* (2021), drip irrigation is quickly gaining popularity as a low-cost and water-saving technique. Drip irrigation is also associated with the application of nutrients (fertigation), thereby, it allows better nutrient management. These benefits possibly convinced scholars such as Yu et al. (2020) and Lakhiar (2024) to claim that drip irrigation may double or triple water efficiency.

In South Africa, the greatly expanded small-scale farming sector, coupled with redistributive land reforms are expected to make a significant contribution to rural development, employment creation and poverty reduction. In the national policy documents that seek to address the very high levels of unemployment, such as the New Growth Path and the National Development Plan, specific objectives have been put in place. The National Development Plan (NDP, 2030), for example, proposed the creation of opportunities for 300 000 households in agricultural smallholder schemes by 2020. In the same vein, the National Planning Commission (NPC, 2021) states that one million new jobs can be created in agriculture and related industries over the next two decades. According to NPC, these jobs are expected to come from labour-intensive forms of small-scale farming in communal areas and on redistributed land, with many engaged in irrigated farming. Particularly, the Commission noted then that there was a huge potential that the area under irrigation would expand from 1.5 million to 2 million hectares (NPC, 2021). In fact, the Irrigation Strategy of South Africa was designed not only to increase the contribution of Agriculture to Gross Domestic Product (GDP), alleviate poverty and creation of employment, but also to optimise irrigation water use efficiency with a view to ensuring long-term sustainability of irrigated agriculture (Obaideen et al., 2022).

The irrigation system for small-scale farming, although it is promising as being cost-effective, some researchers are more cautious about the system’s efficiency claims, pointing to the fact that the impacts of this technology are rarely compared with actual practice (Wainaina,2021). In addition, drip irrigation can potentially have negative effects on the environment through salinization and ground water pollution. This happens when drip irrigation systems are not tailored to their environment, however, if well managed it can be a fundamental method of irrigating crops, especially for tomatoes, among other crops (Wang et al, 2023). Tomato is regarded as one of the essential horticultural plants which can be consumed as either a vegetable or fruit (Kumar, Kumar, Gull & Nayik, 2020). According to Behera *et al*. (2022), tomato production is believed to positively impact health, as it is rich in a variety of vitamins, minerals, sugars, dietary fibres and amino acids, thereby, contributing to nutrition security. Small-scale irrigation in tomato farming, in Limpopo, holds great potential to create employment and reduce poverty in the Province. Tomato production, therefore, can contribute to food and nutrition security while providing income for many households in Limpopo Province.

In this study, the Limpopo Department of Agriculture and Rural Development and The Jobs Fund 5 (LDARD-JF5) programme was used as case study. Through the LDARD-JF5 programme, a total of R120 million was invested in agricultural activities taking place in Nwanedi. The funding was used to construct a Pack House and procure infrastructure, such as drip irrigation systems, tractors, trucks among others, as well as capacity-building of farmers through training on various agricultural management processes. The project also helped secure markets for farmers for retail, wholesale and export. About 150 tomato growers in the area were supplied with two hectares of surface drip irrigation systems which were meant to support farmers with irrigation equipment, in order to promote productivity (Ara et al., 2021). The aim of this study, thus, was to assess the technical efficiency of small-scale drip irrigation systems for tomato production in the Nwanedi irrigation scheme. For this process, firstly, tomato production under small-scale irrigation in Nwanedi was characterised; secondly, water-use in tomato production was measured against the yield of tomatoes produced in Nwanedi and thirdly, the constraints of small-scale drip irrigation systems among the tomato growers participating in LDARD-JF5 programme in Nwanedi were established and finally, strategies for improving these farms' profitability, were recommended.

b. 1.2 Statement of the Research Problem

Scarcity of water and its links to food security are a major global concern, especially in Southern African countries (Filho, 2022); this is an additional challenge to poverty and unemployment in South Africa. Most poor farmers rely on rain-fed agriculture for their survival, making them vulnerable to the highly unpredictable rainfall, due to climate change (Ntuli, 2023). Climate variability are expected to worsen, hence, non-governmental organisations (NGOs), governments and private firms are promoting a variety of low-cost agricultural water management practices. The South African government has made significant investment in small-scale irrigation programmes for resource-poor farmers as well as providing them with an enabling environment through irrigation policies and strategies (Mudhara & Senzanje, 2020). These initiatives are part of the land and agrarian reforms meant to redress the inequalities in land ownership between black and white South African people. Policies, such as the South African Irrigation Strategy and the National Policy on Comprehensive Producer Development Support (2018) have been developed to provide support to small-scale agricultural activities, as well as to protect, improve and optimally utilise scarce natural resources such as land, water and biodiversity (DAFF, 2018). Efficient use of water is, therefore, a critical aspect of agriculture since water is a prime yet underrecognized input of any sustainable farming system. According to Angom & Viswanathan (2023), low-cost, water efficient irrigation technologies, such as drip irrigation are believed to have the potential to increase productivity and subsequently improve food and nutrition security and rural livelihoods. The government and other stakeholders involved in supporting small-scale irrigation have been highlighting the need to expand the agricultural sector, however, they are also aware it would mean increasing the demand of water which is already a scarce resource. In the face of dwindling water resources, it is urgent to investigate how to efficiently use the available water (Zhanget al,2020). This is necessary to improve wasteful irrigation methods which are unsustainable, given the already scarce nature of available water resources. Moreover, wastage of the precious water may lead to interruptions at critical stages in crop growth which can potentially affect crop quality and productivity, which in turn result in low profitability from these crops.

Nare & Thomas (2023) state that, although there is growing interest in the use of low-cost irrigation technologies, there are debates regarding the efficiency of these, for instance, drip irrigation. The LDARD-JF5 in Nwanedi is one such programme in which the government has made a huge investment with the anticipation to increase productivity, contribute to food security and create employment. Through the Limpopo Department of Agriculture and Rural Development Standards (2023/24), R120 million was invested towards setting up drip irrigation infrastructure and building a packhouse for packaging agricultural produce. Given that Nwanedi irrigation is located in a semi-arid area and faces increased water shortages, the need to efficiently utilise water is obvious. This justified the need to undertake an empirical study with a specific aim of measuring water use efficiency of the promoted drip irrigation in tomato production. The study also sought to assess existing opportunities and constraints of the LDARD-JF5 programme for the purposes of suggesting recommendations for the realisation of improved profitability levels by small-scale tomato farmers in Nwanedi Irrigation Farming System.

c. 1.3 Justification for the study

This study is significant because its findings would benefit small-scale tomato growers in Nwanedi, South Africa and beyond, on ways of improving water use through the drip irrigation systems. This system helps small-scale farmers to monitor their water use, thereby, minimising water-related costs, which in turn would improve the overall productivity of small-scale tomato farmers. To other development-related stakeholders, such as the Department of Agriculture and Jobs Fund 5, the study would benefit them through empirically ascertaining the rate of returns that their invested funds received on farming activities undertaken by the small-scale tomato farmers in Nwanedi under their banner. Further, knowledge of efficient or inefficient use of water and its impact on productivity is crucial for ensuring that loans given to small-scale farmers are repaid, thereby, reducing wasteful expenditure. The body of scientific researchers would also benefits from this study through the information generated particularly in water-use efficiency which is characterised by scant literature on tomato production. Finally, policy makers would also gain informed insights pertaining to the viability of drip irrigation technology for small-scale farmers in order to promote or possibly facilitate funding.

d. 1.4 Research objectives

The main objective of the study was to investigate the technical efficiency of water use by small-scale farmers practising drip irrigation under the Nwanedi Secondary Cooperative. To achieve this, the following specific objectives were pursued:

a) To characterise tomato production under small-scale drip irrigation system used in Nwanedi.
b) To measure the economic efficiency of the small-scale tomato production system in Nwanedi.
c) To determine the technical efficiency of water-use by small-scale tomato growers in Nwanedi.

e. 1.5 Research assumption

One key underlying assumption of this study was that specific characteristics of tomato varieties grown in Nwanedi were unknown at the time of executing this research study.

f. 1.6 Research hypotheses

l) The patterns of water use for tomato production in Nwanedi are wasteful;

m) The technical efficiency of water use by small-scale tomato growers in Nwanedi is low.

a. 1.7 Operational definitions of key terms and concepts

Drip irrigation is the application of water through point or line sources at small operating pressures and this water is then distributed in drops in the field, by many gutters distributed along rows of plants (Alcon et al., 2019)

Irrigation water technical cost efficiency (ITCE) is the potential cost savings from adjusting irrigation water to a technically efficient level, holding constant all other inputs at observed levels (Chebil *et al*., 2022)

Technical efficiency is defined as the ability of an enterprise to either produce the maximum possible output from a given bundle of inputs using a given technology, or to produce the given level of output from the minimum number of inputs for a given technology (Mahdhi *et al*., 2021). In the context of this study, technical efficiency, means the ability of a farm to produce a given level of output from the minimum amount of water.

The **LDARD-JF5** is a programme used to co-finance projects by public, private and non-governmental organisations that will significantly contribute to job creation. This involves the use of public money to catalyse innovation and investment on behalf of a range of economic stakeholders in activities that contribute directly to enhance employment creation in South Africa (Limpopo Department of Agriculture and Rural Development Service Standards 2023/24)

Small-scale agriculture is defined as the production of crops and livestock on a small piece of land without using advanced and expensive technologies (Woodhill et al., 2020). It is characterised by small farms that are typically family-owned and operated.

b. 1.8 Theoretical Framework

The non-parametric technique of measuring efficiency was used in this study: this is called "Data Envelopment Analysis" (DEA). This method has been used to measure technical efficiency by researchers, such as Farrel (1957) and Cooper and Rhodes (1978) who originated the concept and name "DEA". Unlike the stochastic frontier estimation method, the DEA has the advantage of not imposing a functional form on the production data (Masterson, 2024). Jordan & Speelman (2020) provide an explanation of the process used when measuring water efficiency. The DEA is used to calculate more consistent measures of efficiency (Cecchini et al, 2021). This is a systems' approach commonly used in sections of management science and economics, in which the relationships between all inputs and outputs are taken into account simultaneously. The method enables determination of the relative efficiency of a farm and the examination of its position in relation to the optimal situation. Jordan & Speelman. (2020) highlight that this methodology allows not only technical, but also sub-vector efficiencies to be calculated, which can be used to specifically monitor the efficiency of water use. In addition, this technique allows for multiple outputs. The following linear program was followed:

$$\text{Min } \varphi$$

$$\text{s.t. } \sum \lambda_j x_{ij} + S+_i = \varphi x_{ijo} \ \forall i$$

$$\sum_{j} \lambda_j y_{rj} + S_r = y_{rjo} \quad \forall r \qquad (1.1)$$

$$S^{+}_{i}, S^{-}_{r} \geq 0 \ \forall i, \forall r$$

$$\lambda_j \geq 0 \qquad \forall j.$$

where x_{ij} is the amount of input *i* for farm j, y_{rj} is the amount of output *r* from farm *j*, and *jo* is the farm to be assessed. The objective variable φ measures the technical efficiency of farm *jo*. The two slack variables, S^{+}_{i} and S^{-}_{r}, measure slack in inputs and outputs, respectively (Masterson, 2024).

c. 1.9 Outline of the Dissertation

Chapter 1 introduces the study covering - the background and rationale for the study, statement of the problem, objectives, research hypotheses, and operational definitions of key terms.

Chapter 2 reviews the published literature on the opportunities and constraints of small-scale drip irrigation systems, as well as recommendations for improved productivity. In the chapter is also discussed the theoretical framework underpinning this research.

Chapter 3 focuses on the research methodology and outlines the methods, techniques and tools which were adopted in this research to answer the research questions.

Chapter 4 presents the results and discussions structured to address each research objective comprehensively. The first section characterises tomato production under small-scale drip irrigation systems in Nwanedi, detailing farming practices, input usage, and production trends. This is followed by an analysis of the economic efficiency of the small-scale tomato production system, highlighting cost efficiency and profitability metrics. Lastly, the chapter examines the technical efficiency of water use by small-scale tomato growers, focusing on water productivity and irrigation efficiency. Each section includes an introduction, methodology, results, discussion, and conclusion, providing a cohesive and in-depth exploration of the research objectives.

Chapter 5 summarises the main research findings, their implications, recommendations and conclusions.

n) CHAPTER 2

o) LITERATURE REVIEW

a. 2.1 Introduction

Many rural populations rely on rain-fed farming for their survival, making them vulnerable to the highly variable and unpredictable rainfall. Some authorities suggest this variability may be increasing due to climate change which has resulted in periodic droughts and famines (Kalele, Ogara, Oludhe, & Onono, 2021; Amede, 2015). According to Bedeke (2023), the poor in Africa, particularly smallholder farmers, are highly vulnerable to climatic and environmental hazards as their options for diversifying their resources and income sources are limited. In fact, the 2015 Intergovernmental Panel on Climate Change (IPCC) assessment report indicates that most countries will experience an increase in average temperature, more frequent heat waves, more stressed water resources, desertification, and periods of heavy precipitation. For African countries, their vulnerability is worsened by the effects of HIV/AIDS, lack of access to land due to the traditional land tenure systems, lack of adequate water, corruption, governance issues, low levels of technology, education and institutional mismanagement (Ochieng *et al*., 2016). This calls for clear response strategies in terms of mitigation and adaptation strategies to deal with the threats posed by climate change.

b. **2.2 Tomato** production and water use efficiency **(WUE)**

i.2.2.1 Global importance of tomato production

Tomatoes are crops of multifaceted significance, underscoring their global importance as key agricultural commodities that support economies, enrich diets, and promote sustainable urban agriculture (NAMC, 2024; Gatahi, 2020). They are among the most widely used fruits worldwide and rank as the second most consumed vegetable, after potatoes (NAMC, 2024). The popularity of tomatoes stems from their versatility, as they can be prepared and enjoyed in numerous ways. According to Gatahi, (2020), tomatoes hold a vital position as both food and cash crop, worldwide, contributing significantly to food security and economic livelihoods. In addition to their traditional role as a staple in diets, tomatoes are valued as an ornamental plant in various parts of the world (Gatahi, 2020). In urban settings, tomatoes are increasingly integrated into food-scaping systems, where they are cultivated in hanging baskets, growing pots, and aquaponics setups for both aesthetic appeal and food production (Gatahi, 2020).

The crop serves diverse market niches, with production aimed at both fresh consumption and processing (NAMC, 2024; Gatahi, 2020). In developed countries, a substantial portion of tomatoes is processed into products such as, sauces, pastes, and canned goods, highlighting its versatility and industrial value. According to Gatahi, (2020), the cultivation practices of tomatoes range from open-field farming to greenhouse production; this allows for year-round availability and adaptability to different environmental conditions.

Globally, tomatoes play a crucial role in agriculture, not only as a staple in diets but also as a significant source of employment. In South Africa alone, tomato production provides jobs for 25,000 to 28,000 people annually, with seasonal demand peaking during the summer months, highlighting its economic and social impact (NAMC, 2024).

ii.2.2.2 Water requirements of tomato crops

According to Chand, Hewa, Hassanli, & Myers, (2021) tomatoes are among the most common crops worldwide; they are also known for their high-water dependency. A study conducted by Adeniran, Amodu, Amodu, & Adeniji, (2010) observed that the water requirement for tomato crops shows significant variability, ranging from 8.7 to 52.8 mm/day during peak demand periods and 0.0 to 45.2 mm/day under other conditions. Further, a study conducted by Welde et al. (2024) estimated the tomato water requirement using CROPWAT 8 software[1], with the calculated requirement being 500 mm throughout the base period. These findings illustrate the tomato crops' dependency on adequate and well-managed water supply for optimal growth and productivity. A recent report by NAMC (2024) identified water supply issues as a major challenge impeding tomato production in South Africa. Given the significant water requirements of tomato crops and the challenges posed by water scarcity, as highlighted in recent reports such as NAMC (2024), understanding the technical efficiency of water use in tomato production is imperative. This knowledge is critical to optimising water utilisation, enhancing productivity, and ensuring the sustainability of tomato farming, particularly in water-stressed regions like South Africa.

iii.2.2.3 Challenges in water use efficiency (WUE) for tomato farming

Achieving optimal water use efficiency (WUE) in tomato farming remains a critical challenge, particularly in water-scarce regions, as tomatoes have high water requirements that necessitate

[1] **CROPWAT 8.0** is a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data (https://www.fao.org/land-water/databases-and-software/cropwat/en/).

precise irrigation management to balance water availability with crop productivity (Welde, Gebremariam, & Kahsay, 2019). Welde et al. (2019) have identified several challenges associated with WUE, including over-irrigation practices where farmers often supply water volumes exceeding the crop's water requirement (CWR). These authors revealed that local farmers used 561 mm of water per growing season, 12.2% above the estimated CWR of 500 mm, leading to wasted resources and reduced WUE. Furthermore, the study by Welde and team (2019) revealed a wide variation in irrigation water use efficiency (IWUE), ranging from 0.357 to 0.876 kg/m^3 depending on irrigation levels, highlighting the difficulty in achieving consistent WUE across different practices and conditions. Environmental and climatic factors such as soil type, evaporation rates, and local climate further complicate water management in tomato farming, making it challenging to implement optimal irrigation strategies (Nikolaou et al., 2020). Addressing these issues requires a combination of farmer education, the implementation of advanced irrigation scheduling techniques, and the adoption of innovative tools to enhance WUE, especially in regions with limited water resources.

iv.2.2.4 Role of Nwanedi in tomato production

Nwanedi plays a pivotal role in tomato production in South Africa, particularly within the Musina Local Municipality (BE, 2015; Lebepe, 2022). Nwanedi's fertile land and irrigation systems support year-round cultivation of tomatoes, making it a critical area for both small-scale and commercial tomato farming (Lebepe, 2022). Nwanedi is home to significant agribusiness initiatives, including the Promoting Agribusiness Linkages (PAL) project, which has been operational since 2004 (Louw et al., 2008). The PAL project which is managed by Tiger Brands in partnership with ECI-Africa and funded by USAID is focused on supporting small-scale tomato farmers in the Nwanedi area. Under the PAL initiative, farmers are provided with essential financial resources and agricultural inputs, such as seeds, fertilizers, chemicals, and irrigation equipment, enabling them to increase their productivity and meet market demand.

As the largest tomato processing company in South Africa, Tiger Brands' processing plants in Musina and Tzaneen are integral to the region's tomato industry. These plants serve as key outlets for the tomatoes produced by small-scale farmers in Nwanedi, ensuring a stable market for their crops. The support provided through the PAL project also helps small-scale producers improve their farming techniques and access better market opportunities, thereby strengthening the local agricultural economy. This collaborative effort has enhanced the role of Nwanedi in tomato production, positioning it as a major contributor to both the national fresh and processed tomato markets in South Africa (NAMC, 2024). The ongoing development of this agricultural hub will ensure that Nwanedi remains a central player in the country’s tomato industry, with a focus on sustainability, efficiency, and growth (Maponya, 2021; Apio, Thiam, & Dinar, 2023).

v.2.2.5 Water resource challenges in Nwanedi

The Nwanedi Irrigation Scheme, located in the Musina Local Municipality of Limpopo Province, faces significant water resource challenges that threaten the sustainability of agricultural production, particularly for crops like tomato and butternut (Lebepe, 2022). According to Lebepe, (2022) declining underground water levels, unpredictable rainfall patterns, and high temperatures all contribute to the Nwanedi's water scarcity issues. These challenges are exacerbated by the increasing demand for water in the agricultural sector, hence, farmers rely on irrigation to maintain consistent crop yields throughout the year. Nwanedi's reliance on water for irrigation has led to concerns about the long-term viability of farming in the area, particularly in the face of water security threats that affect both food production and local livelihoods. As water resources become more constrained, it becomes crucial to adopt water-saving practices and interventions that will help mitigate the impact of water scarcity on crop production in Nwanedi. The challenge lies not only in improving irrigation techniques but also in ensuring that water use is optimised at every growth stage of the crops to minimise wastage and enhance overall water use (WUE) (Welde et al., 2019).

c. 2.3 Impact of water scarcity in *S*ub-Saharan Africa

Okou et al. (2022) add that sub-Saharan Africa (SSA) is the only region in the world where per-capita production of staples has declined over the last half-century. In this region, famines persist, most of which are triggered by drought and erratic weather. Countries in SSA have not been able to reap the potential benefits of irrigation and this is evidenced by the region's level of development which is lowest compared to others (Kadigi *et al*., 2022); for example, despite its rich and varied water endowment, only 4% of arable land in SSA is irrigated, compared to 47% in Asia and 18% worldwide (Kadigi *et al*., 2019). Some 40 million hectares of its land are suitable for irrigation, yet only 7.3 million hectares are irrigated, hence, there is a significant potential for increasing production through investment in irrigation (Mudhara & Senzanje, 2020).

The negative effects of water scarcity have been aggravated by - expanding agricultural needs, land degradation, poor water management practices, and limited institutional and household capacities to store and efficiently utilise available water resources (Hossain et al., 2020). There is growing interest in the large range of low-cost agricultural-water management-technologies in semi-arid developing countries. This is in response to the observation that unreliable water supply is one of the biggest threats to the food security of poor small-scale farmers. In addition to hunger and starvation, the consequences of lack of water include, significantly-reduced economic growth, severe impacts on people's nutritional status, and diminished resilience to future periods of drought (Merrey, 2006; Alaimo, Chilton, & Jones, 2020). This is an indication that irrigation has potential to reduce the effects of climate change and provide a continuous supply of water for agriculture. This demonstrates the crucial role of irrigation in managing water resources efficiently, as this is vital for sustaining agricultural productivity, especially in the face of climate change. Understanding the different types of irrigation systems, particularly drip irrigation, therefore, is essential for optimising water use in crop production.

d. 2.4 Types of drip irrigation systems

The drip irrigation technology consists of bringing water under pressure in a system of pipelines. This water is then distributed in drops in the field by many gutters distributed along rows of plants. This irrigation system is used to grow tomato (*Solanum lycopersicum*), onion (*Allium cepa*), shallot (*Allium fistulosum*), banana (*Musa sapientum*, papaya (*Cerica papaya*) and oranges (*Citrus X sinensis*) among others (Mammary *et al*., 2018). Within the drip irrigation technology, however, there are several subtypes which include - household buckets, drum kits, shiftable drip systems, sub-surface drip irrigation and alternate partial root-zone irrigation (APRI). These are briefly described below.

Bucket kits are regarded as entry-level systems consisting of a simple 20-litre household bucket attached to a pole at about shoulder-height. The bucket is equipped with a 10-metre lateral line, from which 26 micro-tubes extend. When placed mid-way between parallel crop rows, each micro-tube can irrigate four plants. The bucket needs to be filled with water two to four times per day. In this way, each bucket kit irrigates 100 individual plants over a 25 m^2 area, providing all the vegetables a family needs by adding critical vitamins and minerals to the diet. The labour burden (which often falls on women) of hand-watering home gardens can discourage plots of this size, the bucket kit offers an initial step toward sustainable food security and cash income (Farris, 2021).

Drum kits are one step up from the bucket kit in terms of size. These systems consist of a 200-litre drum from which five lateral lines are extended. Each lateral line is 10 metres long and fitted with 26 micro tubes, allowing each drum kit to irrigate a 125 m^2 plot, an area five times larger than the bucket kit covers.

Another sub-type of drip irrigation system in the Shiftable Drip Systems (Al-agele, 2020). These systems resemble more conventional drip systems but have much lower capital costs because they are designed to be shiftable instead of being stationary. The conventional systems require a plastic lateral line for each row of crops, whereas, this system consists of shiftable lateral lines, each of which irrigates about ten rows. An off-the-shelf plastic tank placed two to four metres above the field (and equipped with a simple cloth filter) provides adequate pressure for the system. Water drips out of baffled holes in the lateral systems. The cost reduction results mainly from a system design that allows each lateral line, an expensive component, to irrigate four rows of crops instead of one or two. This is accomplished by extending micro tubes from both sides of the lateral and positioning each one between two closely-spaced parallel rows. The system is pressurised by a concrete tank placed about four metres above the field and equipped with a low-cost filter (Richards et al., 2021).

Subsurface drip irrigation (SSD) on the other hand, is a new and highly efficient irrigation method that is well suited for arid land environments (Fu *et al*., 2021). The subsurface drip irrigation involves the application of water below the soil surface through emitters, and features discharge rates generally in the same range as drip irrigation. The SSD has been proven to be an efficient irrigation method capable of offering - high water use efficiency (WUE), lower soil erosion, fewer weed and disease problems, efficient fertiliser application, design flexibility, maintenance of dry areas for tractor movement at any time, lower labour costs than conventional drip irrigation systems, reduced evaporation and deep percolation losses, and surface runoff elimination (Fu et al., 2021). In addition, SSD can be a suitable irrigation method in arid and semi-arid regions because of its potential to precisely apply, in quantity and position, water and nutrients through a field, however, there are also potential disadvantages with SSD, such as poor or uneven surface wetting and risky crop establishment.

Another type of drip irrigation is the alternate partial root-zone irrigation (APRI) or alternate partial root-zone drip irrigation (ADI). This is a technique which saves water through alternate wetting and drying of root-zones (Liu et al, 2020). According to Singh (2022), APRI is regarded as a new water-saving irrigation technology, as it involves irrigating half of the root-zone while the other half is controlled as dry, and then switched with a regulated pattern. APRI can achieve the aim of - no yield decrease, saving of irrigation water, and enhancing WUE. It can be used when growing different crops, such as tomato, maize and cotton. Various scholars outline some specific advantages of APRI, for example, Daliakopoulos *et al*. (2019) note that APRI raises tomato yield and vitamin C by 7-10 and 12.6%, respectively, but reduces organic acid by 5.3%. Alternate partial root-zone irrigation (APRI) is believed to enhance grapevine WUE by 26.7- 46.4% without yield reduction and improve the fruit quality significantly compared to conventional drip irrigation (Mairata *et al*., 2024). APRI also produces better fruit quality of cucumber along with the increases in WUE without obvious yield decreasing (Ji *et al*., 2022).

Above-surface irrigation system is another type of drip irrigation which works much like subsurface drip irrigation; the only difference is that the drip lines will be on the surface. In this technique, water flows through a filter into special drip pipes, with emitters located at different spacing. Water is distributed through the emitters directly into the soil near the roots through a special slow-releasing device. This is the type of drip irrigation system practiced in Nwanedi; water for the irrigation is drawn from Nwanedi dam and stored in tanks on farm plots. Then pipes are connected to the tank and the drip lines are then connected to the main pipe.

e. 2.5 Barriers to successful implementation of small-scale irrigation

Irrigation is believed to relieve farmers from the effects of climate change, although, several hindrances to its successful implementation have been noted. According to Kloppers (2022), there are two main types of barriers to increasing the productivity and profitability of small-scale irrigation systems, namely, those associated with the technical aspects of irrigation infrastructure and those associated with softer issues such as access to markets, knowledge, farm implements and financing, as well as governance. The authors add that the barriers to improving farm productivity and profitability in small-scale irrigation schemes are a broad and complex mix of institutional, market, infrastructure and production issues. In Ethiopia, the main limitations of small-scale irrigation development include poor scheme management, imperfect market, insufficient technical skills, socio-institutional constraints and financial shortages (Monnet *et al*., 2022).

Firstly, irrigation schemes are expensive to operate and maintain, both in terms of cash and users' time for labour contributions and meetings, therefore, if irrigated agriculture is not sufficiently profitable, people will not invest what is required for success (Small, 2019). Zarei *et al*. (2020) observe that too many irrigation schemes are in fact performing poorly or are defunct for this reason. Moreover, limited knowledge and weak financial capacity have limited community investments in water resources and constrained access to other farm inputs (Zarei et al,2020). Technologies for accessing water pose an especially acute problem. Small (2019) adds that even the cheapest pumps may be prohibitively expensive, without financing.

Another issue which create problems with irrigation systems is the size of plots. Abigail (2019) alludes that small plot sizes of 0.1 to 0.5 hectares which are so prevalent in small-scale irrigation schemes, effectively prevent farmers from producing significant amounts. This makes irrigation only marginally profitable compared to other economic opportunities in urban centres. Small plot sizes mean that irrigators on small plots on rural sites must depend on several sources of income, for example, animal husbandry, fishing or urban work (Tesfaye *et al*., 2021). On the other hand, Bhattacharjee & Roy (2024) argue that for small-scale irrigation to be sustainable, stakeholders need to reduce external investment as much as possible to match the economic capacity of the community and be self-supported ventures. According to the authors, progress is most likely to occur when local communities have the agency to initiate their own reforms to improve irrigation-scheme productivity, sustainability and equity, because empowered communities are better able to identify and adopt appropriate technologies and demand more practical, supportive policies from government agencies.

In Africa, the objective of many small public schemes is food security, as opposed to market integration, which is needed to support any kind of investment in the system (Balineau, 2021). With small public schemes, there are few market linkages, hence, little or no reinvestment in maintenance or infrastructure. The focus on food security fundamentally impact profitability (Bjornlund *et al*., 2022). Shah *et al*. (2020) observe that, in Africa, if schemes were designed with small-scale user group management in mind, they should be built quite differently with respect to service delivery, fee collection, maintenance and self-management. In Zimbabwe, one of the reasons for small-scale irrigation schemes' underperformance is that many were designed as large-scale, single-unit systems and they did not have the flexibility to accommodate small-scale operations (Bjornlund, 2022). Infrastructure barriers for small-scale irrigation schemes include, dilapidated water supply systems, poor construction quality and lack of resources to maintain infrastructure (Bjornlund *et al*., 2022)

f. 2.6 Opportunities of irrigation

As already indicated, the largest concentrations of poor and hungry people are found in the rural areas of South Asia, north-western China and sub-Saharan Africa (Smith, & Wiesmann, 2007). Many poor farmers in these regions lack access to affordable irrigation, face production constraints resulting from seasonal or chronic water scarcity and cultivate less than two hectares of land. As a result, these are logical places to launch wider efforts to spread affordable drip irrigation to small farmers (Owkwanga & Mwesigwa, 2021).

One way of maximizing gains from irrigation is through improving the capacity of farmers in various spheres. Frey *et al*. (2024) argue for increased focus on building small-scale farmers' technical and governance capacity at different levels. Pittock & Grafton (2020) highlight capacity-building through people rather than technology as both a primary challenge and an opportunity. On-farm action to improve livelihoods is required in the short-term while systems, policies and distribution are being improved. According to Evans (2022), farmers require a broad mix of agronomic, irrigation and business skills, as well as training in the selection, operation and maintenance of equipment and infrastructure. There is a need to address the lack of understanding of crop-water requirements, water-saving technologies and crop varieties (Ahmed et al, 2022). Wale et al, (2022) also note fertility and pest control as information requirements to improve yield and water productivity. Another component for water productivity is the successful use of new monitoring technology to improve farmers' understanding of soil moisture and nutrient management (Mdemu *et al*., 2020). It is, thus, clear that for irrigation systems to be successfully implemented, farmers should have the capacity to effectively and efficiently use these systems to avoid unnecessary production costs.

Scholars also mention other advantages that are related to irrigation agriculture. These include - improving farmer participation and collaboration with a broad range of stakeholders (through identifying barriers to participation by individuals and user groups) (Ricart et al., 2019); conflict-resolution methods (giving groups the mandate to consult, mobilize and solve issues (Aduma *et al*., 2024); promoting beneficial relationships between large commercial farms and small-scale farmers; improving access to input and output markets as well as equipment (Meinzen-Dick et al, 2019); promoting transaction-cost reduction and better access to information on markets and new technologies, and how to enter high-value markets (Ma *et al*., 2020); management tools for water scheduling to support high yields and value chain participation strategies to increase the revenue of associations, (including fines and non-irrigation services such as supplying fertilizer and seed, equipment hire, land preparation and market organization) (Shah *et al*., 2020). All these opportunities mentioned provide an enabling environment for farmers to become productive in their agricultural activities.

g. 2.7 Benefits of irrigation

A wide range of benefits of irrigation have been explained in literature, and although most of these benefits are related, however, they are presented separately in the following sections. These benefits include increased productivity, improved food security and nutrition, alleviation of poverty and employment creation.

i.2.7.1 Increased productivity

Smith (2019) argues that irrigation agriculture increases the reliability and consistency of production leading to sustainable crop yields because of the possibility of farming throughout the year. Irrigation agriculture also increases crop diversification options for farmers and improves smallholder farmers' livelihoods through sustained food availability (Umer *et al*., 2024). Awulachew & Merrey (nd) argue that through increasing the opportunity for production and better income, irrigation reduces risks and creates more optimism for poor rural communities. Berhe *et al*. (2022) maintain that irrigation has been a cornerstone of agriculture for thousands of years and has helped food production expand pace with population growth. It enables year-round crop production, higher yields, growth in rural incomes, and a dramatic reduction in acute and chronic hunger.

In monsoon climates with long dry seasons, as well as in semi-arid and arid regions, where access to irrigation water is critical to boost and stabilize crop production. With a secure water supply, farmers can choose to invest in higher-yielding seeds, grow higher-value crops, and harvest an additional crop or two each year. Irrigated plots in developing countries commonly yield twice as much as rain-fed plots do (Mohammed, 2020). By raising small-farm productivity, access to irrigation water is also key to improving rural livelihoods and revitalizing rural economies. Lu (2021) argues that by creating more secure and stable rural communities, access to productivity-enhancing irrigation water can also help stem the tide of migration to already overcrowded cities and slums. Irrigation farming insulates the national agricultural economic sector against weather-related shocks (Yihdego, 2015); thus, irrigation increases the number of crops grown, the length of growing season and allows for cultivation of some cash crops which otherwise would not thrive under rain-fed agriculture.

ii.2.7.2 Food and nutrition security

Apart from increased productivity, irrigation agriculture improves livelihoods through improvement of food and nutrition security. As indicated by the Food and Agricultural Organization of the United Nations (FAO, 2010) the number of undernourished people is higher now than 40 years ago (Giwu, 2024). For millions of poor families in sub-Saharan Africa, access to water makes the difference between hunger and a full belly as well as between a well-nourished child and one stunted by malnutrition - for many, the long dry season is a trying time of one meal a day (Yihdego *et al*., 2019). Most of the rural poor rely on rain-fed land for their survival, making them vulnerable to the highly variable and unpredictable rainfall. Even in years of having normal rainfall, a period of ten to fifteen days with no rain at a critical stage in crop growth can spell disaster for thousands, even millions, of poor farmers. Periodic drought and famine can cause havoc, especially in many SSA countries. The Southern African region is being hard hit by what seem to be increasingly frequent and devastating droughts, floods and famines. Investment in irrigation is often identified as one of the possible responses to this problem and has had considerable success in Asia in terms of achieving national as well as local food security, and stimulating agricultural growth (McCarthy et al., 2023). Increased productivity and diversification of crops enables the growing of more nutritious food crops while cash from surplus is used to supplement staple diets. Umer *et al*. (2024) found that improved farming and irrigation technology, has been shown to enable African farmers to grow more and healthier food varieties.

iii.2.7.3 Poverty Reduction

Food and nutrition security is also closely linked to poverty reduction. Adugna (2023) acknowledges that there are many different concepts of poverty, in various disciplines. It has been increasingly realized that poverty is a multidimensional concept, extending from low levels of incomes and expenditures to lack of education and poor health, and includes other social dimensions such as powerlessness, insecurity, vulnerability, isolation, social exclusion and gender disparities. Asrat & Anteneh (2019) found in Ethiopia that irrigators had more diversified income sources than non-irrigators and that the proportion of poor households among irrigators in the study was significantly lower than non-irrigators.

Jambo et al. (2021) state that small-scale irrigation projects have significant positive impacts on household consumption, agricultural production, nutrition and by extension household-level poverty reduction. In addition, Vijay (2021) used both cross-section and time series data to compare investment in irrigation with investment in rural literacy in India. The author found that investment in irrigation reduces poverty more effectively as compared to investment in rural literacy. A study conducted by Hussain *et al*. (2006) shows that the poverty level in - irrigated, irrigated plus rain fed and rain fed only - are 29, 23 and 37 %, respectively (Libseka *et al*., 2015). This shows that through increased yields, increased cropping areas and higher value crops can mean - increased food supplies, higher calorie intakes and better nutrition levels, as well as poverty levels being significantly reduced.

iv.2.7.4 Employment creation

Another benefit of irrigation is the creation of employment. Irrigation agriculture creates jobs for people with and without land, since more people are needed to harvest, process, and market the crops and to supply farm inputs (Abebe, 2021). The additional farm income ripples through the local economy, generating employment and higher incomes for farm workers as well. Access to irrigation water broadens farmers' crop choices and enables them to grow higher-value vegetables and fruits for the marketplace (Abebe., 2021). According to Giordano & Namara. (2019), areas where irrigation is widely used, agricultural yields and household income are higher, hence, less poverty and undernourishment are observed. In Zimbabwe, Chazovachii (2021) assets that irrigation schemes have created employment, generated income, and enabled farmers to acquire assets such as scotch carts and livestock, as well as pay their children's school fees. The beneficiaries have shifted from once a year (rainy season) to two and three harvests and labour-use's efficiency has improved due to irrigation.

The National Planning Commission's draft National Development Plan (NPC 2011, 197) states that one million new jobs can be created in agriculture and related industries over the next two decades, mostly through labour-intensive forms of small-scale farming in communal areas and on redistributed land, with many engaged in irrigated farming. The Commission believes that there is potential to expand the area under irrigation from 1.5 million hectares to 2 million hectares. It also asserts that market opportunities exist for increased production of fruit for export and vegetables for the domestic market, as well as niche crops, such as nuts, olives and berries, which although they are small-scale but labour-intensive in character (NPC, 2011). This is evidence of the potential of irrigation to create employment and at the same time, reduce poverty.

h. 2.8 Irrigation in South Africa

South Africa is recognised as a "water-scarce" country according to commonly used definition of the term - "total actual renewable water resources" (TARWR) per person per year. Using this definition, South Africa is the 29th driest country out of 193 countries, with an estimated 1110 cubic metres (m^3) of water per person in 2005 (Rahman et al, 2024). Most of the "drier" countries are either small islands or oil states in the Middle-East (Bayram et al,2021). This means that South Africa needs to use irrigation water efficiently as the agricultural sector consumes the largest volumes of water amounting to about 60 % of total water withdrawals (Ayyam, 2019). South Africa's National Development Plan (NDP), hence, has assigned smallholder agriculture, to drive development in rural areas and to improve the livelihoods of at least 370 000 people, specifically in the former homelands (NPC, 2011). The ANC-led government has committed itself to expand the number of smallholder producers selling their produce from 200 000 to 250 000 by 2014, and to 500 000 smallholders in 2020 (Pienaar & Traub, 2015). This attitudes of supporting smallholders is clearly illustrated by the increased budgetary allocation by the Department of Agriculture, Forestry and Fisheries in recent years, with R2.38 billion being allocated to smallholder support programs - the LDARD-JF5 Programme is one example (Malatji & Antwi, 2024). This shows the government's belief in the potential of small-scale irrigation programmes in alleviating poverty, creating employment and contributing to economic growth.

i. 2.9 Drip irrigation and *w*ater use efficiency

Drip irrigation is one of the most commonly-proposed solutions to the water crisis facing many parts of the world. In national and international policy documents, it is seen and promoted as a device to use water more efficiently. Hailu Demo (2021), for example, reported that water use efficiency (WUE) was higher with drip irrigation over traditional methods on different tomato varieties. Other similar reports on the performance of drip irrigation in ensuring water efficiency include - Comparative Assessment of Irrigation Systems Performance (Alonso et al, 2019) and Synthesis-Adaptation of Irrigation to Climate change (Serra-Wittling et al, 2020). According to Postel (2000: 945), the belief in the water-saving potential of drip irrigation is often substantiated with impressive statistics and measurements. The author, for instance, claims that drip irrigation "…has the potential to at least double crop yield per unit water in many applications, including irrigation of most vegetables, cotton, sugarcane, and orchard and vineyard crops".

Dutta (2020) differentiates between, improving water use efficiency and water productivity and profitability. According to the author, "water use efficiency" aims at minimizing water losses by improving technical efficiency while "water productivity and profitability", include increased yield through improvements in water, land and agronomic management practices, reduced evapotranspiration, growing higher-value crops and engaging in value-adding processes. On the other hand, Hornum and Bolwig (2021) explain the necessity of the three technological components of distributed irrigation - access, distribution, and use - for a successful smallholder irrigation system. The authors add that farmers must be able to access and reliably move water and distribute it to their crops with some degree of efficiency. They must also be able to grow crops that generate profits high enough to render their overall investment profitable. The scholars conclude that, unfortunately, capital constraints prevent farmers from investing in all three of these complementary components of distributed irrigation, prohibiting them from reaping maximum returns (Hornum and Bolwig 2021).

j. 2.10 Why water-use efficiency?

Abdelhafez *et al*., (2020) observed that the main user of Egypt's water resources was irrigated agricultural land, which consumes approximately 70% of the total water withdrawal. The irrigated land area, however, must be increased by more than 20% and all irrigated crop yield must be increased by 40% by the year of 2025 to secure food for 8 billion people (De Wrachien *et al*., 2021). According to recent FAO estimates (FAO, 2009), farming, industrial and urban water demands in developing countries will increase by 40% by 2030. Climate change is likely to intensify the water scarcity and lead to greater competition for water between countries and across watersheds and basins (Teferi et al, 2020). Irrigation water is thus becoming an increasingly scarce resource for agriculture in many regions of the world. Manamno. (2022) asserts that when incorrectly applied, irrigation technology can cause losses on investments made by farmers, thus decreasing the economic water productivity index and the overall sustainability, therefore, water resources should be used with a high degree of efficiency or productivity. Improvement in agricultural water management is the best way to increase the utilization of limited water resources. Shah *et al.* (2024) also argue that in addition to increased crops, the improvement of irrigation systems and schemes can lead to more efficient and sustainable agricultural water management. In other words, improved irrigation methods can conserve water without compromising yield or quality. Proper irrigation management will help prevent economic losses (yield quantity and quality) caused by - over or under-irrigation; movement of nutrients, pesticides and other chemicals into the groundwater and other water bodies as well as wasting water resources and energy consumption (Priyan, 2021).

k. 2.11 Understanding water use efficiency

In literature, there is no universally-agreed definition of "water use efficiency". Irrigation scientists and engineers have used the term to describe how effectively water is delivered to crops and to indicate the amount of water wasted at plot, farm, command, or system level. They have, therefore, defined water efficiency as "the ratio of irrigation water transpired by the crops of an irrigation farm or project during their growth period to the water diverted from a river or other natural source into the farm or project canal during the same period" (Kamra et al, 2019). Hatfield & Dold (2019) see water use efficiency as "an indicator of the relationship between the amount of water needed for a particular work and the quantity of water used or diverted." Tariq (2023) sees the term as a non-radial measure of input-specific technical efficiency derived from a stochastic production frontier. Yet other sources, such as OECD (2001) and Tollefson *et al*. (2003) explicate the term in relation to physical and economic outputs per unit of water use. Some scholars have even pointed out that the commonly-described relationship between water (input measured in mm or ML) and agricultural product (output measured in kg or tonne) is an index, and not efficiency (Geng et al, 2019). Still this concept of water use efficiency provides only a partial view because it does not indicate the total benefits produced, nor does it specify that water lost by irrigation is often reused (Lankford, 2023).

The definition of, water use efficiency, has sometimes broadened to encompass the benefits and costs of water used for agriculture in terrestrial and aquatic ecosystems, thus, agricultural water productivity (WP) is defined as the ratio of the net benefits from crops, forestry, fishery, livestock and mixed agricultural systems, to the amount of water used to produce those benefits (Drastig et al, 2021). In its broadest sense, agricultural water productivity reflects the objectives of producing more food, income, livelihood and ecological benefits at less social and environmental cost per unit of water consumed (Kiemo, 2022). Zhou et al., (2021) however differentiate between WUE and WP. The former means the ratio of biomass produced per unit of irrigation water used, that is, the sum of transpiration by the crop and evaporation from the soil; while the latter on the other hand, is defined as the ratio of above-ground biomass per unit of water transpired by the crop.

Su & Singh (2024) observe priorities amongst stakeholders in irrigation. They argue that policy makers seek to lower water usage, and river basin managers try to allocate limited supplies, yet water-saving is not a priority for most farmers. Farmers manage labour and other inputs to get better economic gains (Setoboli *et al*., 2024). Towards that economic aim, most growers make irrigation decisions by relying on subjective judgements, based only on their practical experience and observation (Lankford *et al*., 2020). As a result, benefits from irrigation technology have been limited. Adela (2023) states that regardless of the significance of irrigation practices, it is mandatory to improve the efficiency and utilization of irrigation water. Improvements of irrigation include the following five categories, namely, abstraction, distribution, application, use and disposal. Upon dealing with these categories, it will be easy to ascertain water-use efficiency at each stage or category and come up with targeted mitigation strategies.

I. 2.12 Measuring water use efficiency

Before exploring the available measurements, it is crucial to understand the irrigation system perspective of WUE. This depends upon the water accounting where losses occur at each stage - as water moves from the reservoir (storage losses), conveyed and delivered at the farm gate (conveyance losses), applied to the farm (distribution losses), stored in the soil (application losses) and finally consumed by the crops (crop management losses) for crop production (Zhao & Gao, 2019). Depending upon the area of interest, it is possible to measure different efficiencies - the water conveyance efficiency, application efficiency, water input efficiency, irrigation water use efficiency and crop water use efficiency.

In literature, two main approaches for measuring efficiency can be applied - stochastic frontier analysis (SFA) and the Data Envelopment Analysis (DEA) - representing parametric and non-parametric approaches, respectively (Speelman *et al.*, 2008). According to Tsiomas & Polemis (2019) the parametric approach estimates a parametric production function (or its dual cost or profit function) representing the best available technology and provides a convenient framework for conducting hypothesis testing, and the construction of confidence intervals. On the other hand, the non-parametric approach involves the use of linear programming to construct a piecewise linear envelopment frontier over the data points.

Kadyampakeni *et al.* (2014) provide the expression for estimating irrigation efficiency, as: IE = ET c/WA.

where IE = irrigation efficiency ($m^3.m^{-3}$)

ETc = Crop evapotranspiration (m^3)

WA = Water applied (m^3)

Tya & Othman (2014) on the other hand estimated irrigation water use efficiency as: E_u=Y/WR

whereas E_u = Field Water use Efficiency (t/ha-mm)

Y = Economic Crop Yield (t/ha)

WR = Water requirement of the crop (ha-mm)

As indicated above, the calculation of efficiencies differs based on the variables considered, as well as the specific stage at which the water accounting is done.

m. 2.13 Suitability of the Data Envelopment Analysis

The DEA methodology is considered advantageous over the parametric approach (SFA). Speelman *et al*. (2008) observe that first, DEA does not call for assumptions concerning the functional form for the frontier technology or the distribution of the inefficiency term. Second, it permits the construction of a surface over the data, which allows the comparison of one production method with others in terms of a performance index. Data Envelopment Analysis, therefore, provides a straightforward approach to calculate the efficiency gap that separates each producer's behaviour from best productive practices, which can be assessed from actual observations of the inputs and outputs of efficient farms. The prime advantage of the DEA modelling is that it allows the specification of a multi-product and multi-input firm. DEA offers a method for calculating sub-vector efficiency regarding one production input, for example, irrigation water use (Arega *et al.,* 2006; Frija *et al*., 2009). Calculating sub-vector technical efficiencies, using the stochastic frontier method is said to be highly problematic in terms of computation (Speelman *et al*., 2008; Frija *et al*., 2009).

The disadvantages of DEA, however, are that it is deterministic and sensitive to measurement errors and other noise in the data (Speelman *et al*., 2008). Several studies comparing both methodologies have however shown that results from both methods are highly correlated (Alene & Zeller 2005; Thiam *et al*., 2001; Arega *et al*., 2006). The DEA approach, thus, was used in the current study because of its suitability for the calculation of sub-vector efficiencies. The approach is more flexible due to its ability to avoid a parametric specification of technology, regarding assumptions about the distribution of efficiency and allows curvature conditions to be imposed easily.

n. 2.14 Alignment to National, Regional and Global Strategies/Imperatives

Efficient use of irrigation water contributes to the attainment of several Sustainable Development Goals (SDGs). It touches on SDGs relating to nutrition, poverty, social goals as well as the environment. These are explained briefly in the next sections.

i.2.14.1 Nutrition goals

Sustainable Development Goals 2 (Zero hunger) and 3 (Good health and wellbeing) are closely linked to efficient use of water for irrigation; the goal to end hunger, achieve food security and nutritional status is urgent (Unicef, 2024). SDG 2 talks about - ending hunger by 2030 and ensuring access by all people, in particular, the poor and people in vulnerable situations, to safe, nutritious and sufficient food all year round; ending all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons; doubling the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, as well as secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment by 2030 (UN, 2015). Approximately 9% of the global population, or roughly between 713 and 757 million people globally are undernourished in 2023; a majority of whom live in Asia and about 281 million reside in sub-Saharan Africa (Ritchie, Rosado, & Roser, 2023; FAO, 2024; FAO, IFAD, & WFP, 2015). With over 3.1 million child-deaths each year, due to poor nutrition and 66 million primary school children hungry (23 million in Africa alone), this is a major challenge. The number of stunted children under five declined from 225 million to 159 million globally, however, Africa and Oceania saw a 23% and 67% respective increase in the number of stunted children (FAO, 2024; FAO, IFAD, & WFP, 2015). Good health and well-being will be partly achieved when food and nutrition is guaranteed to all people, including children and the vulnerable.

ii.2.14.2 Poverty-reduction goals

Regarding poverty, Goals 1 (No poverty) and 8 (Decent work and economic growth) are also relevant to agricultural water efficiency. The SDGs 1 and 8, to end poverty in all its forms, everywhere, is especially targeted at the over 836 million people who live on less than 1.25 dollars a day (Global Goals, 2024). Given that most of the poor are engaged in the agricultural sector, its growth and development are crucial for achieving this goal. Access to natural resources, property rights, basic services, (for example, finance) and reduction of risks (price and climatic) become crucial for improving agricultural production. Combating poverty is the main challenge for achieving equitable and sustainable development and water plays a vital role in relation to human health, livelihoods, economic growth as well as sustaining ecosystems (UN, 2024). The role of agriculture development in poverty-reduction is well established in economics literature. There is overwhelming evidence with very few exceptions, that sustained reduction in poverty cannot be achieved without productivity increases in the agricultural sector (Timmer & Akkus, 2008). Time-series data used in various studies have shown that marginal effects of agricultural Gross Domestic Product (GDP) growth on poverty reduction to be significant. As cited in Viana et al. (2022), the World Bank Group (2015) report states that a 1% increase in food production results in a reduction of 0.48% and 0.72% in poverty levels in South Asia and sub-Saharan Africa, respectively. This shows that if water for agriculture is used efficiently, productivity increases, which likely results in higher profits and a reduction in poverty rates.

iii.2.14.3 Social wellness goals

Achieving the social goal of reduced social inequality, especially gender equality (SDGs 5 and 10) depends on improved access to economic resources - land, natural resources, as well as financial services and technology for women and marginalized groups. Emancipation of these groups will be critical in improving agricultural productivity, reducing regional inequalities and achieving sustained income growth. Women comprise 43% of the total agricultural labour force across the globe (FAO, 2024), although there are variations in this composition across the developing world. In sub-Saharan Africa and South-East and East Asia the percentage of women in agriculture is 40%, while in South Asia and Latin America it is 65% and a little over 15%, respectively (Mishra, Maurya, & Arulmanikandan, 2022). Women also make up 69% of small livestock managers according to a study conducted recently on smallholder households in Uganda (Hillesland, Doss, Slavchevska, & Querejeta, 2023).

Abraham & Pingali, (2020) highlight the persistent and significant gender gaps in access to and control of essential resources such as land, labor, credit, infrastructure, information, and technology, which disproportionately disadvantage women due to deeply-entrenched institutional and societal norms. As cited in Dwomoh et al. (2023), FAO (2011) reports that the underperformance of the agricultural sector is, in part, because of this differential access to resources for women, who represent a crucial aspect of production. FAO, (2024) reports that fewer women (compared to men) are involved in the more profitable aspect of agriculture, that is, commercial production, therefore, access to resources such as water for agriculture and increasing water efficiency in the sector may increase agricultural productivity. This will possibly attract more women to participate in agriculture balancing the scales which are currently tipped in favour of men.

iv.2.14.4 Environmental sustainability goals

The environmental goals, particularly, climate action (SDG 13), sustainable production and consumption and the management (SDG 12) and preservation of natural resources and biodiversity (SDG 15) are integral to small-farm development. Temperature rise and the unpredictability of floods, droughts and other extreme weather events resulting from climate change, influence the costs and conditions in which agricultural production takes place. At the same time, managing the environmental externalities of agricultural production, such as greenhouse gas (GHG) and non-GHG emissions, groundwater depletion, and soil degradation among others are also important concerns with regard to increasing food production to meet a growing population.

Sustainable production and consumption, therefore, become an integral part of mitigation and adaptation strategies in the fight against climate change and wastage (especially of food and natural resources). Changes in temperature increase the risks of pest attacks and disease outbreaks (Subedi, Poudel, & Aryal, 2023) with these increasing the cost of cultivation due to the need for pest and disease management which in turn escalates the risks of crop failure. Ritchie, & Roser, (2024) state that even a slight increase in temperature affects the conditions under which the major staples, such as wheat, rice and maize are grown due to altered rainfall or precipitation patterns. Investments in water resources management and the delivery of water services, therefore, are central to poverty reduction, food nutrition and security, and ensure environmental sustainability.

v.2.14.5 African Union Agenda 2063

Aspiration 1 of the African Union Agenda 2063 talks about a prosperous Africa which is based on inclusive growth and sustainable development. It echoes the SDG sentiments through an aspiration to have a continent with equitable and sustainable use and management of water resources for socio-economic development, regional cooperation and protection of the environment. It also reinforces alleviation of poverty in one generation and building of shared prosperity through social and economic transformation of the continent (AU, 2015). The Agenda also seeks to see economies, which are structurally transformed, to create shared-growth, decent jobs and economic opportunities for all. Regarding agriculture, it advocates for modern agriculture for increased production, productivity and value addition which contributes to farmer and national prosperity as well as Africa's collective food security and general development (AU, 2015).

vi.2.14.6 National Development Plan Vision 2030

National Development Plan (NDP) Vision 2030 of the National Development Plan (NDP) calls for an inclusive rural economy wherein: "...rural communities should have greater opportunities to participate fully in the economic, social and political life of the country. People should have access to high-quality basic services that enable them to be well-nourished, healthy and increasingly skilled. Rural economies will be supported by agriculture, and where possible by mining, tourism, agro-processing and fisheries…better integration of the country's rural areas, achieved through successful land reform, job creation and poverty alleviation" (National Planning Commission, 2013:184). The 2030 vision speaks of the inclusivity and integration of rural areas, through successful land reform, job creation and poverty alleviation, and places agriculture as the driving force behind this vision. The NDP identifies the following as key catalytic interventions "expansion of irrigated agriculture, supplemented by dry-land production where feasible". As the primary economic activity in rural areas, the NDP sees agriculture as having the potential to create close to 1 million new jobs by 2030, a significant contribution to the overall employment target. The National Development Plan Vision 2030 also proposes a differentiated rural development strategy – agricultural development based on successful land reform, employment creation, and strong environmental safeguards. The irrigated land area must be increased by more than 20% and that all irrigated crop yield must be increased by 40% by 2025 to secure healthy food for 8 billion people (NPC, 2013), therefore, water resources should be used with a greater degree of efficiency (Hashem *et al*., 2018).

vii.2.14.7 New Growth Path

The New Growth Path (NGP) which was adopted in 2010 is South Africa's vision to place jobs and decent work at the centre of economic policy. It sets a target of five million additional jobs by 2020 and sets out the key employment drivers and the priority sectors that the country will focus on over the medium term. The NGP seeks to shift the economy towards strong, sustained, and inclusive economic growth with an emphasis on the rebuilding of the productive sectors of the economy. Infrastructure development and agriculture have been identified as foundations for more jobs and for addressing rural underdevelopment. The NGP set targets of increasing the smallholder sector by 300 000 households, ensuring 145 000 additional jobs in agro-processing, and upgrading conditions for 660 000 farm workers (DAFF, 2014). The challenge of growing the smallholder sector is closely tied up with the challenge of making smallholder agriculture more remunerative. Presently, more than half of all smallholder households live below the poverty line (DAFF, 2014). The reach of government support services to smallholders has shown notable improvement over time (Carelsen, Ncube, & Fanadzo, 2023; Loki, Aliber, & Sikwela, 2021). Loki et al. (2021) observed that 68% of farming households in their sample of 100 farmers had access to extension services. This momentum needs to continue growing, and other forms of support would also improve the situation (DAFF, 2014).

o. 2.15 Summary of literature review

Climate variability and change have been major causes of shortage of water for agriculture and other purposes. This has increased the vulnerability of developing countries, especially in Africa as they face other challenges such as low levels of technology and education, lack of institutional management and HIV/AIDS, among others. Pressure on water resources has sparked interest in investing in low-cost agricultural water management technologies in semi-arid developing countries. Several drip irrigation systems have been identified from literature; these range from very simple to more sophisticated kits. They are - bucket kits, drum kits, subsurface drip irrigation, alternate partial root-zone irrigation, and above surface drip irrigation systems. Depending on size of farm and availability of resources, small-scale farmers can choose a suitable drip irrigation system that suits their needs, although several barriers to successful implementation of small-scale irrigation have also been identified. Opportunities that can be taken advantage of in irrigation agriculture include, improving the capacity of farmers in various spheres such as technical, governance, business skills, as well as training on selection, operation and maintenance of equipment and infrastructure.

As a water scarce country, South Africa is expected to take measures in ensuring fair distribution of water as well as using water productively and efficiently. The country has made commitments to significantly expand the number of smallholder producers to create employment and contribute to economic growth. Water use efficiency as a concept is quite complex and although In literature, there is a universally agreed definition, in general, it is an indicator of the relationship between the amount of water needed for a crop (or work) and the quantity of water used. The most common approaches for measuring WUE are the Data Envelopment Analysis and Stochastic Frontier Analysis. The DEA methodology is mostly preferred because it is regarded as more flexible due to its ability to avoid a parametric specification of technology regarding assumptions about the distribution of efficiency and allows curvature conditions to be imposed easily. Efficiency of water use for irrigation is central to the achievement of several national, regional and international imperatives showing water's importance to people's health and well-being. These initiatives include the NDP, New Growth Path, AU Agenda 2063 and the UNSDGs. These touch on building shared prosperity, in addition to poverty alleviation and equitable and sustainable use of water resources; inclusive economic growth; development of agricultural infrastructure as well as making smallholder agriculture more remunerative. These would help create employment and reduce poverty.

p) CHAPTER 3

q) RESEARCH METHODOLOGY

a. 3.1 Introduction

In this Chapter, the research methodology used in this study is described and explained. This includes - a description of the area where the study was conducted, the research design, population and sampling techniques, data collection as well as data analysis methods, techniques and tools. In addition, ethical issues which were considered in the study are explained in this chapter. Lastly, the conceptual framework underpinning this study is presented.

b. 3.2 Description of the study area

The Nwanedi area is located about 70 km northeast of Musina Town. The Nwanedi irrigation scheme is situated to the north of the Soutpansberg Mountains, about 40 km northeast of Tshipise in the Vhembe District of Limpopo Province. The area lies in the geographical location: 22˚23'S and 22˚35'S and between 30˚24'E and 30˚34' in the Limpopo Basin. The scheme obtains bulk water from the Nwanedi-Luphephe Dams, which have a combined storage capacity of 20.6 x 106 m^3 (Marubini, 2018). Water is released from the dam into a canal system which distributes the water to the irrigators. The Cross Dam, located in the Nwanedi River and linked to the canal system, provides balancing for the storage (van Vuuren *et al*., 2003). The long-term average annual rainfall is 405mm, of which 369 mm, or 91%, falls from October to March and the annual average total evapo-transpiration is 1400mm. Temperatures vary from an average monthly maximum and minimum of 40ºC and 21.3ºC for summer and winter, respectively (Rangecroft *et al*., 2018). The dominant crop produced in the area is jam tomato with a few farmers who cultivate table tomatoes and other vegetables, such as butternut and pepper (Mashala, 2013). The irrigation scheme spans approximately 2000 hectares of land, with ownership shared between the state and the Communal Property Association (CPA) (Marubini, 2018). The 150 farms are relatively homogenous in terms of plot size, climate, soil type, and other geographical features. Figure 3.1 shows a map of the Nwanedi area.

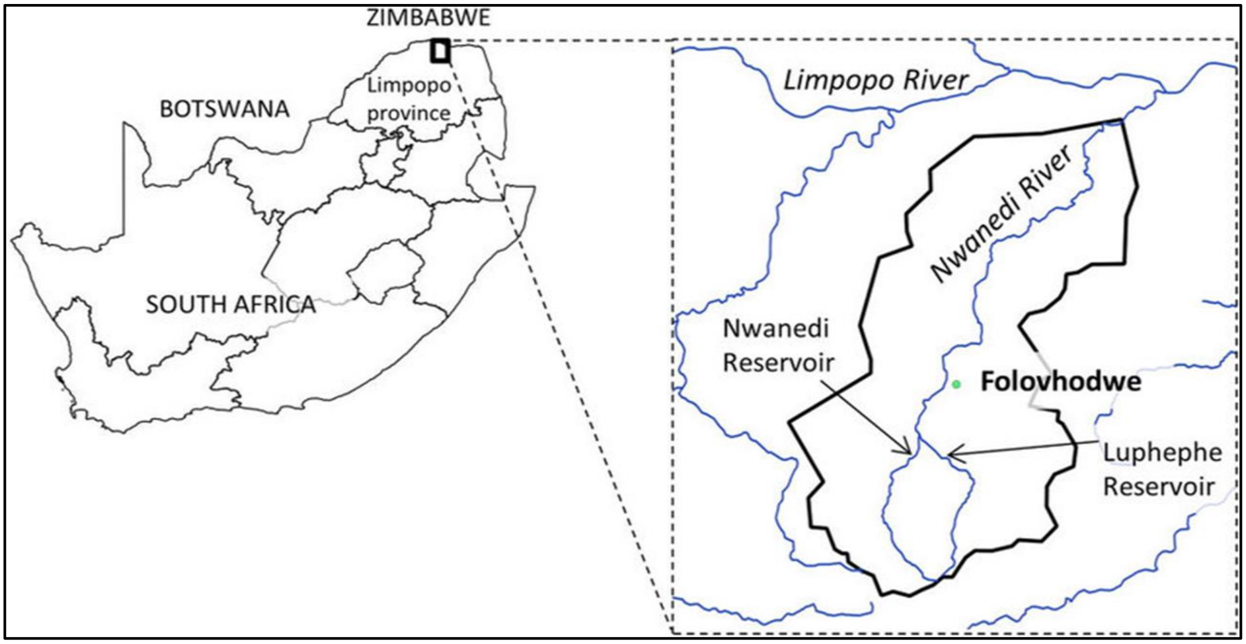

Figure 3.1: Map of Nwanedi area where the study was conducted (Rangecroft *et al*., 2018)

c. *3.3* Research design

The study employed embedded mixed-method design (Schoonenboom & Johnson, 2017) and a questionnaire with closed and open-ended questions was used to collect data from the farmers. This means that both qualitative and quantitative data were collected to triangulate, complement, and expand on the findings of the study. The rationale for this approach is that the quantitative data and their subsequent analysis provide a general understanding of the research problem, while the qualitative data and their analysis refine and explain those statistical results by exploring participants' views in more depth (Creswell, 2003). Table 3.1 provides a concise summary of the research design, outlining the key components and methodologies employed in the study.

Table 3.1: Summary of research design and methodological framework

Specific objective	Variables	Sampling approach	Data collection methods	Techniques	Tools	Data analysis
a) To characterise tomato production under small-scale drip irrigation system used in Nwanedi	Plot size, gender, age, household characteristics, farm activities, access to finance, markets and management style	Systematic random sampling (144)	Interviewing and Survey	Individually completed questionnaire and group interviews	A questionnaire with open and closed-ended questions	SPSS version 25 and R software for statistical computing - descriptive statistics.
b) To measure the economic efficiency of tomatoes production system in Nwanedi	Plot size, household characteristics (gender, age, household size, education) farm activities, water-related costs (cost of water delivery, opportunity cost), irrigation profit, and irrigation profit per unit of water consumed,	Systematic random sampling (144)	Interviewing and Survey	Individually completed questionnaire and group interviews	A questionnaire with open and closed-ended questions (recording water quantity data, that is, water use and water loss)	Stochastic Frontiers Analysis (SFA)

c)	To measure the technical efficiency of water use by small-scale tomato growers in Nwanedi	Crop evapotranspiration (m^3), economic crop yield (t/ha), water requirement of the crop (ha-mm), amount of water used and labour	Compare the input and output-oriented variables for measuring technical efficiency	Interviewing, Survey and literature review to obtain figures on crop yield, water requirement or the crop, labour, and crop evapotranspiration (obtaining weather data, soil water content)	Individually completed questionnaire and group interviews	A questionnaire with open and closed-ended questions	Stochastic Frontiers Analysis (SFA) Linear Regression technique

d. 3.4 Population and sampling procedures

The total population of the study consisted of 150 farmers who were operating under the Nwanedi Irrigation Scheme. Out of these, only 144 farmers who specialised in tomato farming were considered in this study. Particularly, this study used an exclusionary sampling method, involving excluding farmers who were not tomato producers. Since the study included all contracted small-scale tomato farmers, it is important to note that a census approach was employed.

e. 3.5 Research validity and reliability

Noble and Smith (2015) define validity as the precision with which the findings accurately reflect the data. They also define reliability as the consistency of the analytical procedures, including accounting for personal and research method biases that may have influenced the findings. Carlson and Herdman (2015) argue that the use of different research protocols, samples, measures, and statistical analyses are all intended to provide assurance that findings are not idiosyncratic to components of methodology. In this study, errors in measurement were reduced through using 144 farmers involved in tomato farming out of the total 150 farmers operating in Nwanedi. The data collection instrument was pre-tested to ensure that the questions were clear, relevant, and capable of collecting the required data. Pre-testing was chosen because it allowed for refinement of the instrument by identifying and addressing ambiguities and potential misunderstandings before the full study was conducted, enhancing the accuracy and reliability of the data collected. Further, the statistical models were validated against existing literature to ensure their accuracy and appropriate application, thereby mitigating the risk of errors.

f. 3.6 Data collection

Data were collected from both primary and secondary sources. Secondary sources such as published books, articles in accredited peer-reviewed journals, policy documents and credible internet sources were consulted. Primary data were collected from the male and female farmers of all ages. Research participants were asked to individually complete a questionnaire with open and closed-ended questions. After that they were allocated to groups based on age and sex. In these groups, they were asked to complete the same questionnaire. The questionnaire consisted of questions relating to the characteristics of tomato growers in Nwanedi as well as their patterns of water use. In addition, data collection was conducted on variables such as plot size, gender, age, household characteristics, farm activities, access to finance and markets to characterise the tomato-growers while data were collected on plot size, household characteristics, farm activities, water-related costs, value of output to help in determining patterns of water use. Further, data were collected on input-oriented variables (such as water requirement for the crop, labour, electricity and other water-related costs) and output-oriented variables (such as economic crop yield, crop evapotranspiration) to measure technical efficiency of tomato farmers.

g. 3.7 Data analysis

Gathered data were captured, managed and analysed using descriptive and inferential statistics which were computed using both IBM Statistical Package for Social Sciences (SPSS) Version 25 and R software for statistical computing. Specifically, tables and graphs were used to describe and explain the survey data. A simple linear regression model was used to quantify the relationship between quantity of tomatoes sold (in tonnes) and electricity consumption costs (a proxy variable for water use). Lastly, the Stochastic Frontiers Analysis (SFA) approach was used to calculate efficiency of irrigation water use by the 144 tomato farmers. The following calculations were followed:

$$E_u = Y/WR \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.7.1)$$

where, E_u = Field Water use Efficiency (t/ha-mm)

Y = Economic Crop Yield (t/ha)

WR = Water requirement of the crop (ha-mm) Tya & Othman (2014)

h. 3.*8: M*odel specification

There are several steps that can be taken when calculating irrigation efficiency. Some measurements that are required for this are - net irrigation, gross irrigation and estimations of crop water use. Efficiency is generally measured as follows: Efficiency = weighted sum of outputs/weighted sum of inputs. With the usual notation, this can be written as:

$$\text{Efficiency of unit } j = (u_1 y_{1j} + u_2 y_{2j} + \ldots)/(v_1 x_{1j} + v_2 x2_j + \ldots) \qquad (3.8.1)$$

Where: u_1 =the weight given to output 1

y1j =amount of output 1 from unit j

v1 = weight given to input 1

x1j = amount of input 1 to unit j

It is important to note that efficiency is usually constrained to the range.

Net irrigation (IR_n) is defined as the amount of irrigation water required to bring soil moisture level in the effective root zone to field capacity (Etissa *et al*., 2016).

$$IR_n = ETc - P_e + LR \text{ (mm)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.8.3)$$

Where, IR_n = Net irrigation requirement (mm)

ETc = Crop evapotranspiration (mm)

P_{ef} = Effective dependable rainfall (mm)

G_e = Groundwater contribution from water table (mm)

W_b=Water stored in the soil at the beginning of each period (mm)

D = Deep percolation/drainage (mm)

LR = Leaching requirement (mm)

Also, if the estimated LR is found to be less than 10%, it is ignored from the equation. As a rule, under drip-irrigation conditions of high-water tables are rare and as a result groundwater contribution to crop water requirements is normally ignored. Similarly, deep percolation is assumed to be zero. If assuming that W_b, G_e and D are all zero, then the equation becomes:

$$IR_n = ETc - P_e + LR \text{ (mm)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.8.4)$$

Again, if the estimated LR is found to be less than 10%, it is ignored from the equation.

Gross irrigation: Gross irrigation requirement is net irrigation requirement plus losses in water application and other losses. This is expressed in terms of overall efficiencies when calculating gross irrigation requirements from net irrigation requirements:

$$IR_g = IR_n/E + LR \ldots\ldots\ldots\ldots\ldots\ldots (3.8.5)$$

where:

IR_g = Gross irrigation requirements (mm),

IR_n = Net irrigation requirements (mm),

E = Field efficiency of the system (drip system assumed to be 85%)

Estimation and quantifying crop water use

Tomato yield response (Ky): can be estimated through the following relationship described by Doorebos *et al*. (1977).

$$(1-(Y_a/Y_m)) = Ky\ (1 - (Et_a/ET_m))\ldots\ldots\ldots\ldots\ldots\ldots(3.8.6)$$

where, Ky = yield response factor

Y_m= Maximum yield (kg)

Y_a =Actual yield (kg)

ET_m = Maximum evapotranspiration (mm/period)

ET_a = Actual evapotranspiration (mm/period)

i. 3.9 Ethical considerations

All ethical protocols and considerations guiding the conduct of research were adhered to. Firstly, ethical clearance was secured from the University of Venda Research Ethics Committee (Ethical Clearance No FSEA/23/IRD/05; See Appendix 2). After that, permission to conduct the research was sought from Nwanedi Development stakeholders, namely, the Vhembe District Department of Agriculture Rural Development and Land Reform, extension workers, farmer representatives and secondary cooperative. Before commencing with data collection, the nature, purpose and objectives of the research were explained to the survey respondents. Participants who expressed their willingness to participate were asked to sign consent forms and they were also informed about the use of information that they were to provide. It was made clear that information would be used for the sole purposes of the study and may be published in various scholarly platforms.

In order to ensure anonymity, numbers were used to anonymously represent the farmers. After data collection, a workshop was held with research respondents to give them feedback on the findings of the study. The workshop gave an opportunity for respondents to make corrections and provide additional information which helped improve the quality of the results.

r) CHAPTER 4

s) RESULTS PRESENTATION AND DISCUSSION

a. 4.1 Introduction

This chapter presents the results of the study based on the analysis of the primary data collected from 144 small-scale tomato farmers. Descriptive statistics, frequency distribution tables and graphs are employed to aid the presentation and visualisation of the study results. The chapter is organized into 3 sections based on the 3 specific objectives. The first section presents results from descriptive statistics analysis of the characterisation of small-scale tomato production. The second section focuses on results of the Stochastic Frontier Analysis (SFA) technique that was used to measure water use against yield of small-scale tomato farming. To achieve this goal, the electricity cost variable, reflecting the amount of electricity used to pump water for irrigation, was used as a proxy to estimate the amount of water used in these small-scale tomato farms. The third section employs the SFA to measure the technical efficiency of water use by small-scale tomato growers in Nwanedi.

b. 4.2 Characterising tomato production under small-scale irrigation in Nwanedi

i. 4.2.1 Socio-demographic variables

Understanding the characteristics of small-scale tomato production is essential for optimizing agricultural practices, improving yields, and ensuring sustainable food production, hence, by this process, valuable insights into the key factors influencing tomato growth and development are gained. Table 1 presents frequency distribution of the socio-demographic variables that were collected from the survey respondents.

The distribution results for the gender variable shows that the majority of respondents (58%) were females, whilst the remaining 42% were males. This means that nearly 6 in every 10 small-scale tomato farmers are females while the remaining 4 being males. Regarding age, the largest proportion of small-scale tomato farmers (56%) fell within the age range 51-65; followed by 28% for the age group 66 years old or above; then 14% who were between 36 and 50 years old and lastly, 2% who were 35 years or less. This shows that nearly 6 in every 10 small-scale tomato farmers are aged between 51 and 65 years; followed by 3 in every 10 small-scale tomato farmers who are 66 years old or older; 1 in every 10 small-scale tomato farmers are between 36 and 50 years old and nearly 2 in every 100 small-scale tomato farmers are 35 years old or less.

In relation to the education variable, the majority of respondents (69%) had an education level up to Grades 8-12; followed by 22% who reported that they had up to Grade 7 education level; 6% had no formal education and lastly, a smaller proportion (3%) reported that they had completed post-secondary education. This implies that approximately 7 in every 10 farmers have Grades 8-12 education; 2 in every 10 have education up to Grade 7 while the remaining 1 in every 10 farmers possess no formal education. A small proportion, of 3% representing farmers who had post-secondary education means that nearly 3 in every 100 farmers have post-secondary education.

In relation to farming experience, the largest proportion of respondents (77%) had over 5 years of experience in farming, followed by 22% who revealed they had 2-5 years of experience, and lastly, a small proportion (1%) who reported had 1-2 years of experience. This means that nearly 8 in every 10 farmers possess over 5 years farming experience while the remaining 2 in every 10 farmers possess between 2-5 years farming experience. The remaining tiny proportion of 1% means that nearly 1 in every 100 farmers have 1-2 years farming experience.

Lastly, regarding tomato production training, the majority of the respondents (78%) had received training in tomato production, while 22% had not received any training. This means that nearly 8 in every 10 farmers have received training in tomato production while 2 in every 10 farmers have not received training in tomato production.

Table 4.1: Socio-demographic breakdown of survey respondents

Variable	Category	Frequency	Percent
Gender	female	84	58.33
	male	60	41.67
Age	51-65	81	56.25
	66 and above	40	27.78
	36-50	20	13.89
	35 or less	3	2.08
Education	Grade 8-12	100	69.44
	Up To Grade 7	31	21.53
	No formal Education	9	6.25
	Post secondary	4	2.78

Variable	Category	Frequency	Percent
Farming Experience	Over 5 years	111	77.08
	2-5 years	31	21.53
	1-2 years	2	1.39
Access to training in Tomato production	yes	113	78.47
	no	31	21.53

Those who had received training in tomato small-scale production revealed that their training covered areas such as - chemical usage, planting and cultivation, pest and disease control, spraying program and fertilizer application. Chemical usage (42%) represented the main area of training received by farmers; followed by planting and cultivation (24%); then fertilizer application (19%); spaying program (10%) and lastly, pest and disease control (5%) (see figure 1 below). This means that nearly 4 in every 10 farmers are skilled in chemical usage; 3 in every 10 small-scale tomato farmers are skilled in planting and cultivation; 2 in every 10 small-scale tomato farmers are skilled in fertilizer application, and nearly 2 in every 10 small-scale tomato farmers are equally divided between small-scale tomato farmers who are skilled in spraying and pest and disease control.

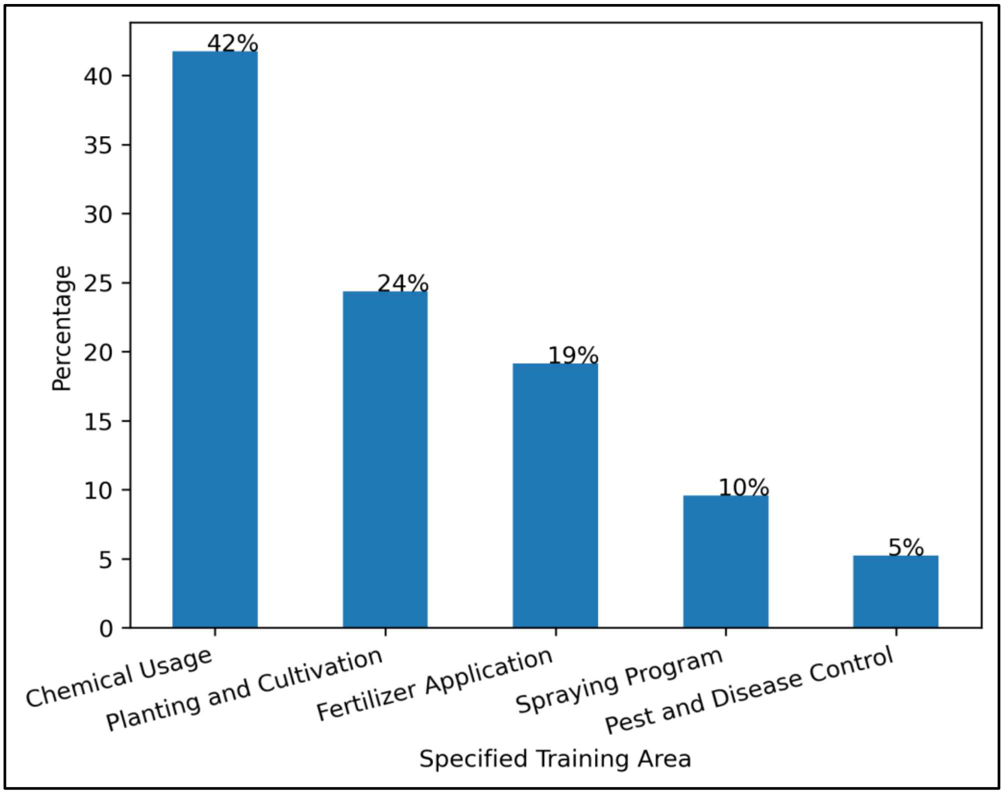

Figure 4.1: Frequency distribution of training areas received by small-scale tomato farmers

ii. 4.2.2 Characterisation of small-scale tomato farmers by their sources of income

The data analysis revealed that nearly 99% of small-scale farmers received their income from farming exclusively the tomato crop. Apart from growing tomatoes, some surveyed small-scale tomato farmers also grew crops like butternut, chilies, watermelon and others. As clearly shown in Figure 4.2, tomato crop (97%) represents the main source of income for the majority of surveyed small-scale farmers, as expected. Fifty-seven percent of small-scale tomato farmers also grew butternuts, 32% grew chilies, 26% grew other crops and lastly, 17% grew watermelon. The result is significant as it reveals that all the small-scale farmers were tomato farmers, which forms the foundation of this study.

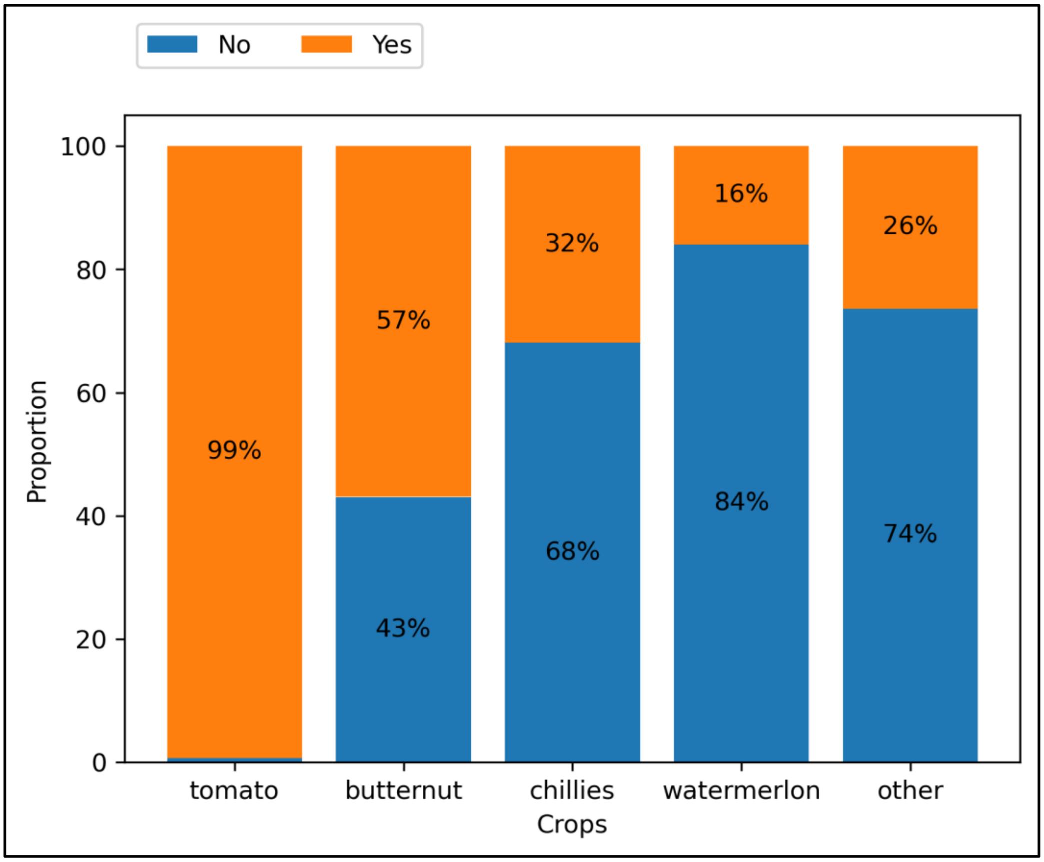

Figure 4.2: Distribution of different crops grown by small-scale tomato farmers

iii. 4.2.3 Number of employees

The findings revealed that the total number of employees employed by small-scale farmers range between 1 to 39 employees. On average, the small-scale farmers employ 10 employees with a standard deviation of approximately 5 employees. Figure 3 depicts the distribution of the number of employees employed by the small-scale tomato farmers. The first and third quartile values of 8 (Q1) and 12 (Q3) respectively means that 25% of the small-scale farmers employ at most 8 employees while 75% employ at most 12 employees. Table 4.3 and Figure 4.3 jointly describe the distribution of labour-related variables. As clearly shown on Figure 3, small-scale tomato farmers employ, on average, a higher number of permanently hired males and females compared to other classes of employees, such as seasonal and permanent family males and females as well as seasonal hired males and females.

Table 4.3: Descriptive statistics for different labour-related variables

Employee Category	count	mean	std	min	25%	50%	75%	max
Seasonal Family Male	17	2.41	2.40	1	1	1	2	8
Permanent Family Male	130	1.28	0.61	1	1	1	1	5
Seasonal Family Female	30	1.70	1.15	1	1	1	2	5
Permanent Family Female	131	1.33	0.60	1	1	1	2	4
Seasonal Hired Male	64	1.70	1.29	1	1	1	2	8
Permanent Hired Male	137	3.07	1.28	1	2	3	4	6
Seasonal Hired Female	67	2.33	2.16	1	1	2	2.5	10
Permanent Hired Female	135	2.79	1.15	1	2	3	4	6
Total Number of Employees	144	10.375	4.60	1	8	10	12	39

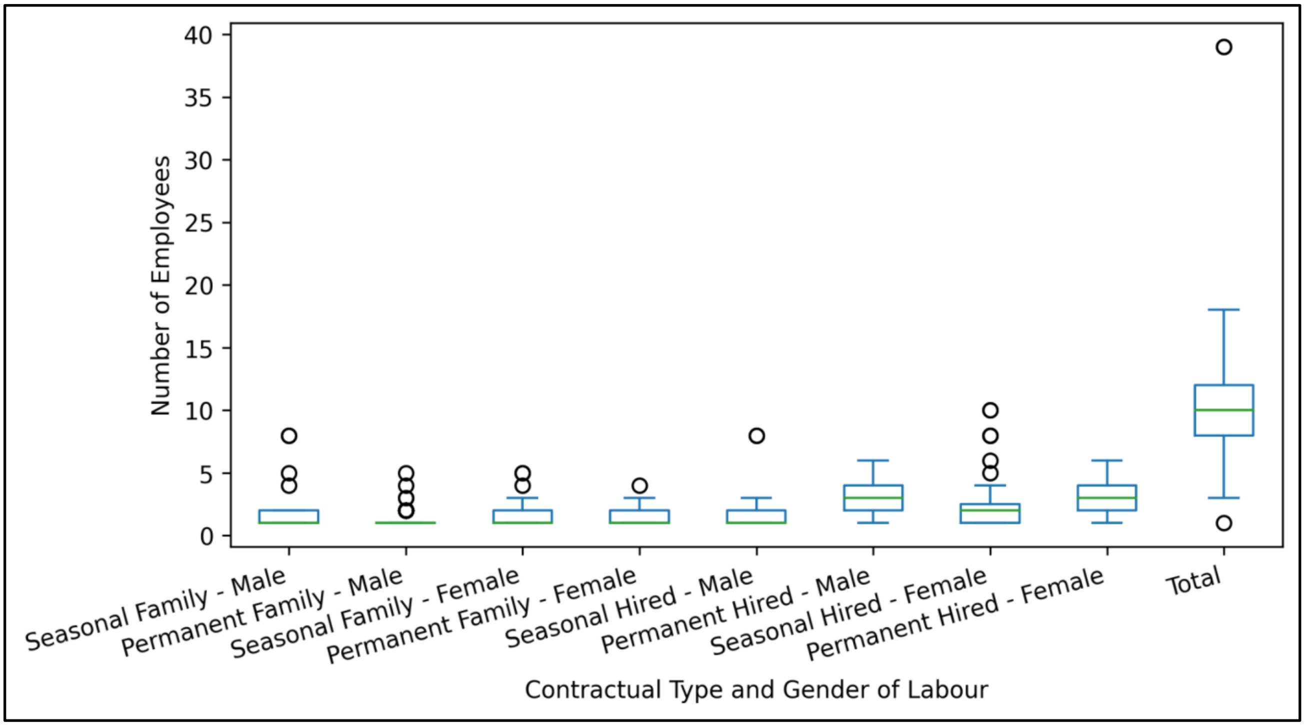

Figure 4.3: Boxplots showing distribution of employees by gender

iv. 4.2.4 Farm size

Figure 4.4 presents a box plot depicting statistical information about the farm sizes of the small-scale tomato farmers who participated in this survey study. Descriptive statistics for the farm size variable shows that the average farm size was 11.90 hectares, with a standard deviation of 9.55 hectares, indicating considerable variability in farm sizes. As clearly shown on Figure 4.4, the smallest farm size reported is 3 hectares, while the largest is 100 hectares. The distribution of farm sizes shows that 25% of the small-scale tomato farmers have farm sizes of 7.75 hectares or less (1st quartile (Q1)); 50% have 10 hectares or less (median (Q2)), and 75% have 14 hectares or less (3rd quartile (Q3)). This suggests that while most small-scale tomato farmers work on relatively modest farms in terms of their sizes, there are some small-scale tomato farmers whose farms are significantly large, as indicated by the maximum value.

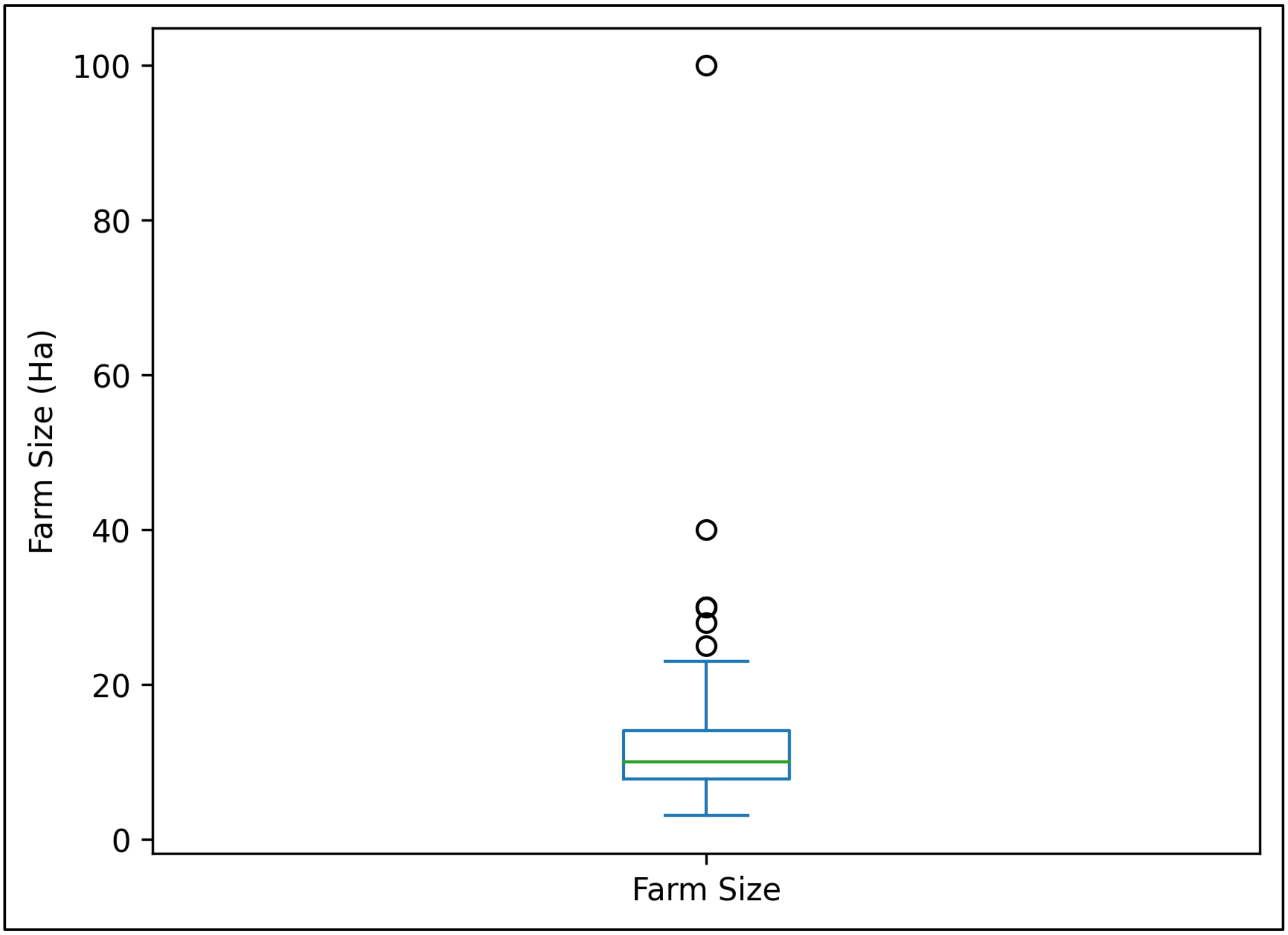

Figure 4.4: Boxplot depicting the distribution of farm size variable

v. 4.2.5 Farm income

Figure 4.5 presents a graph depicting the distribution of different crops that generates revenue for the surveyed small-scale tomato farmers at Nwanedi. The first subgraph on the left side of the graph shows crops that generate the first revenue stream for the surveyed small-scale farmers. That is, apart from generating revenue from exclusive tomato farming, the surveyed small-scale tomato farmers also farmed other crops, such as chilies (3%), eggplant (2%), butternut (2%) and okra (1%).

The majority of small-scale tomato farmers (91%), however, revealed that they receive their main income from tomato farming. The subgraph at the center of the graph shows the distribution of crops that generate second stream of income for small-scale tomato farmers and are distributed as follows; butternuts (47%), chilies (18%), tomato (10%), calabash (8%), okra (8%), watermelon (7%), carrots (1%), green beans (1%), onions (1%) and beans (1%). The subgraph on the far right of the graph depicts the distribution of crops that generated third income stream income for the surveyed small-scale tomato farmers and these include crops such as butternuts (27%), chilies (27%), watermelon (21%), okra (8%), pansburg (6%), brinjols (5%), green peper (5%), and calabash (2%).

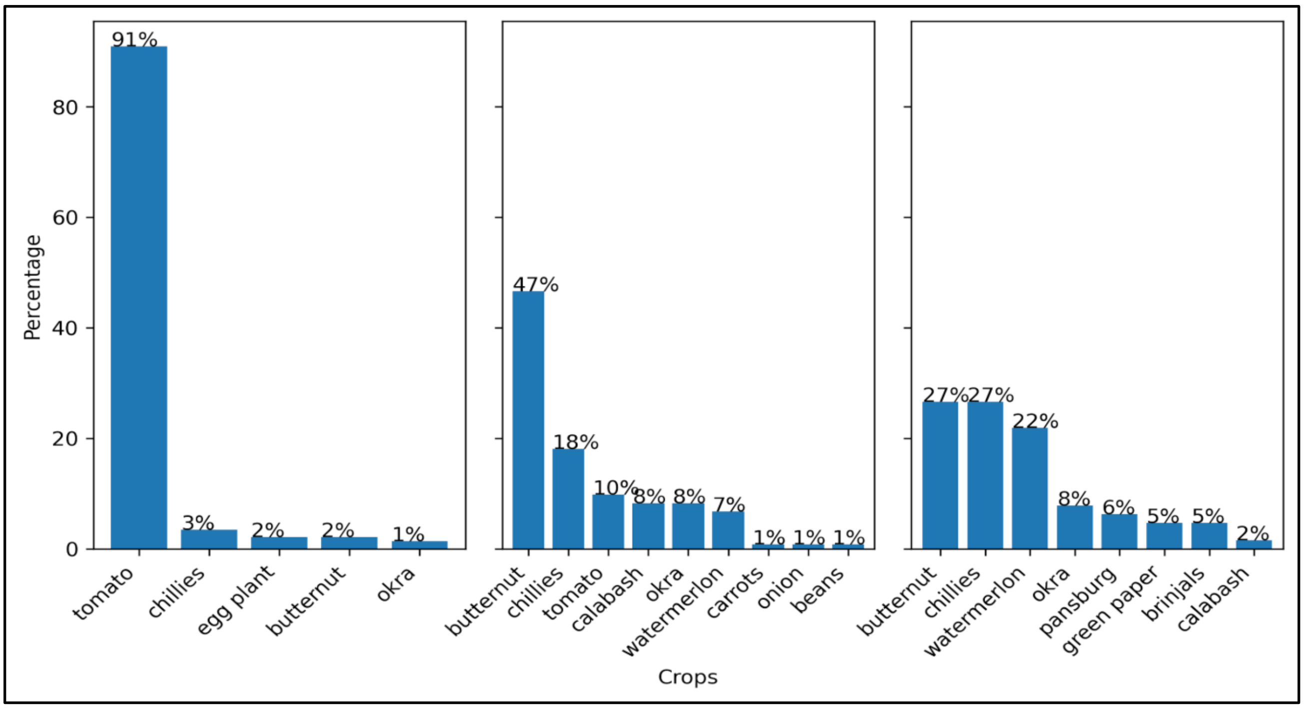

Figure 4.5: Distribution of crops contributing to different streams of incomes for surveyed small-scale tomato farmers

vi. 4.2.6 Costs incurred by small-scale tomato farmers

The Table below presents descriptive statistics for small-scale tomato production's input cost variables. Table 4.4 and Figure 4.7 jointly describe the different input variables such as fertilizer, seeds, electricity, labour, transport, packaging and other costs. On average, labour costs constitute the bulk of inputs costs for small-scale tomato farmers as demonstrated by mean labour costs of R79,928.62 ± R29,500.00. Seeds and fertilizer are second and third largest contributors to the cost structure of the small-scale tomato farmers. The wide cost range shown in Table 4.4 and Figure 4.7 clearly demonstrates the diverse nature of small-scale farmers. Particularly, the figures reveal that the majority of tomato farmers spent relatively little on farm inputs compared to nearly a quarter who spent the bulk of financial resources on key farm inputs (see Table 4.4 and Figure 4.7 for detailed results).

Table 4.4: Descriptive Statistics summarising farm input cost variables

Statistics	fertiliser	Seeds	electricity	labour	transport	packaging	Other
count	144	144	144	144	143	143	95
mean	R26,667.54	R34,795.83	R12,847.92	R79,928.62	R5,332.34	R2,610.69	R4,165.38
std	R10,842.60	R31,056.43	R8,567.40	R29,500.00	R6,766.36	R1,441.31	R5,866.02
min	R3,400.00	R1,000.00	R2,000.00	R2,500.00	R1,200.00	R1,000.00	R500.00
25%	R15,000.00	R12,750.00	R9,375.00	R63,500.00	R3,220.00	R1,500.00	R1,900.00
50%	R26,000.00	R21,000.00	R13,000.00	R81,000.00	R4,200.00	R2,100.00	R3,000.00
75%	R36,250.00	R44,000.00	R15,000.00	R92,000.00	R5,100.00	R3,200.00	R5,000.00
max	R55,555.00	R116,000.00	R90,000.00	R200,000.00	R60,000.00	R7,000.00	R50,000.00

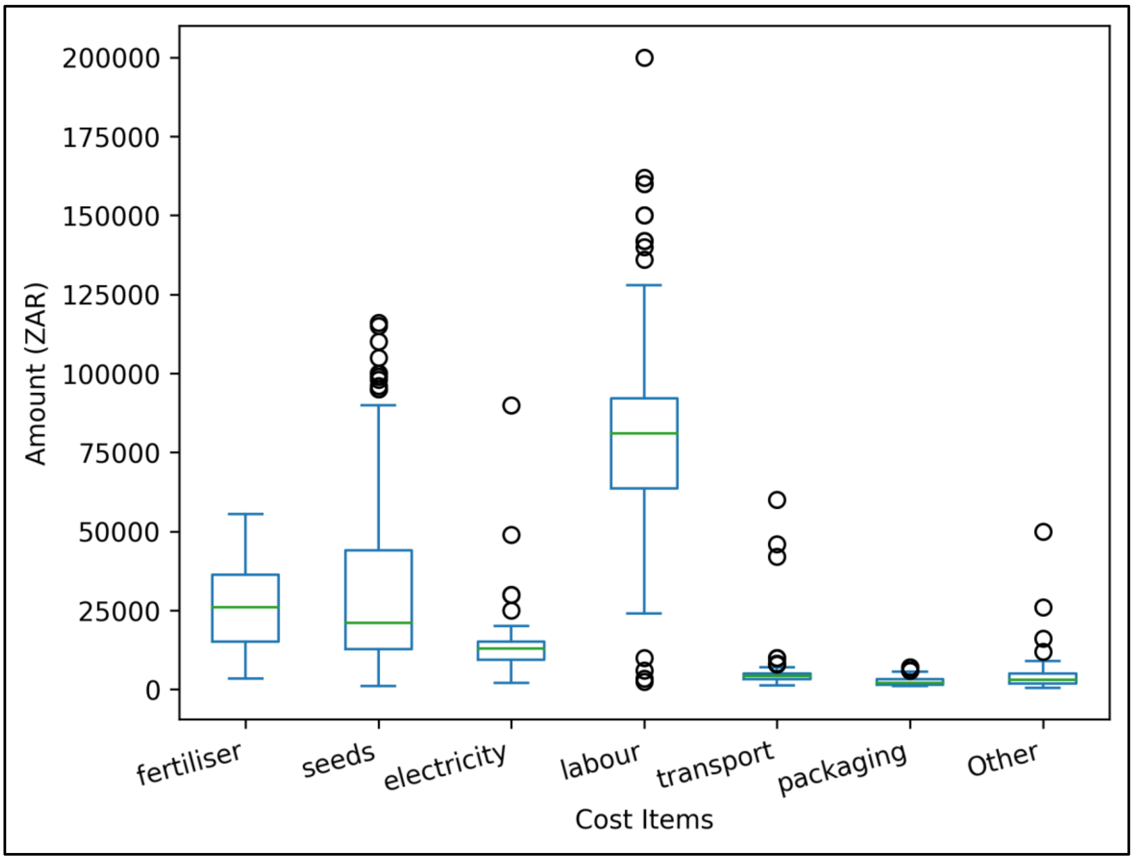

Figure 4.7: Box plot depicting distribution of tomato production input costs.

As shown in figure 4.7, all input variables exhibit high variability, with the exception of the fertilizer input. The variability in labour and seed inputs can largely be attributed to differences in farm sizes. Larger farms require more labour and seed inputs, contributing to greater variability across the dataset. This is particularly significant given the wide range in farm sizes, which spans from 3 to 100 hectares.

vii. 4.2.7 Distribution of small-scale tomato farmers’ expenditure of income from farming

Survey respondents were asked to highlight the areas where they spent the proceeds from farming. As clearly expressed in Table 4.5, the bulk of revenue generated by small-scale tomato farmers from selling their farm produce goes to pay salaries and wages of farm workers (R86,220.66 ± R33,637.09), followed by savings (R48,182.97 ± R35,803.76), then equipment (R20,233.97 ± R15,887.51), housing (R16,333.96 ± R7,518.13), education (R10,910.22 ± R13,792.15) and others (R8,331.20 ± R5,267.75). Figure 4.8 presents graphs which further demonstrate the distribution of financial resources spent by small-scale tomato farmers across the 6 key expenditure variables.

Table 4.5: Frequencies, Quartiles, SDs for different expenditure item variables

Statistic	Equipment	Housing	Education	Savings	Pay-workers	Other
count	142	53	143	142	139	44
mean	R20,233.97	R16,333.96	R10,910.22	R48,182.97	R86,220.66	R8,331.20
std	R15,887.51	R7,518.13	R13,792.15	R35,803.76	R33,637.09	R5,267.75
min	R6,222.00	R0.00	R1,400.00	R4,600.00	R8,000.00	R2,000.00
25%	R14,000.00	R12,200.00	R4,500.00	R18,000.00	R70,000.00	R3,850.00
50%	R16,000.00	R15,000.00	R7,500.00	R40,000.00	R86,000.00	R9,000.00
75%	R21,000.00	R20,000.00	R12,000.00	R79,000.00	R97,500.00	R10,000.00
max	R160,000.00	R40,000.00	R90,000.00	R190,000.00	R190,000.00	R20,200.00

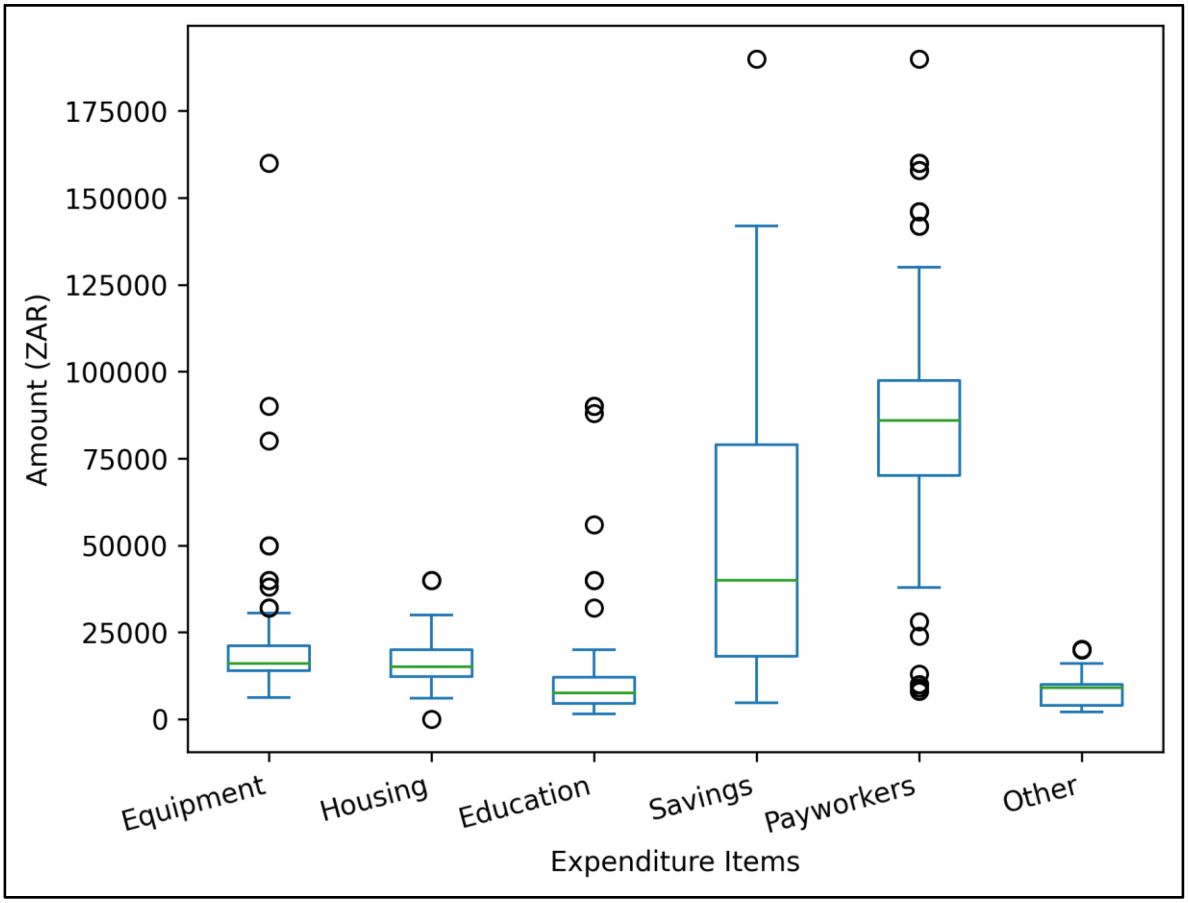

Figure 4.8: Boxplot depicting the distribution of tomato farmers' expenditures.

viii. 4.2.8. Existing markets for tomatoes

Figure 4.9 shows the distribution of markets to which small-scale tomato farmers supply their tomatoes. The first, second and third subgraph represents first, second and third role players respectively for which crops are produced. As clearly shown in Figure 4.9, the bulk of the tomatoes are produced for ready-made markets such as Tiger Brand, Mozambique, Durban, Johannesburg, Spar and the local market. Characterizing small-scale farmers based on the markets they supply, such as prominent brands like Tiger brands, is crucial as these markets may impact their efficiency; for instance, producing for reputable brands encourages farmers to adopt sustainable practices, which, in turn, enhances their efficiency.

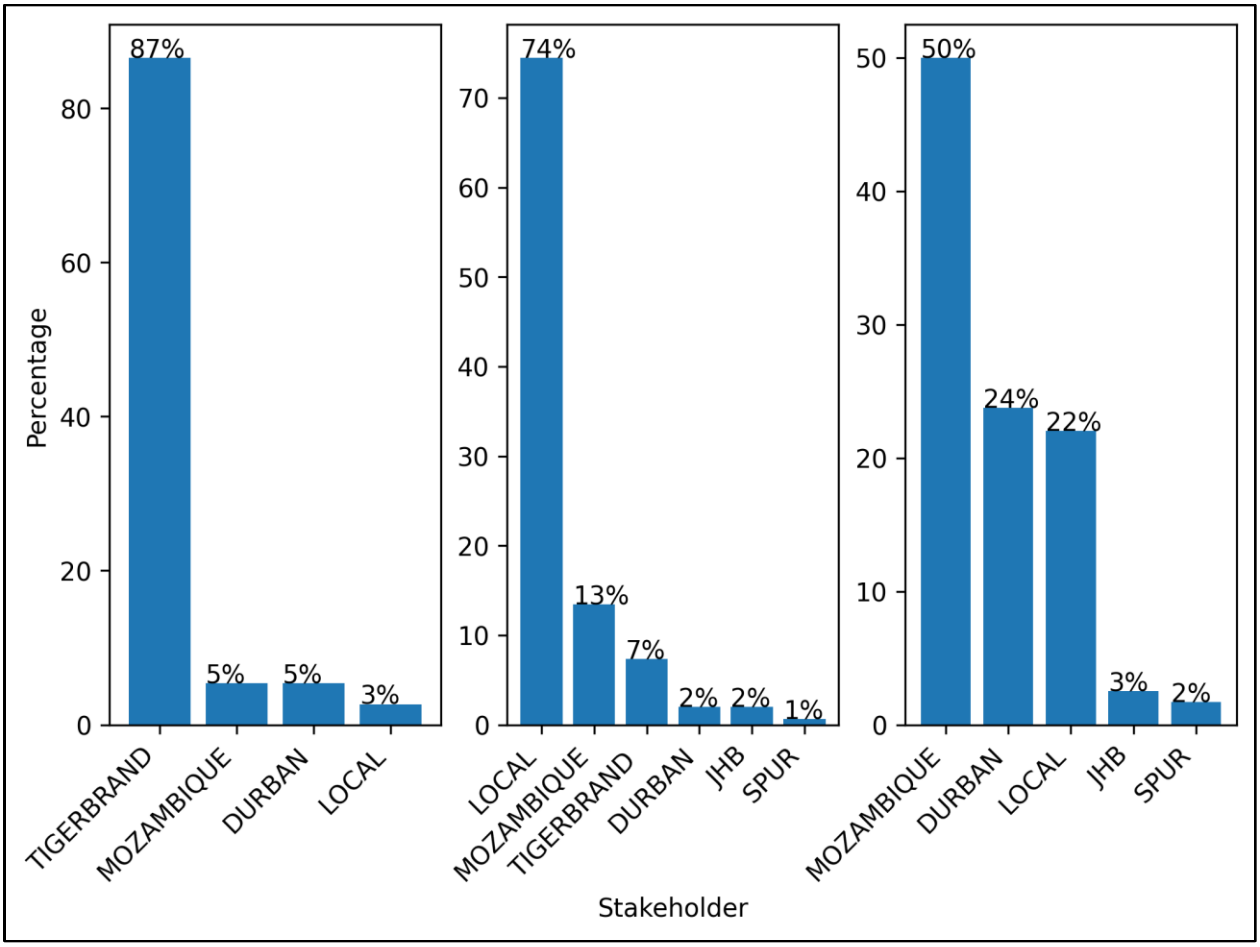

Figure 4.9: Distribution of markets that small-scale tomato farmers produce food

c. 4.3 Measuring water use against the yield of tomatoes produced in Nwanedi

In order to achieve the objective of measuring water use against the yield of tomatoes produced in Nwanedi, the researcher employed two approaches, the first of which involved fitting a Cobb-Douglass production function relating to electricity use, to the quantity of tomatoes produced. The p-value for log electricity is 0.4464 which is not significant, again showing that electricity cost is not a useful predictor of quantity produced. Table 4.6 presents the final maximum likelihood estimates, standard errors, z-values, and p-values for the parameters of the model, including the intercept, log of electricity, sigma squared (variance of inefficiency), and gamma (proportion of variance due to inefficiency).

Table 4.6: Final maximum likelihood estimates for the model

Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	5.928	0.449	13.198	< 2.2e-16 ***
log(electricity)	0.038	0.050	0.761	0.4464
sigmaSq	0.582	0.084	6.890	5.585e-12 ***
Gamma	0.992	0.008	119.278	< 2.2e-16 ***

The second approach involved fitting a simple linear regression model to quantify the relationship between quantity of tomatoes sold (in tonnes) and electricity consumption costs. Again, the electricity cost variable was used as a proxy for water use, in line with Alam, Pavelic, Sikka, Krishnan, Dodiya, Bhadaliya, & Joshi, (2023). Figure 4.10 presents a scatterplot illustrating the nature of the relationship between the two variables. Each point represents an observation, with quantity sold on the y-axis and electricity consumption on the x-axis. The scatterplot is also visually assessing the correlation between these two variables. As clearly shown in Figure 4.10, the line of best fit has a slope of 0.0021 and this is not significant (p = 0.39) showing that the electricity cost is not a useful predictor of quantity produced. This result means that an increase of R1000.00 in electricity costs results in a 2.1 tonnes increase in quantity of produced.

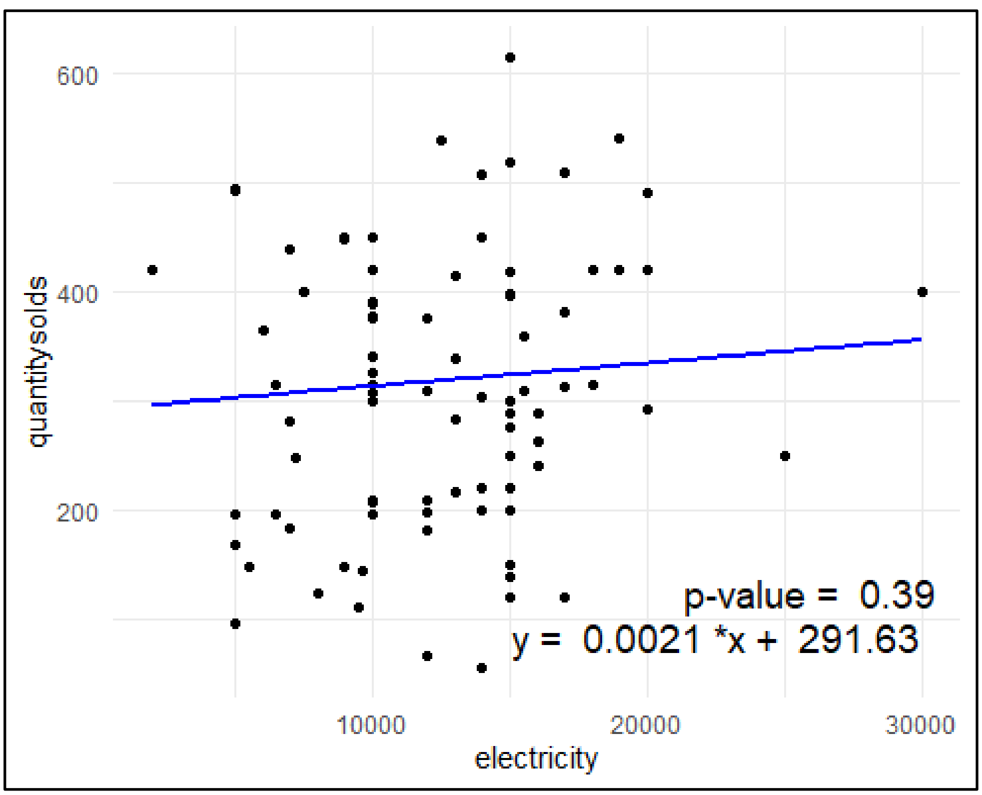

Figure 4.10: Scatterplot of Quantity vs. Electricity Consumption

d. 4.4 Measuring the technical efficiency of water use by small-scale tomato growers in Nwanedi

To fulfill the third objective of this study which is that of measuring the technical efficiency of water use by small-scale tomato growers in Nwanedi, a stochastic frontier analysis which estimates a Cobb-Douglass production function incorporating inefficiency effects was performed. Model (1) was fitted to the data by relating the income variable to the electricity variable which was used as a proxy variable for measuring water use. Electricity used to pump water was then used as a proxy of the quantity of water used.

$log\ (Income_i) = \beta_1 + \beta_2\ log\ log\ (Electricity_i)\ + V_i - U_i$ ....(**4.4.1**)

where V_i is a random error term (noise) and U_i is a non-negative random variable representing inefficiency. As clearly shown in Table 4.7, the likelihood ratio test confirms that the stochastic frontier model (ECF) fits the data significantly better than the OLS model without inefficiency (p = 0.0001139).

Table 4.7: Likelihood ratio test results

Model	**Df**	**LogLik**	**Df**	**Chisq**	**Pr(>Chisq)**
OLS (no inefficiency)	3	-95.894			
Error Components Frontier (ECF)	4	-89.101	1	13.586	0.0001139 ***

The final maximum likelihood estimates give the parameter estimates, standard errors, z-values, and p-values for the model. Table 4.8 presents the final maximum likelihood estimates for the Error Components Frontier model, where inefficiency decreases the endogenous variable (as in a production function). The dependent variable is logged, and the iterative ML estimation terminated after 8 iterations, with log likelihood values and parameters of two successive iterations within the tolerance limit.

Table 4.8: Final Maximum Likelihood Estimates for the Error Components Frontier (Battese & Coelli, 1992)

Parameters	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	11.964	0.862	13.873	< 2.2E-16***
log(electricity)	0.202	0.091	2.224	0.026162*
sigmaSq	0.695	0.126	5.509	0.00000003605***
Gamma	0.923	0.044	20.806	<2.2E-16***
sigmaSqU	0.641	0.140	4.598	0.000004269***
sigmaSqV	0.054	0.025	2.132	0.033021*
Sigma	0.834	0.076	11.018	<2.2E-16***
sigmaU	**0.801**	0.087	9.196	<2.2E-16***
sigmaV	**0.231**	0.054	4.264	0.00002011***
lambdaSq	11.976	7.470	1.603	0.108861
Lambda	3.461	1.079	3.207	0.001343**
varU	0.233			
sdU	0.483			
gammaVar	0.813			

Significance codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
**log likelihood value: -89.10
**cross-sectional data
**total number of observations = 120
**mean efficiency: 0.59

The intercept indicates the baseline or starting point of the income when all other predictors are zero. In this case, exp (11.963687) = 156950.7 represents the estimated geometric mean of the income when electricity is set at zero. In other words, farmers receive an income of R156,950.70 when no costs are incurred on electricity. The implication of this finding is that the income received from the constant model means that tomato producers may receive an income of R156,950.70 from rain-fed tomato farming arrangement, that is, a situation where no electricity is used to irrigate the land.

The coefficient of log(electricity) is 0.202 with a standard error of 0.091. This coefficient is significant (p = 0.026). The coefficient represents the elasticity of output with respect to electricity. Specifically, it indicates that a 1% increase in electricity input is associated with an approximate 0.202157% increase in income, holding other factors constant. In other words, one unit increase in electricity results in a 1.59 times increase in farm income. This means that there is a direct positive relationship between farm income and water use. The higher the water usage in tomato farm production, the higher the income received from selling the farm produce.

The gamma parameter indicates the proportion of the variance in the income that is due to inefficiency. The estimated value is 0.923 and it is highly significant (p-value < 0.001). The interpretation is that inefficiency accounts for approximately 92.29 of the total variance in the observed incomes. This means that nearly 8% of variance observed in farm incomes can be attributed to how tomato farmers use water.

Lambda represents the ratio of standard deviations of the inefficiency term to the noise term. The estimated value is 3.461; this is highly significant ($p < 0.01$). The value quantifies the relative importance of inefficiency compared to random noise in contributing to the observed variability in the output (income). This means that the inefficiency of tomato farmers is approximately 3.5 times more important than random noise in determining income received from tomato production sales.

Predicted efficiency scores

Figure 4.11 jointly presents the descriptive statistics for the efficiency scores based on 120 observations and the lineplot depicting the visual representation of the efficiency score variable. As clearly shown in Figure 4.11, the statistics reveal a mean efficiency value of 0.59 with a standard deviation of 0.2. The median is slightly higher at 0.62 while the trimmed mean remains consistent at 0.59 which indicates robustness of the reported mean against outliers. The median absolute deviation is 0.24, while the minimum and maximum values are 0.09 and 0.91, respectively, resulting in a range of 0.81. The distribution shows a slight leftward skew with a skewness of -0.38 and is somewhat flatter than a normal distribution, as indicated by a kurtosis of -0.89. The standard error of the mean is 0.02, reflecting the precision of the mean estimate. The mean efficiency value of 0.59 suggests that, on average, the units in your dataset are operating at approximately 59% of their maximum potential efficiency. Since, the most ideal efficiency situation is 100%, it follows from this finding that there is huge room for enhancing the performance of tomato farmers in Nwanedi. Further, by looking at Figure 4.11 which is presenting a serial plot of the efficiency scores for the individual farmers, it can be easily inferred that small-scale tomato farmers can be characterized either as - poorly performing (<25%), below average performers (25-50%), above average performers (50-75%) and high performers (>75%).

Variable	X1
N	120
Mean	0.59
SD	0.2
Median	0.62
Trimmed	0.59
MAD	0.24
Min	0.09
Max	0.91
Range	0.81
Skew	-0.38
Kurtosis	-0.89
SE	0.02

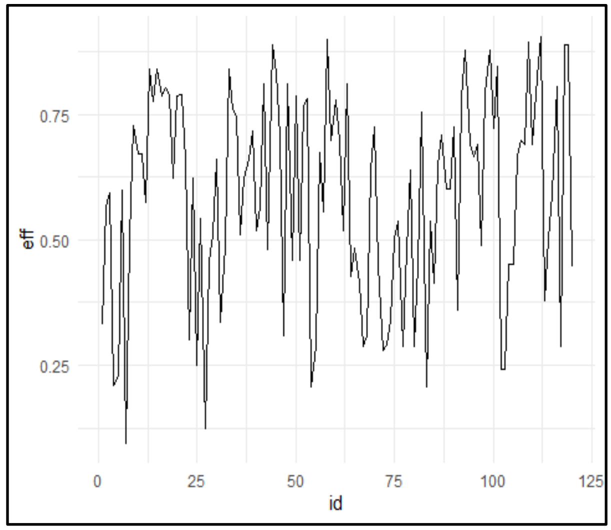

Figure 4.11: Serial plot of efficiency scores

In order to determine whether efficiency of small-scale tomato farmers is influenced by demographic and experiential factors such as - age, gender, education, and farming experience. The Stochastic Frontier Analysis was refitted to the data while including the demographic and experiential factor variables to check if the efficiency depended on any of the factors - age, gender, education and farming experience. Table 4.9 presents the SFA model results.

Table 4.9: Maximum likelihood estimates for the error components frontier model

Parameter	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	12.084	0.858	14.09	< 2.2e-16 ***
log(electricity)	0.189	0.089	2.12	0.0338579 *
Z_(Intercept)	0.334	0.899	0.37	0.71003
Z_Ageg51-65	0.340	0.523	0.65	0.51534
Z_Ageg66 and above	-0.105	0.580	-0.18	0.85585
Z_GenderM	-0.143	0.320	-0.45	0.65540
Z_Education1Grade 8 and Above	-0.303	0.365	-0.83	0.40555
Z_Farmingexperience1over 5 Years	-0.307	0.390	-0.79	0.43156
sigmaSq	0.675	0.380	1.78	0.0758165 .
Gamma	0.925	0.044	20.99	< 2.2e-16 ***
sigmaSqU	0.624	0.369	1.69	0.0902855 .
sigmaSqV	0.051	0.028	1.82	0.0694759 .
Sigma	0.822	0.231	3.55	0.0003838 ***
sigmaU	0.790	0.233	3.39	0.0007046 ***
sigmaV	0.225	0.062	3.63	0.0002827 ***

Parameter	Estimate	Std. Error	z value	Pr(>|z|)
lambdaSq	12.300	7.793	1.58	0.11448
Lambda	3.507	1.111	3.16	0.0015953 **

Significance. codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
**log likelihood value: -86.74; **total number of observations = 120; **mean efficiency: 0.59

It is clear from the results presented in Table 4.9 that none of the p-values in Table 4.9 above are significant, showing that none of the variables - gender, educational level, farming experience and age - are useful predictors of efficiency. Table 4.10 presents the likelihood ratio test results comparing two models: Model 1, an OLS model with no inefficiency effects, and Model 2, an Efficiency Effects Frontier (EEF) model. The significant chi-square test ($p < 0.05$) indicates that the EEF model provides a significantly better fit to the data compared to the OLS model.

Table 4.10: Likelihood Ratio Test Results for Model Comparison

Model	Df	LogLik	Df Difference	Chisq	Pr(>Chisq)
Model 1: OLS (no inefficiency)	3	-95.894	-	-	-
Model 2: Efficiency Effects Frontier (EEF)	15	-83.536	12	24.715	0.01055 *

Significance. codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

The comparison between Model 1 (OLS with no inefficiency) and Model 2 (Efficiency Effects Frontier) indicates that water use inefficiency is indeed present among small-scale tomato farmers. The significant Chi-square value (24.715) with a p-value of 0.01055 suggests that the Efficiency Effects Frontier model, which accounts for inefficiency, fits the data significantly better than the OLS model. Consequently, the findings show that small-scale tomato farmers are not perfectly efficient in their water use.

4.5 Conclusion

This chapter presented the findings of this research whose objectives were - to characterize tomato small-scale farmers; measure water use against yield and measure the technical efficiency of water use by small-scale farmers in Nwanedi. Overall, it was observed that small-scale tomato farmers can be characterized into either - poor performing farmers, below average performing farmers, above average performing farmers, and high performing farmers - as evident by efficiency values ranging from 0.09 to 0.91 with a reported average of 0.59. SFA results revealed that electricity as a proxy variable for water use was a significant predictor of farm income, however, water use was an insignificant predictor of the quantity of tomatoes (tonnes). The findings revealed the significance of log(electricity)'s coefficient which suggests a meaningful impact of water use on tomato production efficiency.

CHAPTER 5

DISCUSSION, RECOMMENDATIONS & CONCLUSION

5.1 Introduction

The previous chapter dealt with data analysis, presentation, and reporting of results. This chapter outlines this research's major findings and relates them to current literature, providing recommendations and conclusions. It also demonstrates the achievement of the study's objectives.

5.*2 Discussion of key findings*

The findings reported in this study are based on 144 small-scale tomato farmers from the Nwanedi irrigation farming scheme in the Limpopo Province of South Africa. The study was based on 3 key objectives - (1) to characterise tomato production under small-scale drip irrigation system used in Nwanedi; (2) to measure the economic efficiency of the tomatoes production system in Nwanedi and (3) to measure the technical efficiency of water, use by small-scale tomato growers in Nwanedi.

The study revealed that most small-scale tomato farmers were females (58%) versus males (42%). A contrasting study conducted by Mwangi, Ndirangu, & Isaboke (2020) reported that the majority of smallholder tomato farmers were males (77%) versus females (23%). Another study conducted by Donkoh, Tachega, & Amowine, (2012) reported that majority tomato farmers in Northern Ghana were males (70%) versus females (30%). In the current study, majority of small-scale farmers were aged between 51 and 56 (56%); majority had Grade 8-12 education (69%) and had over 5 years of farming experience (77%). The finding on experience concurs with those established by the study conducted by Donkoh, Tachega, & Amowine, (2012) which revealed 58% of small-scale tomato farmers had experience ranging between 6-10 years. Notably, a significant portion of farmers had received training in tomato production (78%), suggesting that education and experience play a crucial role in successful farming practices. A study by Sinyolo et al. reported training uptake of 9% for a study conducted on irrigators and non-irrigators, investigating the impact of smallholder irrigation on household economic well-being.

The findings of this study revealed that small-scale tomato farmers can be characterized into - poor performing farmers, below average performing farmers, above average performing farmers, and high performing farmers. This study established that efficiency levels of Nwanedi tomato farmers ranged between 0.09 and 0.91 with a reported average efficiency value of 0.59. This characterizes the efficiency of farmers into two unique groups - below-average small-scale tomato farmers and above average small-scale tomato farmers. The implication of this characterisation is that the observed mean efficiency level of 0.59 among tomato producers in Nwaledi indicates the presence of enough room for continuous improvement by these small-scale farmers; for example, small-scale tomato farmers operating below average have room to improve their farm operations towards the maximum ideal value of 100%. Further, this means that small-scale tomato farmers can reduce the resources needed to produce the average output by 41% if they improve their farming techniques. This finding is consistent with Tenaye's (2020) study, which reported a mean household-level efficiency value of 59% among smallholder farmers in Ethiopia.

The second objective of this study was to measure the water use against the yield of tomatoes produced in Nwanedi. The study used two approaches to investigate this research objective. Both methods revealed that water use, as measured by proxy variable “electricity costs” was not a significant predictor of the quantity of tomatoes produced under drip irrigation. The proxy variable used for water use has a non-significant positive effect on the quantity of tomatoes produced by small-scale farmers in Nwanedi. There are three possible explanations for the insignificant coefficient value of log(electricity). First, electricity costs may not be a suitable proxy variable for water use in South Africa's current context. As a public good, electricity charges are primarily intended to recover operating costs for electricity suppliers, like ESKOM. Secondly, the insignificant parameter value may be attributed to the negligible impact of water use on tomato production, which is not statistically significant. Thirdly, the insignificant parameter value may be due to the consistent application of water to tomatoes by all farmers through drip irrigation. Consistent water application through drip irrigation can lead to reduced variability due to the system's ability to deliver water uniformly. Soil conditions and farming practices are additional factors that may contribute to the insignificance of water use proxy variables, potentially overshadowing the impact of water use. As much as water is an important input in tomato farming, its influence on farming as measured by its proxy variable emerged statistically insignificant.

The third objective was to measure the technical efficiency of water use by small-scale tomato growers in Nwanedi. The stochastic frontiers model relating tomato income with electricity cost (proxy variable for water use) yielded the statistically significant coefficient value of 0.202 and a standard error of 0.091 for log(electricity) variable ($p < 0.05$). This finding demonstrates the elasticity of tomato income with respect to water use input variable. Further, the estimated gamma parameter value of 0.923 revealed that nearly 8% of variance observed in tomato incomes could be attributed to how small-scale farmers used water. This shows that water use (as measured by its proxy electricity variable) plays a significant role in determining the profitability of tomato farming. The implication of this finding is that improving water use efficiency can have a substantial impact on income for Nwanedi small-scale tomato farmers. This finding revealing the significance of the proxy variable for water use is consistent with findings reached by Phali, Mudhara, Ferrer, & Makombe, (2022) and Sinyolo et al. (2014) who reported the critical impact of irrigation water on farm revenue. In particular, these authors demonstrated that water access and security played a crucial positive role in determining the economic well-being of farmers.

The SFA model relating tomato income with water use proxy variable reported efficiency values within the range of 9-91%. This explains the variable effect that water use, as measured by electricity costs, has on income from tomato for Nwanedi small-scale farmers. A similar study by Mwangi, Ndirangu, & Isaboke (2020) reported a lower average technical efficiency value of 40% among smallholder tomato farmers in Kirinyaga County, Kenya, compared to the 59% found in this study; the efficiency range in their study was 4-95%. A study by Tenaye (2020) reported the same average efficiency value of 59% as found in this study, but with a wider range of 0-95%. The implication of this finding is that there is significant potential for Nwanedi small-scale tomato farmers to further enhance their farm efficiency, given that the ideal efficiency value is closer to 100%.

5.*3* Conclu*sions*

This study has revealed that 58% of small-scale tomato farmers in the Nwanedi Irrigation Scheme are female, emphasizing the crucial role women play in tomato production in the region. Additionally, the finding that the elasticity of water use, as measured by electricity consumption, accounts for 8% of the variance in farm income underscores the significant impact of efficient water use on farm income. This highlights the urgency of optimizing resource utilization to boost agricultural profitability. Furthermore, the study identifies an 81% range in efficiency, indicating considerable variability in operational efficiency among small-scale tomato farmers, suggesting that targeted interventions could enhance performance across the sector. Finally, the 34% coefficient of variation in farming practices reveals significant differences in how tomato farmers in the Nwanedi Tomato Farming Scheme operate, a variation that is particularly noteworthy given that the sample consists of farmers participating in a sponsored-contract farming program.

The study demonstrated the inelastic relationship between water use and tomato production, using Stochastic Frontiers Analysis and Simple Linear regression techniques. Another key finding of this study was the observed elasticity of water use (as measured by electricity consumption) on farm income, which accounted for 8% of the variance in farm income. Furthermore, the study found a wide efficiency range of 81%, suggesting that small-scale tomato farmers have varying levels of efficiency in their operations. This finding underscores the need for future research to implement long-term monitoring and evaluation, and to examine the obstacles that hinder the adoption of efficient farming measures, such as lack of knowledge and infrastructure. These findings are significant for agricultural institutions, agricultural economists, farmers' unions, manufacturers with interests in agriculture through sponsorship farming arrangements like Tiger Brands and financial institutions.

5.4 Recommendations

It is recommended that targeted policies and support programs are developed to specifically address the challenges faced by female tomato farmers, including access to resources, training, and financing, to further empower and enhance their contribution to agricultural production.

It is recommended the adoption of water-efficient technologies and practices to help farmers optimise water use and improve farm income; for example, strategies such as drip irrigation and water conservation strategies, through subsidies or incentives.

The researcher recommends the implementation of training programs and capacity-building initiatives that focus on improving the operational efficiency of small-scale farmers, with a particular emphasis on best farming practices, technology adoption, and efficient resource management.

It is recommended that further research is conducted to identify the factors contributing to this variability and tailor support programs to address these factors, ensuring that farmers under the contract-farming program receive consistent guidance and resources to standardize and improve farming practices. Specifically, future studies should adopt a more comprehensive approach by using two separate Stochastic Frontier Analysis (SFA) models, namely, one excluding water use as a variable and another incorporating water use. This comparison would allow for a clearer assessment of the impact of water use on farm income and provide more accurate insights into the technical efficiency of water use among small-scale tomato farmers.

Further, it is also recommended that future studies investigate barriers to efficiency adoption by small-scale tomato farmers in Nwanedi. Particularly, the study efforts should focus on identifying constraints and strategies for addressing them. These small-scale farmers were properly funded through contract farming schemes, hence, research efforts could seek to identify the main barriers that prevent farmers from adopting more efficient practices, such as lack of knowledge, or infrastructure limitations. Studies like these would open avenues for developing policies and programs to address identified barriers which facilitate the creation of a more enabled environment for small-scale tomato farmers to adopt efficient farming practices.

Finally, this study recommends the need for implementing long-term monitoring and evaluation in order to track progress, adjust strategies as well as promote best tomato-farming practices.

Specifically, implementing a monitoring and evaluation system will enable the tracking and assessing of the effectiveness of efficiency improvement programs over time for small-scale tomato farmers. In addition, the system will also enable usage of collected monitoring data in adjusting program strategies and addressing any emerging challenges. The results that will be shared from the monitoring and evaluation process will contribute to the promotion of best tomato-farming practices and subsequently, encourage other small-scale tomato farmers to adopt efficient tomato-farming methods.

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e.

t) Appendices

a. Appendix 1: Letter to the farmers for data collection

Dear farmer

My name is Masindi Lodric Mariba. I am a student at the University of Venda registered for the Masters in Rural Development (MRDV) programme within the Institute for Rural Development. I am conducting research focusing on ***Technical efficiency of water use by small-scale irrigation farmers in Nwanedi.*** Through this communication, I am requesting you to participate in this study.

University of Venda has entered into an agreement with the Management of Nwanedi Secondary Cooperation to work together and find ways that will lead to the improved performance of the Nwanedi irrigation scheme. As part of the agreement the university committed to conduct research and avail relevant information that will lead to improved decision making by the farmers as they carry out their farming activities. The university through the School of Agriculture will involve itself in carrying out various research on farming activities around the irrigation scheme. The management of the Secondary cooperative committed that the farmers will cooperate in the research through providing relevant data. The data will only be used for the purpose of the research and feedback will be given to the farmers about the results. The university also committed to involve its students in the research process. It is within this background that this questionnaire is being administered to you soliciting for data on various aspects of your farming activities. You are free to participate in this research. Participation is voluntary and you are kindly therefore being asked to provide answers to the following questions as truthfully as you can. The information will only be used for the purpose of the research.

Signature of Researcher ____________________ **Date** 2024 March 11

I………………………………….. have read and understood the contents of this invitation to participate in the study. Thus, I hereby voluntarily consent to participate in the research.

Respondent signature _______________________ **Date** _________________

b. Appendix 2: Ethical clearance tools

ETHICAL CLEARENCE NO: FSEA/23/IRD/05

SUPERVISORS/ CO-RESEARCHERS/ CO-INVESTIGATORS

NAME	INSTITUTION & DEPARTMENT	ROLE
Prof Jethro Zuwarimwe	University of Venda, Institute for Rural Development	Supervisor
Prof Marizvikuru Manjoro	University of Venda, Institute for Rural Development	Co-supervisor

Type: **Student Research**

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

Approval Period: **August 2023 – July 2025**

The Faculty Research Ethics Committee (FREC) of the Faculty of Science, Engineering and Agriculture hereby approves your project as indicated above.

University of Venda
PRIVATE BAG X5050, THOHOYANDOU, 0950), LIMPOPO PROVINCE), SOUTH AFRICA
TELEPHONE (015) 962 8504/8313 FAX (015) 962 9060
"A quality driven financially sustainable, Comprehensive University"

General Conditions

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following.

- The project leader (principal investigator) must report in the prescribed format to the REC:
  - Annually (or as otherwise requested) on the progress of the project, and upon completion of the project.
  - Within 48hrs in case of any adverse event (or any matter that interrupts sound ethical principles) during the project.
  - Annually, research projects may be randomly selected for auditing.
- The approval applies strictly to the protocol as stipulated in the application form. Should a change to the protocol be deemed necessary during the project, the project leader must apply for approval of these changes before their implementation. Should there be a deviation from the study protocol, without the necessary approval for the change, the ethics approval is automatically forfeited.
- The date of approval indicates the earliest date that the project may begin. Should the project have to continue after the expiry date; a new application must be made, and a new approval received before or on the expiry date.
- In the interest of ethical responsibility, the FREC retains the right to:
  - Request access to any information or data at any time during the course or after completion of the project,
  - To ask further questions; Seek additional information; Require further modification or monitor the conduct of your research or the informed consent process.
  - withdraw or postpone approval if:
  - Any unethical principles or practices of the project are revealed or suspected.
  - It becomes apparent that relevant information was withheld from the REC or that information has been false or misrepresented.
  - The required annual report and reporting of adverse events was not done timely and accurately,
  - New institutional rules, national legislation or international conventions deem it necessary.

ISSUED BY:
FACULTY OF SCIENCE, ENGINEERING AND AGRICULTURE RESEARCH ETHICS COMMITTEE

Date considered: August 2023

Chairperson: PO. Bessong

University of Venda
PRIVATE BAG X5050, THOHOYANDOU, 0950), LIMPOPO PROVINCE), SOUTH AFRICA
TELEPHONE (015) 962 8504/8313 FAX (015) 962 9060
"A quality driven financially sustainable, Comprehensive University"

c. Appendix 3: Research Questionnaire

May you provide the following information?

1. Gender of respondent ______________
2. Age____________
3. Education level _____________
4. How long have you been in the farming business?____________
5. Other than farming what are the other sources of income for the family?

Farm income	Non-farm income sources

6. How many people are being employed at your farm?

Family labour				Hired labour			
Male		Female		Male		Female	
Seasonal	Permanent	Seasonal	Permanent	Seasonal	Permanent	Seasonal	Permanent

7. What is the size of your irrigated plot?______________
8. In the past season what crops were grown?

Season	Crops grown	Area planted	Yield	Quantity sold	Price per unit
Season 1					
Season 2					
Season 3					

9. For each of the crops grown in the past year what was the cost on:

Season	Crops	Fertilizers	Seeds	Electricity	Labour	Transport cost	Packaging cost	Others
Season 1								
Season 2								

Season 3								

10. Of the income from irrigation farming how much was used to:

	Buy farming equipment	Build a housing	Pay for education	Savings	Pay workers	Others
Season 1						
Season 2						
Season 3						

11. Who are the stakeholders in the crops produced and the value creation process?

Crop	Role Player 1		Role Player 2		Role Player 3		Role Player 4	
	Marketing costs	Selling price	Marketing costs	Selling price	Marketing costs	Selling price	Marketing costs	Selling price

12. How much water was used in the past season or how much money was used to pay for electricity to pump water?

    ____

13. How much have your livelihoods changed due to irrigation farming?

Main livelihood sources	
Before participation in irrigation	Currently

14. What are the main challenges that you think will affect the irrigation project?

    ____

15. List the main institutions and organizations you are a member of and state the benefits you derive from being a member.

Main institutions and organizations	
Institution	**Benefits to members**

16. Of the following challenges, which ones are being experienced due to the irrigation project?

Possible environmental challenges due to irrigation	
Challenge	**Possible solution**
Water pollution due to fertilisers and chemical use	
Soil erosion	
Destruction of plants	

Introduction of new pests and diseases	
Saline soils	
Destruction of wild life habitat	
Destruction of aquatic life	
Others	

17. Sources of information

Source of information i.e. Smart phone	What kind of information i.e. Market prices