Access to Irrigation and its Impact on Vulnerability to Poverty and Food Security amongst South African Farming Households

by

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GENERAL ABSTRACT

The significance of participating in irrigation technology in eliminating vulnerability to poverty and improving farming households' food security status cannot be overemphasized. Numerous studies have empirically examined the influence of farm management practices, including irrigation, on poverty reduction and overall household well-being. However, a notable gap exists in the literature concerning the specific impact of irrigation farming on vulnerability to poverty, multidimensional household poverty, and the welfare of rural farming households. This study aims to address this gap by exploring the nuanced relationship between irrigation participation and key welfare indicators within the context of rural communities. The study consists of four main objectives, each of which is an article and chapter of this thesis. In each of the articles, the significance, methods, data, findings and policy implications are detailed, and these are presented in the below sections.

In the first objective, the study employed the documentary analysis approach and bibliometric technique to mine and analyse relevant documents for evaluating facts and evidence, which largely concurs with the method of information gathering used in the qualitative study method. In the analysis period (1991-2022), the most published articles on impacts of irrigation on household poverty appeared to be in 2022, indicating the growing concern on depleting food resource access. Overall, the findings revealed that irrigation adoption produced better yields and increased farm incomes thereby reducing rural household poverty as well as vulnerability to poverty. The study, therefore, suggests that more sophisticated and innovative methods, such as the proposed multi-level framework, conglomerate approach, and community-led solutions, should be developed and implemented to promote household food dynamics, food system resilience, and governance in the context of South Africa.

The second segment of the research focuses on the effect of participation in irrigation farming on food security among rural farming households. The study employed an endogenous treatment effect with ordered outcome to achieve its objectives. The empirical findings indicate that the engagement of rural households in irrigation farming has a higher probability of mitigating food insecurity. This is attributed to the enhanced productivity and improved food accessibility that irrigation farming provides, particularly in the face of severe weather-induced shocks like drought. The findings also showed that the gender of the household head, the size of the household, unemployment status, access to market outlets, remittances and crop diversification (CDV) factors increase the likelihood of rural farmers' involvement in irrigation

farming, as well as reduces their food insecurity. Based on the findings, the study suggested that government intervention policies and a restructuring of rural operations to include more technological innovations such as advanced irrigation systems be reviewed.

The third segment of the study focuses on the vulnerability of smallholder farmers to multidimensional poverty, which was carried out using the Alkire Foster multidimensional poverty index developed by the Oxford Poverty and Human Development Initiative. The findings showed that the deprivation indicator ranges from 5% to 90%, where about 66% and 55% were deprived of food security (SDG2) and education (SDG4), respectively. The results of the probit analysis reveal that gender, remittances, crop diversification (CDV), education, seasonal farming and market outlets significantly influence the multidimensional poverty and vulnerability to multidimensional poverty of rural households in the study areas.

The last part of the study examines the factors that influence farmers' participation in irrigation farming, as well as how it affects farmers' welfare (proxy by food consumption expenditure per capita) and household poverty (indicated by the poverty gap index, poverty severity and poverty vulnerability). The endogenous switching regression (ESR) model was employed to account for selection bias that could be caused by both observed and unobserved household factors, including observed and unobserved farm-level factors. The empirical results show that gender, household size, educational attainment, crop diversification and market outlets, among others, influenced farmers' decisions to practise irrigation farming. Farmers engaging in irrigation farming have their food consumption per capita increased by 44%, while non-participants would have increased their consumption expenditure per capita by 23% if they had participated. Moreover, the participating farmers reduced their poverty gap index by 20% and poverty severity by 22%, whereas non-participating farmers could have reduced their poverty gap index and poverty severity by 5% and 17%, respectively had they engaged in irrigation farming. Participation in irrigation farming also reduced poverty vulnerability by 25%, while non-participants may have reduced poverty vulnerability by 3% had they participated.

Overall, the study suggests that the household food dynamics and food system resilience and governance in the context of South Africa need to devote more time to reliable and innovative methods, such as the conglomerate approach, community-led solutions and appropriate strategies, which need to be implemented in order to mitigate the collapse of the nation's food systems. In addition, the study recommend that enhancing farmers' access to irrigation is crucial for meeting the Sustainable Development Goals (SDGs), which aim to eradicate poverty in all its manifestations everywhere. Lastly, the study suggests that improving policies related to improving education and increasing crop diversification among other factors, could contribute to reducing the multidimensional poverty and the households' vulnerability to poverty.

DECLARATION 1

I, Adetoso Adebiyi Adetoro, hereby declare that:

i. The research reported in this dissertation, except where otherwise indicated, is my own original research.

ii. This dissertation has not been submitted for any degree or examination at any other university.

iii. This dissertation does not contain any other person's data, pictures, graphs, or other information unless specifically acknowledged as being sourced from those people.

iv. This dissertation does not contain other authors' writing unless specifically acknowledged as being sourced from them. Where other written sources have been quoted, then:

a) Their words have been re-written, but the general information attributed to them has been referenced; and

b) Where their exact words have been used, their writing has been placed inside quotation marks and referenced.

v. This dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, with the source(s) being detailed in the thesis and in the references section.

[redacted]

Student's signature: Date: 30 November 2023

Adetoso Adebiyi Adetoro

As the candidate's main supervisor, I, Dr Mjabuliseni Ngidi, agree to the submission of this dissertation for examination.

Supervisor's signature: [redacted] Date: 30 November 2023

Dr Mjabuliseni SC Ngidi

As the candidate's co-supervisor, I, Prof. Gideon Danso-Abbeam, agree to the submission of this dissertation for examination.

Co-supervisor's signature: [redacted] Date: 30 November 2023

Prof. Gideon Danso-Abbeam

DECLARATION 2: PUBLICATIONS

The following publications form part of the research presented in this study.

Published

Publication 3 – Chapter 4

Towards the global zero poverty agenda: Examining the multidimensional poverty situation in South Africa.

Publication 4 – Chapter 5

Impact of irrigation on welfare and vulnerability to poverty in South African farming households.

Under review

Publication 1 – Chapter 2

The impact of irrigation on household vulnerability to poverty, and effects on food security in Africa: A review.

Manuscript ID: SCIAF-D-23-02182

Scientific African

Publication 2 – Chapter 3

Effect of irrigation farming participation on food security among rural household farmers: Empirical evidence from South Africa.

Manuscript ID: JAFR-D-23-01244R1

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DEDICATION

This piece of work is dedicated to Almighty God, the Lord and saviour of my life, because without Him I would be nowhere today. I am grateful for His knowledge, wisdom and protection.

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CHAPTER ONE

1.1 Background of the study

This chapter provides a general overview of the study. It presents the background to the study and its conceptualisation. It describes the issues relating to South African households' access to irrigation and the impact thereof on households' welfare, households' vulnerability to poverty and food insecurity. Following that, the problem statement the study attempts to address is discussed. The chapter also presents research questions, aim and objectives of the study. The justification for the study is described, along with the theoretical and methodological overviews, showing how the study contributes to scientific knowledge and policy recommendations. Lastly, the list of articles is presented.

Globally, food insecurity is worsened by the high prevalence of rural poverty, and is exacerbated by climate variability and change, which often pose threats to vulnerable groups with low purchasing power, pervasive malnutrition, and lack of or poor access to food and health services (Gillespie & Van den Bold, 2017; Nyathi et al., 2022). The prevalence of high poverty, combined with the large number of inhabitants, is a key factor affecting household's food security. In the global South of the semi-arid environment, particularly the margin alongside arable land to farm, the length of the growing period and highest yield are expected to shorten under current and future global change (Yang et al., 2016). As a result, the components of food security: availability and utilisation will increase the risk of hunger in the region, owing to climate variability and change (FAO et al., 2018). According to a report by Hasegawa et al. (2021), under high and low emission scenarios, 20 to 36% and 11 to 33% of the population would experience hunger, respectively, caused by worsening climate events globally. Recent studies have also reported that the unequivocal climate warming to the planet is evident from observations of rising temperatures, decreasing rainfall, dissolving snow and ice, as well as a rise in sea levels (Gupta, 2018; Soeder, 2020). This presents multiple threats to ecosystems and biodiversity, thus affecting food production and security and human systems (Crist et al., 2017). Therefore, appropriate measures to adopt strategies for effective adaptation and mitigation are crucial to ensure food availability and accessibility, and the affordability of improved nutrition at both the national and household level.

Studies utilising the multi-model and hydrological ensembles of the Coupled Model Inter-comparison Project Phase 5 (Sharmila et al., 2015; Gosling & Arnell, 2016; Ren et al., 2017; Nguyen et al., 2018) have shown uneven effects of climate change on global water resources. The global generation of water resources in different country sectors accounts for more than 90% of total water consumption, and this is represented by the product life cycle found in the supply network's ever-growing web of connections (Zhao et al., 2019). Consequently, the growing worry is the security of the water for inhabitants residing in places susceptible to drought occurrences and the increased threat to the world economy (Nguyen et al., 2018). Smallholder irrigation practices are still an effective way to increase rural farmers' agricultural output, ensure household food security, and reduce rural poverty in the case of water security (Sinyolo et al., 2014). Consequently, the security of water is central to improving the efficiency of irrigation connectivity in poverty alleviation and food security for families (Darko et al., 2016). In essence, a water shortage can impede food manufacturing, have a negative effect on food security and exacerbate poverty (Renzaho et al., 2017). Water scarcity presents multiple threats to food production and price, and agricultural outputs and produce, particularly in arid and semi-arid regions. This includes income generated from the agricultural sector (Binyam & Desale, 2015).

Globally, just 19% of farmland is irrigated, despite the fact that irrigation provides 40% of the world's food systems, thus contributing to socioeconomic development (Devaux et al., 2020). Irrigation farming has become the bedrock for agricultural infrastructure to enhance a sustainable economy. For instance, in Asia, irrigation led to household poverty reduction through the implementation of low-cost irrigation with tube wells that enhanced food production and livelihoods (Ahmed et al., 2022). In addition, the use of irrigation treadle pumps with pump engines that are less expensive and smaller, the design of water allocation, and the advancement of credit agreements have enabled poor families to gain access to irrigation and improve their standard of living (Giordano & De Fraiture, 2014; Fischer et al., 2022).

In contrast, there has been poor implementation of irrigation technologies in Southern Africa, and water supplies for irrigation have not been developed enough to support the effort to reduce poverty in sub-Saharan Africa. The low level of implementation is associated with the rising cost of control pumps and another farm equipment in the region (Chikafa et al., 2023). In addition, the inability to develop sustainable credit schemes and to design reliable water markets has greatly affected poverty-reduction efforts (Smith, 2004). According to the International Water Management Institute (IWMI), the expenses are too exorbitant for the entire sub-Saharan African region because of a few significant collapses that have detracted from the efforts (IWMI, 2006; Calderon, 2021). Many studies have been conducted to investigate household food insecurity in the semi-arid regions of Southern Africa, and these have revealed several factors that can enhance food security, including irrigation, land quality, income, household size, farmer's wealth, and land size. In this context, water security has been highlighted among other factors as the most regulating factor to food production and security, especially in rural communities (Oral & Akpinar, 2017; Lam et al., 2022). Pawlak and Kolodziejczak (2020) identified a low rate of management and technical expertise, as well as a lack of preparation, as the main contributing factors to the lower levels of household food security and efficiency. Despite the enormous collaborative efforts of various international organisations and the South African government, as well as non-governmental organisations (NGOs), in monitoring and alleviating hunger and food insecurity, South Africa's population remains affected by poverty and food insecurity to a great extent (Masuku, 2018). Given the worsening state of food insecurity among the rural households in South Africa, it is essential to explore options and factors that could help to improve food security status in South Africa. However, the extent to which irrigation farming participation could help improve food security status of rural farming households has not been extensively explored in South Africa. In addition, given the poverty reduction potentials through enhanced productivity as reported by Gioardano et al. (2023), this study examines the impact of irrigation participation on households' welfare, household poverty and vulnerability to poverty.. Moreover, assessing household vulnerability to poverty and the effect of irrigation on food security in line with the SDG agenda is crucial for effective mitigation and adaptation and for the formulation of key policies to promote long-term agriculture.

1.2 Problem statement

South Africa is experiencing hunger because of severe food insecurity, exacerbated by heavy rainfall, energy crisis, high unemployment, rising living cost and recurrent drought episodes due to climate change (Stats SA, 2021). In 2021, approximately 11.6% of South African households reported experiencing hunger (Stats SA, 2021). According to idealised scenarios of increasing savannah and desert cover, South Africa has reported a rise and fall in annual rainfall (Williams and Kniveton, 2012). This presents multiple resultant effects on household vulnerability to poverty and food production systems due to changes induced in water and energy balance systems (Wang et al., 2012; Serraj et al., 2019). In the context of irrigation agriculture, it is observed that environmental alterations have significant implications for rural communities, making them vulnerable to multifaceted manifestations of extreme poverty. These consequences manifest in the form of deteriorating air quality, fluctuations in temperature and weather patterns, ultimately exacerbating the prevalence of illness and food insecurity within these communities.

Studies have shown that climate change and socio-economic impacts respond to changes in precipitation, temperature, land use and land cover, desertification, environmental degradation, population size, low rates of rural funding, and the global market (Kelly et al., 2015; Vieira et al., 2020). A dense and quality study is required to monitor and evaluate irrigation effects on household vulnerability to poverty and its impact on food security, owing to the adverse effects of climate change and its socio-economic impacts.

Food insecurity and household vulnerability to poverty in South Africa are among the topical issues in agroecosystems and have a considerable influence because of the variety of effects that include socio-economic impacts (Van Ginkel et al., 2013; Poppy et al., 2014; Molotoks et al., 2021). In relation to household vulnerability, climate change and drought impact households' ability to grow food and affects the quantity of food produced. These vulnerabilities accelerates the food insecurity situation (Ngumbela et al;., 2020).. This could have affected the household food security status in the KwaZulu-Natal and Eastern Cape provinces after the flash floods and drought episodes; these areas remain the most affected hotspots vulnerable to extreme poverty in South Africa (Pyle, 2006; Dagada, 2017; Graw et al., 2017; Quinn et al., 2020; Busayo et al., 2022). As such, the urgency in smart irrigation agricultural schemes to ameliorate household susceptibility to poverty and improve food security needs to be assessed. This is because a better understanding of irrigation effects on household vulnerability to poverty and food security, and their associated consequences, makes it possible to adopt focused, efficient mitigation and adaptation steps to ensure climate sustainability and resilience. This study provides new insights into the effect of irrigation systems on household welfare, households' vulnerability to poverty and food security studies field by considering the case of South Africa. In general, it is important to define the relationship between household vulnerability to poverty and the effect of irrigation on South Africa's food security. This presents a deeper understanding of key issues of household food security and poverty which is still inadequate (Ngumbela et al., 2020), which is necessary to improve the comprehension of irrigation practices and climate-resilient agriculture, especially in a semi-arid environment. Therefore, this research aims to analyse the large-scale household vulnerability to poverty and the effects of irrigation on food security using the South African case, which is ranked as the third most biodiversity-rich country globally.

1.3 Research questions

Food insecurity issues are global concerns that have attracted growing attention from scholars to provide solutions through policy recommendations, with the main goal focused on eliminating poverty in all forms across the globe. Despite the vast research, there are still areas that could contribute to this big objective that currently are under-explored, leaving some questions unanswered and consequently creating a research gap that needs to be filled. Against this backdrop, this study seeks to answer the following questions:

i. What are the lessons learnt in the literature on the consequences of households' irrigation on household vulnerability to poverty and its impact on food security?

ii. What are the empirical implications of farmers' involvement in irrigation farming on the rural households' food security?

iii. What factors influence multidimensional poverty and vulnerability to poverty of rural households?

iv. To what extent does participation in irrigation contribute to household welfare and reduce impact poverty vulnerability?

1.4 Aim and objectives

The aim of this study is to analyse rural farming households' access to irrigation and the impact thereof on vulnerability to poverty, as well as its effect on food security in South Africa.

The aim will be achieved through the following specific objectives:

1. To systematically conduct a bibliometric analysis on the impacts of irrigation access on food security and vulnerability to poverty.

2. To assess the impacts of irrigation participation on farming households' food security status.

3. To examine the drivers of multidimensional poverty and vulnerability to poverty situation in South Africa

4. To evaluate the impact of irrigation on vulnerability to poverty and the welfare of farming households.

1.5 Justification for the study

Investigating food insecurity and household vulnerability to poverty offers an opportunity to characterise household vulnerability to poverty and the effects of irrigation on food security. The food and nutrition security requirements of vulnerable populations, particularly those most at risk, are frequently not well comprehended. To address this, a comprehensive approach involving multidimensional analysis and empirical assessment is necessary. By deconstructing food insecurity challenges into various dimensions, tailored recommendations can be developed for the rural households located in the study area and replicated in other areas facing similar food insecurity issues around the world. Customizing interventions to meet specific needs is of utmost importance. This is crucial for coping with the potential consequences of future changes in food web production and its associated functions. Global climate change has significantly affected the natural food web cycles over the past decades (Seddon et al., 2021), presenting multiple socioeconomic challenges to local societies. Therefore, it is crucial to investigate household vulnerability to poverty and high rates of food insecurity from the impact of irrigation due to change in climate in South Africa, more specifically as a case study area. South Africa was identified by the Climate Change Intergovernmental Panel (IPCC) in 2022 as a disaster-prone region owing to the resilient flash floods and drought conditions that grip the country. These conditions have caused a catastrophic risk to food security, agroecological systems and sustainable human wellbeing (IPCC, 2022; Venturini et al., 2022). In addition, this study appraised climate-smart agriculture, which uses an irrigation farming approach to managing landscape conditions to identify the significant interlinked challenges of household vulnerability to poverty and its impacts on food security. In this study, the linkage between household vulnerability to poverty and the impact of irrigation on food provides useful information on climate resilience to guide decision-making and the dynamics between food security and rural hunger through efficient small-scale irrigation schemes in South Africa.

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CHAPTER TWO

IMPACT OF IRRIGATION ON HOUSEHOLD VULNERABILITY TO POVERTY AND FOOD SECURITY IN AFRICA: A REVIEW

Adetoro, A. A., Ngidi, M. S. C., Danso-Abbeam, G., & Okolie C.C. (2023). The impact of irrigation on household vulnerability to poverty, and effects on food security in Africa: A review

Abstract

The importance of irrigation technology participation in eliminating vulnerability to poverty and improving wellness is directly associated with food security. The rising food and nutrition insecurity in South Africa, particularly the rural areas, is a pressing concern, compounded by insufficient scientific knowledge to guide decision-makers in devising effective strategies for poverty alleviation and addressing food insecurity within the context of irrigation farming. This study examined the mitigation of household vulnerability to food insecurity and poverty, in accordance with the growing body of research on the combined effects of irrigation and its consequences for household vulnerability to poverty, as well as food security. This study employed two methods, namely, the documentary analysis approach and bibliometric technique to extract and analyse relevant documents for evaluating facts and evidence, which largely concurs with the method of information gathering used in the qualitative study method. The study found that in 2022, the highest article on impacts of irrigation on household poverty was published, indicating the growing concern on depleting food resource access. Overall, the findings revealed that irrigation applications produced better yields and increased farm incomes thereby reducing rural household poverty as well as vulnerability to poverty. This study posits that there is a need for the development and implementation of more advanced and inventive strategies, such as the proposed multi-level framework, conglomerate approach, and community-led solutions, in order to enhance household food dynamics, food system resilience, and governance within the specific context of South Africa (SA).

Keywords: food security; irrigation; poverty alleviation; vulnerability.

2.1. Introduction

Irrigation provides numerous ecological benefits in agroecosystems, including crop growth, landscape management and re-vegetation of disturbed soils, especially in dry land during periods of less-than-average rainfall (Aleksandrova et al., 2014; Tiwari et al., 2018). Irrigation significantly helps in providing food security and poverty alleviation by enhancing the quality of life for households and rural inhabitants (Tesfaye et al., 2008; Fanadzo, 2012). One of the most crucial elements in boosting crop productivity and enhancing overall agricultural effectiveness is irrigation (Adetoro et al., 2020). Irrigation exerts a positive effect on the food security of households, poverty reduction, and income from agriculture (Adebayo et al., 2018). Despite its role in ameliorating household food security and poverty, vulnerable household communities continue to be affected by food shortages globally because of persistent droughts and floods (Tora et al., 2021). This poses serious threats to food security, sustainable livelihoods as well as the household community, exposing them to extreme poverty. The development of irrigation comes with a price, however, and might also have negative effects on the environment and human health, including salinisation, greater flooding, and water-borne illnesses, particularly in Africa (Afjal Hossain et al., 2012).

A matter of current concern pertains to the expected adverse effects of climate change on the production, distribution, and associated functions within the food webs, as highlighted by Vermeulen et al. (2012) and Prather et al. (2013). In addition, the effects of climate change on small farmers will be extremely detrimental, severely affecting household food security. The sensitivity of households to climate change confirms the high rates of food insecurity because of falling prices for agricultural goods, rising input expenses, and concern over the incidence of animal diseases (Adetoro et al., 2022). The need to mitigate/lessen the effect of irrigation on households in vulnerable communities to poverty and food security cannot be overemphasised. Therefore, monitoring the effect of irrigation on households' vulnerability to poverty and its effects on food security is crucial to improving food web production and sustainable planning outcomes. Smallholder irrigated agriculture must be given top priority to achieve the Sustainable Development Goals (SDGs), specifically SDG number one goal which is relevant to eradicating poverty and hunger and to ensure food security and sustainability, as well as alleviate household poverty (Matshe, 2009; Tshuma, 2012; Mugambiwa & Tirivangasi, 2017, UN DESA, 2023). On the other hand, extreme weather and environmental incidents like heavy rainfall or severe flooding and droughts can cause major harm to household farm owners' plants and properties (Hay, 2007; Rahman & Alam, 2016; Chandra et al., 2017). Studies have revealed that the rainfall variations in the Southern Hemisphere, especially the arid areas of the Global South, pose significant threats to food security and restrict the capabilities of local household communities to cope with and overcome these potential difficulties (Brown et al., 2012; Mesquita & Bursztyn, 2017). Relevant research in the literature such as the FAO has estimated that severe food insecurity with agriculture's added value to the world economy was 1.9 trillion dollars in 2013, with an annualised rate of 3.5 trillion dollars for undernutrition from a worldwide agrarian economy (gross domestic product) of 2.7 trillion dollars in 2016 (Leser, 2013; McGuire, 2015). In 2020, 2.37 billion people worldwide lacked access to enough food owing to the insurgent COVID-19 pandemic, and with the increased frequency of severe to moderate food shortages, which increased in the last decade (World Bank, 2019, 2020). Globally, in 2020, between 720 and 811 million people were predicted to be hungry, while in 2030, 660 million people might still experience hunger, partly because of the long-term effects of the COVID-19 outbreak on food security worldwide (World Bank, 2020; FAO et al., 2021).

Global climate change has given rise to vulnerability to poverty and impacts on irrigation farming and reduced agricultural yields, among others. Due to the complex nature of the impacts of irrigation on household food security in recent years and the threat of household poverty, not much research has examined and identified the relationship between household poverty frailty and food security and the impact of irrigation farming (Ewing & Msangi, 2009; Lemos et al., 2016). Studies on household vulnerability to poverty and food security have become focal issues in agroecosystems (Van Ginkel et al., 2013; Poppy et al., 2014). More recently, most research has centred on problems of household vulnerability to factors like drought stress (Chinwendu, 2017), adaptation to climate change (Mbow et al., 2014; Campbell et al., 2016), smallholders' irrigated agriculture (Nakawuka et al., 2018; Vogels et al., 2019), food security (Prosekov & Ivanova, 2018), and rural livelihoods (Alobo Loison, 2015). While these studies have extensively examined the impact of irrigation on households' vulnerability to poverty and food security, there has been relatively less focus on its role in poverty reduction. However, recent research findings have specifically investigated how irrigation farming affects household vulnerability to poverty and its implications for food security. Notable studies by Mthethwa & Wale (2020), Kassie & Alemu (2021), and Akudugu et al. (2021) contribute to our understanding of these dynamics. This therefore warrants an analysis of how irrigation affects households' vulnerability to poverty and its effects on food security using the scient metric method. The research aims to explore household sensitivity to food insecurity and poverty, specifically focusing on the impact of irrigated farming. By assessing irrigation's effect on household vulnerability to poverty and its role in poverty reduction during food security crises influenced by socioeconomic and climatic factors, this study seeks to enhance our understanding of relevant scientific knowledge. Additionally, it aims to address key questions related to alleviating household vulnerability. The investigation aligns with emerging scholarship on synergizing irrigation's impact, considering implications for poverty, food security, and sustainability. The study's findings offer valuable insights into the potential consequences of irrigation for household poverty vulnerability and underscore the importance of well-informed decisions in evaluating regional food security sustainability.

2.2 Methodological note

This study utilised search words that were relevant to the study's goal of identifying documents on the "Impact of irrigation on household vulnerability to poverty, and household vulnerability and food security in South Africa". For conducting a scientometric study, the search and evaluation of scholarly publications were limited to those published exclusively in the English language. To facilitate this process, three platforms were utilised: Google Scholar, Science Direct, and the Web of Science Core Collection (WOS) platform provided by Thomson Reuters. The inclusion of more papers in this study may have been warranted; nevertheless, their exclusion was hindered by the language barrier. Our analysis focused on English language because a significant number of scientific journals and conferences predominantly disseminate research findings in the English language. Consequently, English-language publications tend to have broader accessibility among academics across the globe. Consequently, scholars who disseminate their research in the English language have the potential to access a wider readership, thereby increasing the likelihood of receiving more citations and gaining greater prominence within scientometric databases. The primary focus of several scientometric databases and tools is the indexing and analysis of papers written in the English language. Although several databases do contain non-English journals, their coverage is typically more restricted, necessitating additional work when looking for non-English papers. The investigation and comprehension of the effect of irrigation on household vulnerability to poverty in respect of food security served as the foundation for this analysis. The objective of the documentary analysis was to evaluate details and evidence, which closely aligns with the method of information collection used in the qualitative research method (Altheide & Johnson, 2011; Tracy, 2019). In addition is worth noting that this study only recognises the significance of cumulative and transformational trends and does not attempt to deal with the structural units.

In order to find scholarly publications on "irrigation" AND "food security" OR "food insecurity" AND "poverty" OR "poverty alleviation" AND "vulnerability*", this review research considered a variety of search themes. The search was done in the topic field of the registries in the WOS in order to obtain more accurate results (Aleixandre-Benavent et al., 2017). To ensure greater precision in the records acquired, the words were enclosed in quotation marks. We restricted the search to the years 1999 to 2022 in order to concentrate on South Africa (see Table 1). In terms of literature reviews, the bibliometric technique is a good invention because it compiles every pertinent document required for the study (Okolie et al., 2022). Different databases, including Dimension, Web of Science, PubMed, etc., are used in the bibliometric technique. As long as there are papers published in that field of research (such as health science, engineering, environmental and social sciences, etc.), it may also be used in all other disciplines of study. One of the most rigorous methods for showing the past and present organisation of the area of study through cluster analysis, keyword occurrences, bibliographic coupling, co-authorship and citation is bibliometric analysis (Ogundeji & Okolie, 2022; Okolie et al., 2022). This method can be used to analyse the various aspects of published intellectual materials, including institutions, countries, most significant academic journals, and highly cited documents. Scientific bibliometricians may evaluate or display bibliometric data using a variety of software tools, one of which is the Bibliometrix package.

A variety of inclusion and exclusion requirements were taken into consideration to measure academic advancement in relation to the effect of irrigation on family susceptibility to poverty, household vulnerability, and food insecurity in South Africa. We employed a topic-specific search for quick discovery and retrieval. As stated by Aleixandre-Benavent (2017), and later by Okolie et al. (2022) and Okolie and Ogundeji (2022), the topic search was used because of its efficacy. First off, we only used published articles as document formats; we did not utilize notes, errata, quick surveys, editorial reviews, and book chapters. Furthermore, considering that some of these papers never make it to the publication stage, we only utilised journals as sources and omitted conference proceedings, trade journals, and undefined. We subsequently removed articles that were "in press", and only kept those that had reached the stage of final publication. We chose papers from the disciplines of agriculture, social science and environmental science, instead of those from microbiology, material science, psychology or the health profession when choosing the topic areas. Languages other than English (e.g. Japanese, Portuguese, Arabic, etc.) were excluded from the bibliometric review. Last, but not least, a period of 23 years was selected as the review period to be able to gather the majority of the papers (see Table 2.1 and Figure 2.1).

Table 2.1: Scientometric analysis inclusion and exclusion standards

Criterion	Eligibility	Exclusion
Web of Science		
Country	South Africa	Every other country
Types of documents	Articles	Review, proceeding paper, early access
Source type	Journals	Book series, book
Publication stage	Final	Article in press
Study area	Plant Sciences, Environmental Sciences, Ecology, Social Sciences, Agricultural and Biodiversity Conservation	Econometrics and Finance, Business, Economics, Genetics and Molecular Biology, Energy, Engineering, Management and Accounting, Medicine, Biochemistry, Business
Used language(s)	English language.	Non-English
Dated	Between 1999 and 2022	< 1999, & > 2022

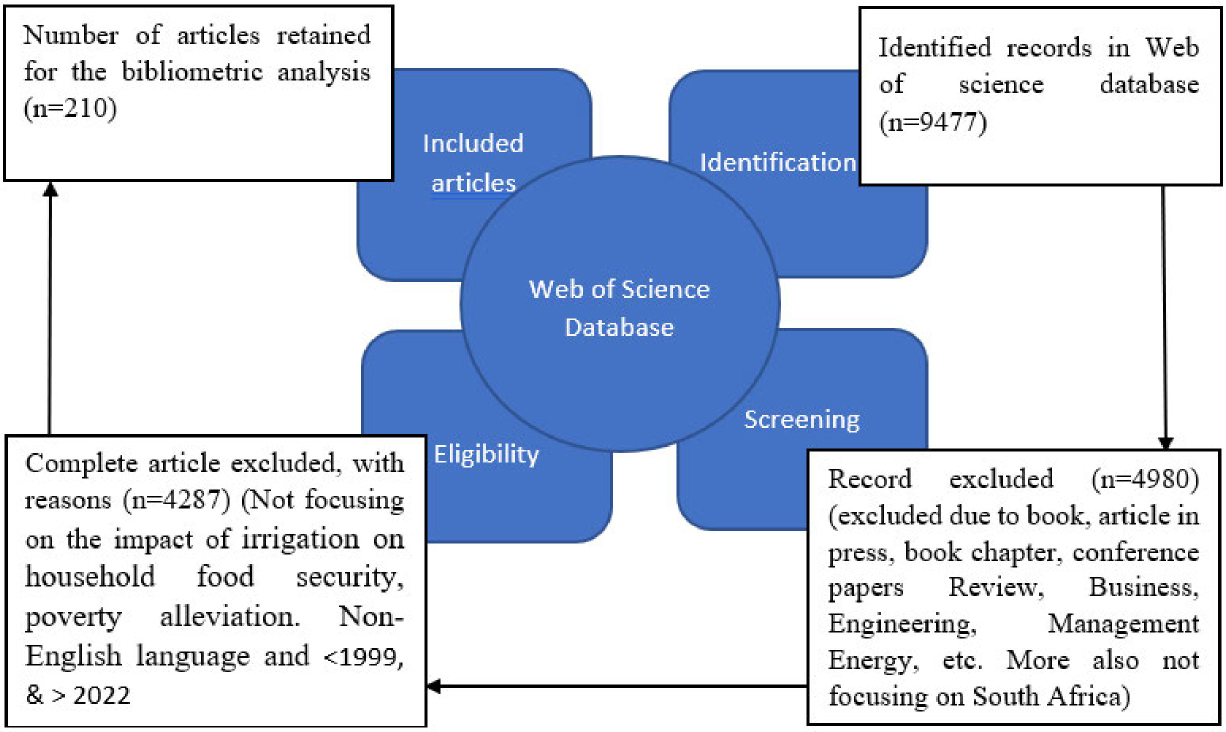

Figure 2.1: The bibliometric extraction flow chart (Adapted from Ogundeji & Okolie, 2022)

2.3. Findings and discussion of the bibliometric analysis

The fundamental bibliometric information on the impacts of irrigation on household poverty vulnerability and its implications for food security, gathered using the R-studio tool of Aria and Cuccurullo (2017), as displayed in Table 2.2. In the study period (1999 to 2022), 210 publications from 93 sources were published. The research included 669 authors and 784 author appearances, with a 43% international co-authorship rate. Research collaboration, particularly international collaboration, is usually believed to benefit both the organisations and the researchers involved and to improve the quality of the research (Van den Besselaar et al., 2012), leading to more citations (impacts) and greater numbers of scholarly publications (Khor & Yu, 2016). By working together, partners may cut costs and resources in half, get access to top-notch facilities, capitalise on each other’s experience, exchange recently developed techniques, skills, and information, strengthen areas of weakness, and benefit from the diversity of professional cultures. Collaboration may improve major topics of concern, provide new perspectives, and tackle cross-border or global difficulties (Khor & Yu, 2016). The authors/article index (3) was calculated by dividing the total number of authors by the total number of articles. The co-authors/article index indicates the average number of authors for each article (4). Co-authorship of research articles is a clear indicator of scientific collaboration. A single author or two or more co-authors are both acceptable for research articles. Researchers from the same institution, the same nation, or two or more nations may co-author a paper. These variables aid in understanding how scientific collaboration is evolving and how researchers are producing new knowledge (OECD, 2009).

This index considers author appearances, whereas "authors/article" only counts an author once, regardless of how many articles he or she has authored. Authors/article is thus less than co-authors/article. All 184 writers, with the exception of 26 solo authors, were involved in multi-author publications. Throughout the study period, each paper received an average of 16 citations. According to Lotka's rule of scientific output, the constant (L$C) for the study on the impact of irrigation on household vulnerability to poverty and its consequences for food security was 0.79, the beta coefficient (L$B) was 3.31, and the Kolmogorov-Smirnoff goodness of fit (L$R2) was 0.97. The overall mean of 9 and a 5% annual growth rate show that the influence of irrigation on family poverty vulnerability and the study of its implications for food security have increased over time. As noted by Adetoro et al. (2022), the government, agricultural water managers and policymakers should scale up irrigation technology facilities, especially for poor households, and create more awareness to improve the livelihood of rural households, given the significance of irrigation participation for poverty reduction and household welfare. Studies on the impacts of irrigation on family poverty vulnerability and food security that were published between 1999 and 2022 are shown in Table 2.3 and Figure 2.1, together with the average total number of citations per article by year in radar chats style. In 2017, just three articles were published, a slight decrease from previous years, although this number rose in the years that followed. Most of the articles were published in 2022 (n = 37), which was also the most productive year.

Table 2.2. Information summary on retrieved articles (1999 to 2022)

Description	**Results**
Timespan	1999:2022
Sources (journals)	93
Total retrieved articles	210
Document average age	5.69
Average citations per document	16.01
References	10 492
Annual growth rate %	5
Keywords plus (ID)	785
Author appearances	784
Author's keywords (DE)	551
Authors	669
Authors per article	3.19
Co-authors per document	4
Authors of single-authored documents	26
Multi-authored documents	184
International co-authorships %	43.06
Lotka's law of scientific output	
Constant – L$C	0.79
Beta coefficient – L$B	3.31
R-square – L$R	0.97

Table 2.3: Annual production AND average total citations per year (ATC/Y)

Year	Articles	ATC/Y
1999	1	3.8
2000	1	0.4
2001	0	0.0
2002	0	0.0
2003	1	0.8
2004	1	0.9
2005	2	5.6
2006	1	0.2
2007	3	1.1
2008	5	2.3
2009	7	6.6
2010	1	0.6
2011	11	2.8
2012	7	1.1
2013	6	1.4
2014	7	2.5
2015	6	1.6
2016	10	3.3
2017	3	3.2
2018	19	2.7
2019	24	2.1
2020	29	1.8
2021	28	1.8
2022	37	0.7

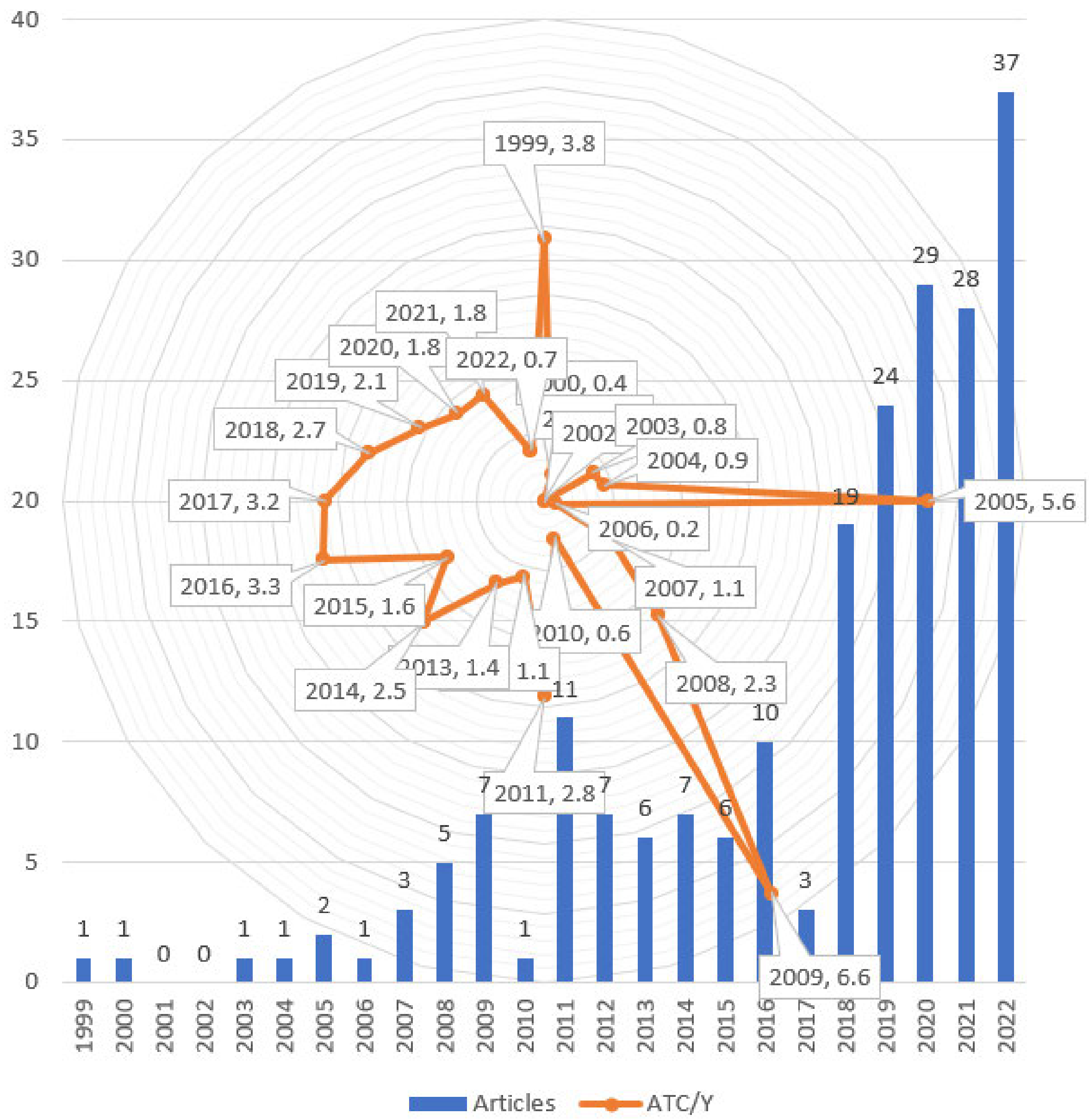

Figure 2.2: Annual production of articles AND average total citations per year (ATC/Y)

Table 2.4: Most vital keywords and keywords-plus

Author keywords (DE)	**Articles**	**Keywords-plus (ID)**	**Articles**
Food security	57	Poverty	29
South Africa	26	Climate change	24
Climate change	18	Security	19
Poverty	18	Management	17
Food insecurity	14	Impact	16
Livelihoods	13	Irrigation	16
Irrigation	11	Adaptation	13
Vulnerability	10	Agriculture	13
Dietary diversity	9	Food security	13
Africa	8	Insecurity	13
Adaptation	7	Vulnerability	13
Agriculture	6	Impacts	11
Poverty alleviation	6	Farmers	10
Resilience	6	Productivity	9
Urban agriculture	6	Resources	9

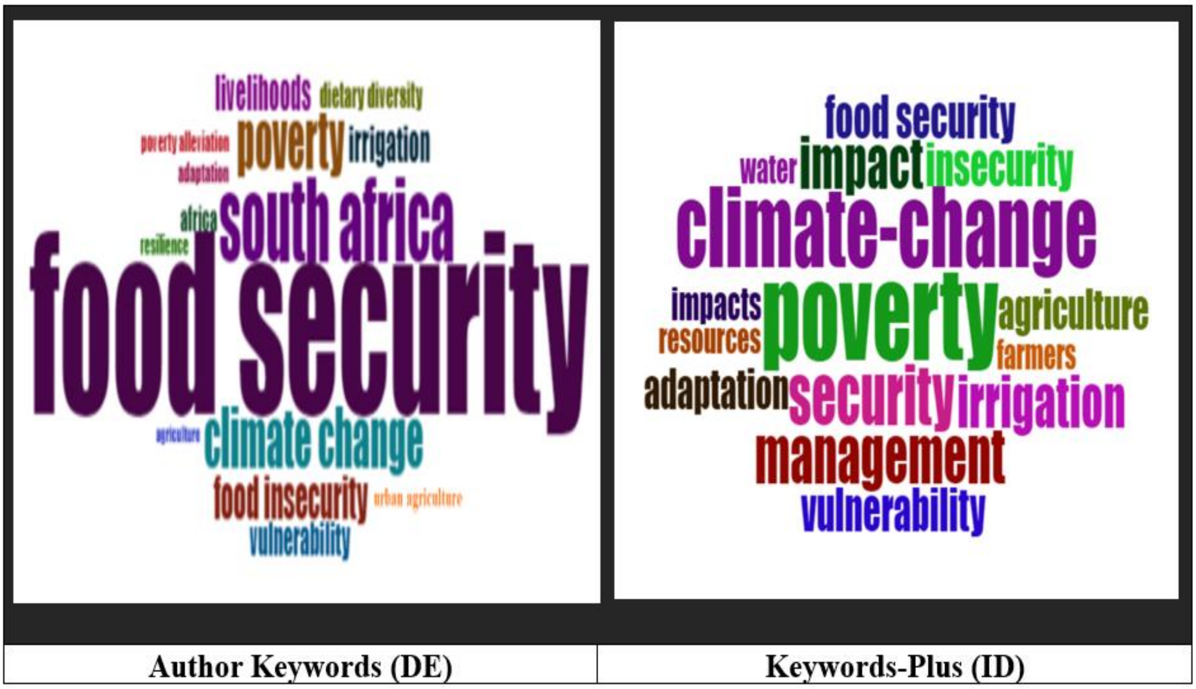

Figure 2.3: Frequency of word occurrences of the top 15 most often-used authors' keywords and keywords-plus on the impact of irrigation, vulnerability to poverty, and its effects on food security

Author keywords (DE) and keyword-plus (ID) based on the subject of published resources from 1999 to 2022 were two sets of keywords contained in the WoS database, which was employed in this bibliometric research. Printed publications on the impact of irrigation on household vulnerability to poverty and its effects on food security were found to have the top 15 most important author keywords and keywords-plus, which are listed in Table 2.4 and shown in Figure 2.3. The word "food security" was used by 57 of the writers, making it the most frequent keyword in the downloaded published scientific works. The most frequently used keywords in our downloaded scholarly articles, with their occurrence in brackets, were South Africa (26), climate change (18), poverty (18), food insecurity (14), livelihoods (13), irrigation (11), vulnerability (10), dietary diversity (9) and Africa (8). Also, keyword-plus (ID) revealed that poverty (n = 29) had the most occurrences in the articles reviewed, followed by climate change (n = 24), security (n = 19), management (n = 17), impact (n = 16), irrigation (n = 16), adaptation (n = 13), agriculture (n = 13), and food security (n = 13). Author keywords (DE) and keywords-plus (ID) had seven keywords in common (food security, climate change, poverty, irrigation, vulnerability, adaptation and agriculture). This is due to the numerous hotspots and the evolution of research on the impact of irrigation on household vulnerability to poverty, and its effects on food security in this sector. This result is consistent with the work of Okolie et al. (2022), who found that food security, climate change, adaptation, and agriculture were among the most frequently used keywords in “climate-smart agriculture amidst climate change to enhance agricultural production”. The keywords and keywords-plus capture the views of some previous authors pertaining to the impact of irrigation on household vulnerability to poverty and its effects on food security. For example, Adebayo et al. (2018) found that irrigation significantly helps provide food security and poverty alleviation by enhancing the quality of life for households and rural inhabitants. More so, according to Adetoro et al. (2020), one of the most crucial elements in boosting crop productivity and enhancing overall agricultural effectiveness is irrigation.

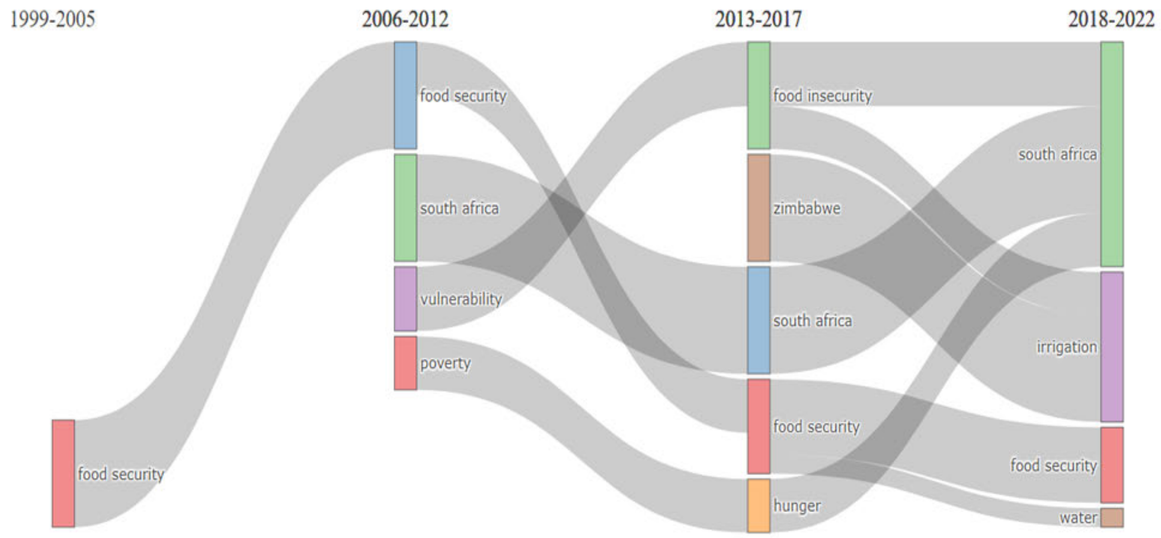

Figure 2.4. Thematic evolution of the frequency of the authors’ keyword occurrences from 1999 to 2022

2.4. Socioeconomic impact of irrigation on household vulnerability to poverty and linkages to the Sustainable Development Goals (SDGs)

Irrigation technologies are implemented to increase agricultural output in areas hampered by a lack of precipitation in terms of long-term water supply requirements. The negative impacts of irrigation may worsen if irrigation water supply decreases due to climate change and excessive water requests in upstream regions (Bobojonov & Aw-Hassan, 2014; Malek et al., 2018), and South Africa is used as a case study here. With recent advancements in farming methods that require little usage of water, such as drip-irrigation devices, which are primarily used in urban farming, effective irrigation facilities have been investigated and proposed (Jägermeyr et al., 2016; Benedetti et al., 2019). These are classified as passive responses, since it is not recognised that these actions are being carried out in response to the growing adaptation in climate change (Tripathi & Mishra 2017). A study conducted in Benin used drip irrigation powered by solar energy as a method of boosting food security for households and checked it in different townships. Their findings show that, compared to alternative technological advances, solar-powered drip irrigation substantially increased family income and nutrient intake, while also being more affordable (Burney et al., 2010). On-station tests in the Niger region were used to compare drip irrigation to irrigation using watering cans. The findings demonstrate that drip irrigation works better to produce better yields, increased water returns, and increased labour yields (Woltering et al., 2011).

Due to the most recent episodes of drought, 6.8 million inhabitants of South Africa faced hunger in 2017 because of severe food insecurity exacerbated by climate change (Stats SA, 2016). The numbers decreased in 2021 compared to 2017, as food inadequacy and hunger faced by many South African households increased, with around 2.1 million of people was reported to have experienced hunger (Stats SA, 2021). To mitigate the effects of food inadequacy, commercial farmers are investing in irrigation techniques, varying the times of planting and harvesting, growing different short-duration crops, using mixed cropping, altering planting dates and establishing agroforestry in South Africa (Tripathi & Mishra, 2017). Although smallholder farming households continue to rely on traditional methods of farming and food production, poverty and environmental degradation do not have to be inevitable outcomes of contemporary technology (Giller et al., 2021). This study serves as a timely intervention at a time when agriculture is being given more attention in the context of objectives for sustainable development (SDGs). Therefore, there is a need and a chance to assess the effect of irrigation on family poverty vulnerability and reduction in the face of a food security collapse influenced by socioeconomic and climatic factors. This will increase the importance of smallholders and households playing a role in agricultural production and the management of natural resources. With the rapid urbanisation in South Africa, it is crucial to integrate strategies to mitigate the negative impacts, such as efficient irrigation schemes, and to implement resilience agriculture to counter household vulnerability to poverty and secure quality food for a growing population. All countries adopted the SDGs and the Paris Accord initiatives in 2015 to direct performance towards sustainability within the 2030 Agenda for Sustainable Development and UN Legal Structure on Climate Change processes (United Nations, 2017). The 2030 Sustainable

Development agenda includes the collection of 17 interlinked goals such as hunger eradication, sustainable farming, and climate activity (United Nations, 2017).

The aim of this study was to provide comprehensive and integrated details to address the impacts of irrigation on household vulnerability to poverty and a reduction in it in the face of food security collapse influenced by socioeconomic and climatic factors in accordance with the Sustainable Development Goals (SDGs). This study concentrated on the SDG indicator framework, focusing on the intra- and inter-linkages of SDGs 1 and 2 (no poverty), as well as SDG 13 (zero hunger and climate action). The first (no poverty – SDG 1) seeks to eradicate poverty by 2030, ensure social welfare for the weak and poor, and broaden access to essential services. The second goal (zero hunger – SDG 2) aims to eliminate hunger, achieve food security and promote health in all aspects by 2030, and to always promote sustainable agriculture. The thirteenth goal (climate action) calls for immediate interventions to fight climate change and its consequences. More precisely, SDG 13 aims to create awareness and build knowledge and capacity to prevent climate change. Studies have revealed a positive relationship and synergies between food security and most of the goals, and under the current development methodologies, there are trade-offs between SDGs 12 (responsible consumption and production) and 15 (life on land) (McBean, 2017; Pradhan et al., 2017). Consequently, incorporating these SDGs (1, 2, 12, 13 and 15 into the world's food system can offer opportunities for averting disaster and adapting to it, and enhance sustainable agriculture for effective food security and integrating an ecosystem and biodiversity nexus into planning. On the basis of many cutting-edge techniques, this can control the sustainable modification of current production and consumption patterns (Watson et al., 2012). Recent studies show that climate change (SDG 13) depicts the present developmental activities, with which most of the goals have negative relationships (trade-offs), in contrast to Vision 2030 (Kroll et al., 2019; Lusseau & Mancini, 2019). Consequently, climate change targets put great emphasis on addressing climate change, and information on SDG 13 measures are interdependent on the two indicators (SDG 1 and 11), with many positive linkages (United Nations, 2017). Similarly, for approximately half of the investigated interconnections, trade-offs have been noticed among SDG 2 and SDG 13 (Pradhan et al., 2017). Crop productivity can improve with land protection and restoration (SDG 15) (Wolff et al., 2018). Likewise, effective irrigation techniques and climate-resilient agriculture can reduce water demand, which may enhance ecosystem health and biodiversity (SDGs 6 and 15) without decreasing the production of food (Jägermeyr et al., 2017). For instance, strengthening sustainability and minimising food waste can reduce the negative relationships for both SDG 2 and other objectives that have been observed (Obersteiner et al., 2016). Increasing the efficiency of smallholder farmers and limiting food waste and loss by 2030 are the aims of SDG 2 and SDG 12 (Kumar et al., 2016; United Nations, 2017). Therefore, to attain SDG 12 by 2030, the goal is to cut per capita food losses in half at the production and consumption levels, as well as to cut food losses and contribute to climate change mitigation and adaptation.

Agroecosystems that promote biodiversity and long-term land-use planning contribute to food safety (Montagnini & Metzel, 2017). Transitioning away from existing development paradigms and assessing the consequences of such lock-in impacts can prevent climate change, while also achieving long-term food security. Sustainable intensification of climate-smart agricultural practices can provide climate change adaptation and mitigation synergies, linking SDG 2 and SDG 13 more positively (McBean, 2017). According to Vardy et al. (2017), the Intergovernmental Panel on Climate Change (IPCC) report indicated that most of the currently observed trade-offs for SDG 13 and the other SDGs are unsustainable indicators that can be transformed into efficiencies based on various countermeasures that can be implemented to keep global climate change well below 1.5°C (McElwee et al., 2020; Vera et al., 2022). There are crucial combinations that can support the combined execution of the SDG and climate action plan, with reference to climate reaction strategies in relation to consumption and production.

2.4.1 Household vulnerability and adaptation to poverty and food insecurity in South Africa

Food security and poverty remain challenges, with just 30 000 commercial farmers in Southern Africa, including South Africa, being responsible for most of the region’s food production and farming (Jägermeyr et al., 2017; Muimba-Kankolongo, 2018). The extent of South Africa’s vulnerability to food insecurity is exacerbated by environmental vulnerability factors of climate change, which affect households’ capacity for food production. Several countries are part of the national contributions (NDCs) towards the Paris Agreement’s adaptation and mitigation plans through their food systems (Rosenzweig et al. 2018; Dasandi et al., 2021). Consequently, there is a lot of focus on traditional farming techniques that can be climate-smart and sustainable (for example crop and livestock management), but less emphasis on the facilitating services that can help with adoption (for example climate services and credit). Conventional agricultural practices have received much attention that can be transformed into sustainable livestock and crop management that is climate-smart with fewer service improvements (Gosnell et al., 2019; Mazhar et al., 2021). Sufficient and considerable income is required globally for farming mitigation and adaptation by small, developed nations, which spend between 3 billion USD per year on mitigation and adaptation, which could be an undercount because of the small sample size in the respective studies (Williams et al., 2015; Chapagain et al., 2020).

Africa is the world's second most extremely dry continent, with a severe dearth of water that poses significant threats to food security and sustainable human wellbeing (Mthethwa & Wale, 2020). According to local and indigenous expertise, climate change is having an impact on food production in drylands, especially those in African countries, and will continue to be affected by anticipated climate change in the future (Stavi et al., 2021). Most countries, especially in the semi-arid environment of the global South, often practise irrigated agriculture to ensure food security and sustainability, as well as to alleviate household poverty (Wossen et al., 2014; Gebru et al., 2021). Studies (e.g., Adeleke et al., 2020; Kusangaya et al., 2021) show that most countries in North Africa, the Middle East and Southern Africa, including South Africa, suffered from a dearth of water in the 1990s which affected food security as well as ecosystem functioning, and the situation has continued to worsen. (Many nations moved away from focusing on food and water security due to the dearth of water between 1990 and 2025 (Rogers, 2006). It has been disclosed that Africa, including South Africa, will encounter severe climate events in the future, which may impact household frailty in relation to food security and increase vulnerability to hazards.

Over the years, water resources for irrigation have increased by over 100%, accompanied by an increase in nitrogen fertiliser use of around 80%, and food availability per capita has continued to increase by more than 30% since 1961, owing to the increasing population globally (Du et al., 2014). This is because existing food systems, including manufacturing, refining, packaging, stockpiling, transportation, retail, usage, loss, as well as waste, feed the vast majority of people worldwide and provide a living for over one billion people. For instance, findings on issues and challenges relating to food insecurity and water dearth in Africa reported at a 2012 conference projected that, by 2030, as many as 250 million people in Africa will be residing in areas with severe water pressure and food scarcity, which is expected to displace 700 million of people as situations worsen and become more unpredictable (El-Ganzori et al., 2012; Foggitt, 2021). Moreover, since 2000, the number of people experiencing high water stress and food shortages in sub-Saharan Africa has increased from 531 million to 747 million (United Nations, 2017; UNESCO & UN-Water, 2020).

Many developing nations promote irrigation interventions because of droughts and floods to lower household poverty vulnerability and to promote food security. For instance, the Malawi Growth and Development Strategy promotes irrigation investments as one of the country's targets to lessen the burden of the potential effect of climate change and food insecurity and poverty (Nhamo et al., 2016; Schuenemann et al., 2018). Despite the enormous funds allocated to irrigation schemes, Malawi is still suffering from persistent food shortages and hunger because of recurring floods and droughts in the region (Shiferaw et al., 2014; Besada & Werner, 2015). Moreover, Kenya witnessed resilient expansion over the past decades, but rural infrastructure and climate change exacerbate worries about food insecurity and poverty owing to the country's 2020 short rains season assessments (United Nations, 2017; Cai & Choi, 2020). The country experienced a small amount of rainfall that resulted in poor harvests and a drastic decline in livestock conditions (Faaland et al., 2000; Peters et al., 2022). Malawi, through its Malawi Development and Growth Technique, is among the nations that has supported irrigation (Nkhata, 2014). Economically, South Africa loses 4.9% of its overall gross domestic product (GDP) on average every year because of the joint effects of floods and droughts in the region (Stats SA, 2016; Muimba-Kankolongo, 2018).

2.4.2 Effect of farm irrigation on poverty vulnerability of households and resilience

Sub-Saharan Africa region continues to attract increasing attention by scholars on the topic of household vulnerability to poverty and their resilience to poverty. Sub-Saharan Africa is considered as one of the regions in the world with the highest rate of food insecurity, with almost a quarter of its citizens of over 230 million people experiencing malnutrition (Payne, 2010; Dzanku, 2019). The 2030 Sustainable Development Goals recognised the severe repercussions of increased food poverty as requiring immediate attention. In South Africa, the contribution of farmers in terms of irrigation is low, with the total area of small-scale land under irrigation making up only about 0.1 million ha (8%) of the total irrigated area (Calzadilla et al., 2014; Cai et al., 2017). Smallholder farmers are important to South African economic growth because they have the potential to improve rural livelihoods, but farmers' involvement in various irrigation systems is suboptimal (Adetoro et al., 2022; Bjornlund et al., 2019). Many empirical research studies have shown the importance of farming practices like irrigation for lowering poverty and increasing household food security for long-term human well-being and ecosystems.

Irrigation has a significant role in supporting rural economies in the developing world to overcome the climate change-induced vulnerabilities of food insecurity, poverty and crop failure, famine, and livelihood threats (Turral et al., 2010; Hellin et al., 2012; Adeniyi, 2016). In essence, agriculture is normally dependent on the rainfed system and, when there is no rain there is no agriculture, which indicates the benefit of irrigation. Irrigation is the primary means of intensification and will remain the basis of security for food policies in the context of climate change variability and change (Awulachew et al., 2010). Studies show that small-scale irrigation is helps considerably in developing countries to enhance rural food security, increase resilience, alleviate poverty and for adaptation to climate change (Amare & Simane, 2017; Mugambiwa & Tirivangasi, 2017). Despite the importance of irrigation projects in terms of growth and investment, they are still limited in terms of objectifying their full capability, especially in a semi-arid environment like SA (Benjaminsen et al., 2006; Bahta, 2021). Many of the unbelievably poor rural households rely on crop production for a living (Vedeld et al., 2012; Francis, 2019). To alleviate poverty in the context of climate change and land degradation, food production systems have to become efficient and reduce output variability. Moreover, the declining rainfall and increasing temperatures have led to the exacerbation of drying trends, with profound effects on South African households' food security (Kew et al., 2021). Weather and climate-related events will continue to increase due to the impact of climate change as projected by global circulation models (Mechler & Bouwer, 2015; Stott et al., 2016). Consequently, changes in human existence, along with the increasing population, have led to an increase in the demand for food (Crist et al., 2017). Using sustainable food production methods that can endure extreme circumstances is linked to farmers' productivity stability, housing, infrastructure, and social networks (Barros et al., 2014; Altieri et al., 2015).

The information in Table 5 shows the effect of irrigation on households' vulnerability to poverty and the associated effects on food security to highlight the factors and forms of impacts, data sources (models, variables, and techniques) and the temporal reference utilised and any gaps in knowledge identified. The findings established in the literature used indicate the relationship between the effect of irrigation on household poverty sensitivity and the associated effects on food security. These factors include hydrological and agricultural drought hazards, floods, soil erosion, landslides and heat waves, and have had a significant effect on the household or intra-household vulnerability of communities to poverty and food insecurity. However, the results/findings vary according to place and climatic zone. According to the majority of studies, there generally is a positive link between vulnerable households and poverty, food insecurity and a number of environmental factors, including air temperature, the effect of floods, changes in land use, soil degradation, rainfall, and changes in the environment. Several studies have reported negative relationships between the effect of household vulnerability on poverty and food security status. The continuous monitoring of the effect of irrigation on household sensitivity to poverty and its effects on food security in the aftermath of climate change are serious challenges for environmental conservation and recovery policy.

Consequently, considering the empirical data that describes the importance of irrigation schemes for economic growth and investment, little attention has been paid to implementing their full potential (Fuenfschilling & Truffer, 2014). As a result, to fill the gap in the existing literature, the current research suggests a multi-level methodological framework for household vulnerability and the mitigation of poverty and food insecurity and, by extension, the need to confront the causes and effects of extreme weather conditions on food security. SDG1 (no poverty), SDG2 (zero hunger), SDG13 and SDG15 (life on land) were indicated in the context of food security and poverty to further substantiate the research outcome. Subsequently, the suggested multi-level methodological framework for household vulnerability and the mitigation of poverty and food insecurity was designed to enhance a sustainable food security system, along with poverty reduction and eradication, and support for climate action and decision-making. Furthermore, the proposed multi-level methodological framework provides information on the vulnerability of households to poverty and the associated effects on food security through a conglomerate approach to solve multifaceted risks following the crippling effects of climate change on the agricultural economy.

Table 2.5. Related studies on the impact of irrigation on household vulnerability to poverty and the associated effects on food security

S/N	Factors/Forms of impacts	Country	Data source (models, variables, and techniques)	Findings/Gaps	References
1.	Climate variability and drought	Ethiopia	Heckman's two-step model, descriptive statistics, econometrics techniques, household survey questionnaire, and focus group discussions	The findings show that the contribution of irrigation to household income has a limited role to support the sustainability of livelihood in times of prolonged drought. The model shows that the amount of household income is significantly influenced by other factors, with a positive correlation with household participation in small-scale irrigation.	Feleke et al., 2020
2.	Drought, flooding, soil infertility, diseases and pests, and insect invasion	Southern Niger	Logistic regression model, random sampling technique, field visit, and questionnaire survey involving qualitative and quantitative data	The model shows that environmental factors are significant factors influencing the odds ratio of daily household rations. Findings revealed that a gender-based imbalance exists, with a negative and significant relationship between poverty and food security and with a high poverty index among the population causing food insecurity.	Zakari et al., 2014
3.	Pest and disease invasion, environmental stresses, socio-economic and climate stresses, poverty,	South Africa	Sustainable livelihoods framework, vulnerability expected poverty (VEP) model, Stats SA General	The findings show that the household's social grant recipients are most vulnerable to food insecurity, while the majority of non-social grant recipients had up to 86% with a low vulnerability to food insecurity. The VEP model shows	Mthethwa and Wale, 2020

	drought, floods, and heatwaves		Household Survey 2018, Stata Corp LLC (version 15) and cross-sectional household data	good quality and a correlation between food security status and food insecurity vulnerability. Gender-based socio-economic imbalance in rural households' susceptibility to hunger should be addressed and reformed as a policy priority through gender empowerment interventions.	
4.	Demography, land-use change, water resource degradation and recurrent droughts	Ethiopia	Vulnerability expected poverty (VEP) approach, ordinary least squares method (OLS), cross-section data, household survey and structured questionnaire	The model shows higher performance and a good overall fit, with exposure to irrigation as one of many factors indicating a statistically significant and positive coefficient. Hence, the overall number of affected families was discovered to be higher than the number of people currently vulnerable to food insecurity. Findings show that advancement in irrigation consistently boosts productivity and reduces poverty food shortage in families.	Bogale, 2012
5.	Climate change, drought, race and gender inequalities	South Africa	Review of current literature, community survey, household questionnaires and demographic data	The findings show that the Eastern Cape province is more vulnerable to environmental factors than other provinces, with a greater vulnerability to food insecurity, owing to its demographic, health and socioeconomic profiles, and remains trapped in structural poverty.	Ngumbela et al., 2020
6.	Desertification, droughts, and water security	Nigeria	Household survey data and logistic regression model	The logistic regression model revealed a significant and positive correlation between years of study and the likelihood of adoption of irrigation technology. Hence, the	Adebayo et al., 2018

				size of the household was statically important and inversely correlated with the likelihood of using irrigation in agriculture. The findings revealed irrigation technology use has a positive and significant impact on crop production, crop revenue, and food security for households.	
7.	Drought, land degradation and climate variability	South Africa	Endogenous switching regression (ESR) model, cross-sectional data, household survey, survey questionnaire, poverty gap indicator, severity of poverty, and vulnerability to poverty	The findings show that about 45% of the households die not participate in irrigation farming, while the rest did. Hence, the income from livestock farming was statically important and had a positive impact on decision to practice irrigation farming.	Adetoro et al., 2022
8.	Prolonged food insecurity, recurrent droughts, and floods	Malawi	Household survey, endogenous switching regression model, questionnaire survey involving quantitative and qualitative questions	The results indicate that irrigation increased food security status and agricultural earnings, as well as agricultural output annually and caloric intake per person. As an outcome, both teams of irrigating farmers realised higher levels of caloric intake than farmers who did not take part in the plan, demonstrating the positive effect of irrigation on daily per capita caloric intake.	Nkhata, 2014

9.	Soil erosion, droughts and floods	South Africa	Household Food Insecurity Access Scale (HFIAS), a questionnaire survey involving quantitative and qualitative questions	The findings revealed that household food insecurity was made worse by a drop in the price of agricultural goods, a rise in the cost of agricultural inputs, and concern over the emergence of animal diseases, leading to greater reliance on government grants. Due to climate change effects, household livestock diseases had a significant negative correlation with food insecurity indicators like the HFIAS rating, food quality, and food supply.	Shisanya & Mafongoya, 2016
10.	Flash floods, water stress, food insecurity, poverty, heavy rainfall and heat stress	Pakistan	Multivariate probit model, structured questionnaire, household survey and censored least absolute deviations (CLAD) model	The findings show that there was a positive correlation between the number of adaptation practices and schooling, male working class, farm size, family size, extension services and access to credit and wealth. The model indicates significant regional effects and is consistent with a wide range of error distributions that provide the most precise policy effect estimates.	Ali & Erenstein, 2017
11.	Deforestation, floods, landslides and heat stress	Philippines	Logistic regression model, cross-sectional household survey, Family Income and Expenditure Survey (FIES), Annual Poverty Indicator Survey (APIS)	The findings show that vulnerability and poverty profiles are somewhat similar in several dimensions across classes of households; this is indicative of the change between the vulnerability and poverty profiles. An estimated 40% of the population is vulnerable to poverty. When the insecurity threshold is set to the reported levels of poverty in the	Chaudhuri & Datt, 2001

				population, the likelihood of experiencing poverty in the coming years is higher than the average risk.	
12.	Hydrological drought, climate variability	Ethiopia	Econometric models, binary logistic regression model, structured questionnaire, review of literature	The findings show that irrigation had a positive effect on crop production, usage, and income generation, which indicates an advancement in food safety. The age of farmers increased their farming experience at the 10% level of significance, and significantly and positively influences the choice make use of small-scale irrigation systems.	Jambo et al., 2021
13.	Food scarcity, poverty and climate variability	South Africa	Instrumental variable Poisson model, Household Food Insecurity Access Scale (HFIAS), questionnaire survey involving quantitative data	The results indicate that supply chain engagement significantly reduced food shortages among small-scale farmers, with 66.7% of the farmers reporting food security, 17.65% reporting only a slight level of food uncertainty, 7.84% reporting to be reasonably food insecure, and 7.84% who were vulnerable to food insecurity. The model demonstrates its suitability for determining the level of food security in households and the key variables affecting smallholder farmers.	Ndlovu et al., 2022
14	Catastrophic floods and severe droughts, water stress, food crises, trade	sub-Saharan Africa	Green revolution, Alliance for a Green Revolution in Africa (AGRA), FAO, 2012	According to the findings, food and agricultural manufacturing in Sub-Saharan Africa has increased much slower than in other developing regions since the 1990s, indicating that somewhere between 1996 and 2005, food	Sasson, 2012

	barriers, fair trade and climate variability		commitment, MDGs, trade barrier, CGIAR, 2011	production increased by 2.6%, compared to 3.3% in all developing countries. Hence, the technological improvements rely on agricultural manufacturing and agroforestry systems that incorporate improved African agriculture, insurance and access.	
15.	Floods, civil strife, frequent, poverty, drought, landslides, water scarcity and climate variability	Kenya	Agro-ecological zones model (AEZs), questionnaire survey, face-to-face interviews, cross-sectional household survey, general observations and recording	The findings show multiple negative relationships between household food crop production and the duration of drought, thus exposing the vulnerability of the area to food insecurity if drought events worsen. Food security and poverty were the major contributors to food insecurity among smallholder farmers. The agro-climatic model revealed severe drought events that often led to total crop failure, while some areas experienced flooding.	Oluoko-Odingo, 2011

2.5. A multi-level methodological framework for household vulnerability and mitigation of poverty and food insecurity

The multi-level analytical framework that has been proposed aims to assess household vulnerability to poverty and its effects on food security. This assessment is conducted by examining the extent of vulnerability that households face when dealing with unpredictable unfavourable events. The evaluation takes into account the features of household risk, as depicted in Figure 2.5. The household's coping capacity is measured through a conglomerate approach to solving multifaceted risks by mitigation of, preparedness for, response to, and recovery from natural and human-made hazards. Therefore, the multi-level methodological framework characterises the long-term dynamics of three key indicator responses for household vulnerability and impacts encompassing irrigation, poverty, and food security (Figure 2.5). The purpose of this multi-level methodological framework is to present an idea for how irrigation farming might affect a household's susceptibility to poverty and its effect on food security. This is because household vulnerability characterises the interlocking domain between irrigation, poverty, and food security, which is vital in guiding interventions that are crucial for improving the food web production and sustainable planning outcomes. Most studies have focused on household vulnerability to poverty and its effects on food security (Bogale, 2012; Sasson, 2012; Zakari et al., 2014; Mthethwa & Wale, 2020; Ngumbela et al., 2020; Jambo et al., 2021; Vera et al., 2022), with limited emphasis on the effects of irrigation on food security and poverty reduction.

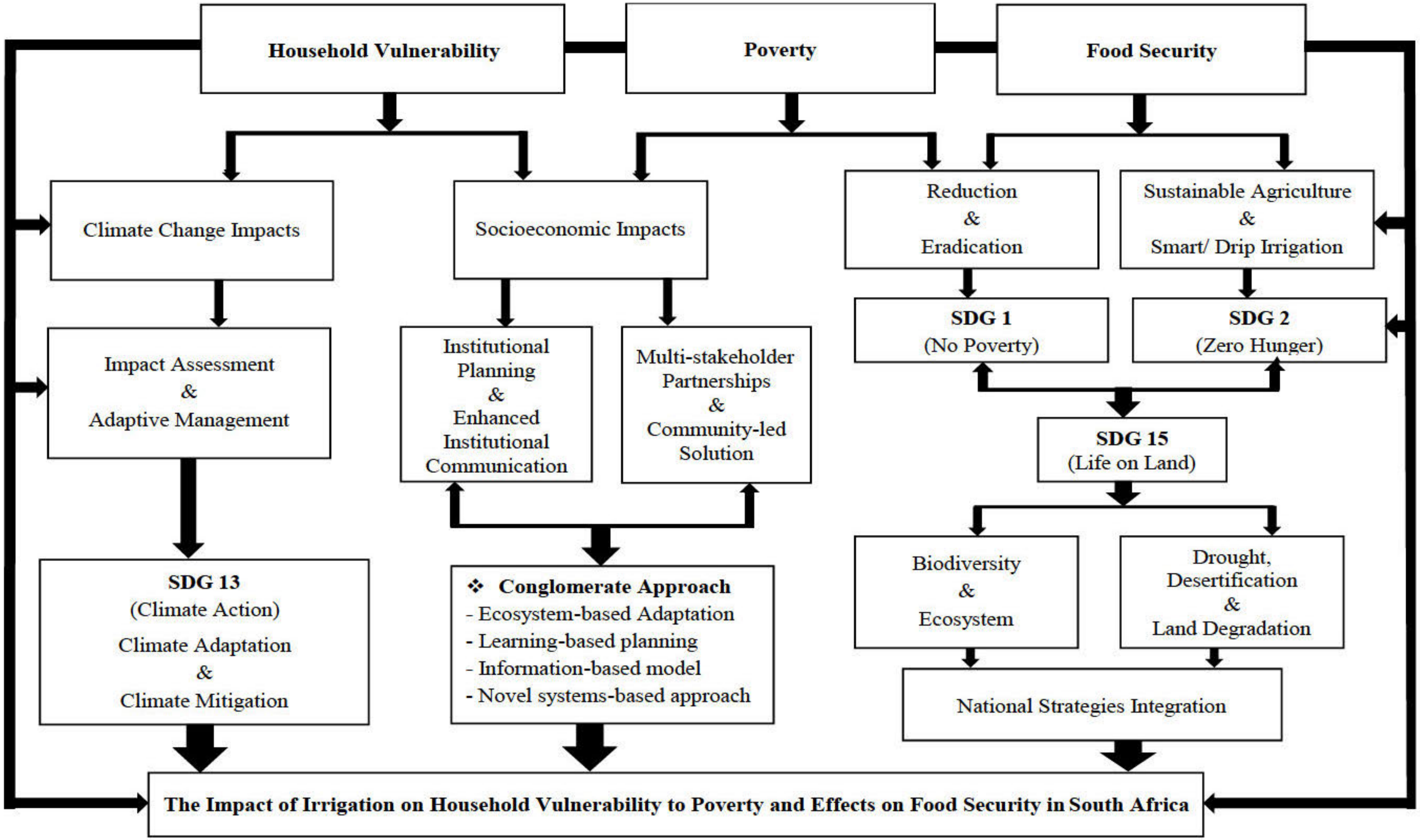

Figure 2.5. A multilevel methodological framework for reducing poverty and food insecurity and household vulnerability

This section presents the definition of the multi-level methodological framework for household vulnerability and reduction of poverty and food insecurity.

The interrelationship between the methodological framework and multiple levels of household vulnerability, the reduction of hunger and poverty and the key components are discussed as presented in Figure 2.5. Household vulnerability relates to how susceptible individuals and families are unable to handle unpredictable negative events, like heavy rain and/or flash floods and droughts, which cause major loss of crops and property damage to household farmers. The attributes of the harm and the capacity of the household to react are based on the degree of vulnerability, which, in turn, depends on the properties of the household, particularly how asset-based it is (Vatsa, 2004; Hossain & Rahman, 2021). The household vulnerabilities are complex and comprehensive throughout the hierarchy, with a high influence from the variety of all forms of effects, including climate change and socio-economic impacts (Abildtrup et al., 2006; Reidsma et al., 2010). The levels of economic development and adaptive capacity of communities to climate change vary spatially and temporally at both the global and local scales (Whitney et al., 2017; Cinner et al., 2018). Climate variability and change are exacerbating food insecurity and negatively changing farming activities, and it is particularly natural systems and agricultural systems in sub-Saharan Africa are under threat, endangering human livelihoods (Edame et al., 2011; Abegunde et al., 2019). Climate change and rising global temperatures are viewed as significant dangers to agricultural production (Qasim et al., 2018). Socio-economic impacts on household vulnerability can be determined by external factors such as land use and land cover, desertification, environmental degradation, density of population, low rates of rural funding, and the world market (Kelly et al., 2015; Vieira et al., 2020). The socio-economic impact is the consequence of human activities, which in turn limit the ability to change and adjust (Kriegler et al., 2012; Barros et al., 2014). For instance, farmers' socioeconomic factors include variables like gender, sources of income, location, heritage, and traditions, all of which influence access to irrigation and/or the capacity to pay for water and water-related privileges or services. These vulnerabilities are compounded by the socioeconomic vulnerability and factors of climate change that affect households' ability to grow food. Continuous monitoring and assessment are integral to impact assessment and the adaptive management processes of its dynamics at large scales (Cash & Moser, 2000; Zuniga-Teran et al., 2022).

Impact analysis and adaptive management are regarded as effective management techniques for food and water security in the face of climate change, ecosystem preservation and long-term sustainable livelihood which are critical socioeconomic factors (Bunch et al., 2011; Van der Voorn et al., 2012; Afuye et al., 2021). Impact assessment is an approach to measuring the social importance and efficiency of effects like programmes, policies, and practices (Edwards & Meagher, 2020). For instance, the effect of irrigation on household vulnerability to poverty and its effects on food security are found through analyses of the economic, social, and environmental effects of public policy. Household vulnerability should be integrated into the policymaking processes to identify, predict, and evaluate the environmental, social, health, and economic impacts of poverty and food insecurity. These processes present opportunities for indigenous engagement, public participation, and restoration in addressing the effect of irrigation on household vulnerability to poverty and a reduction in the face of the collapse of food security. Managing natural resources through adaptive management can lead to a reduction in risk and the making of sound decisions when faced by uncertainty in terms of the household's vulnerability to threats picked up through system monitoring (Williams & Brown, 2014). Adaptive management is a structured process that enhances the management of policies and practices by learning from the outcomes of operational programmes, including projects, policies, and practices (Edwards & Meagher, 2020; Manevska-Tasevska et al., 2021). The practice involves acting under uncertain circumstances, using the most current technology and supervision, assessing results, and re-evaluating and adjusting choices as mankind searches for a sustainable economy (Poff et al., 2016; Stupak et al., 2021). Institutional planning and enhanced institutional communication will necessitate decision-making to promote the effective implementation of efforts to reduce climate change and ensure socioeconomic adaptation, including institutional and administrative engagements. This will include multi-stakeholder partnerships and community-led solutions based on climate action, fair justice, and equity. This transition to efficient irrigation practices and climate-resistant farming will have to be supported by adapting to the changing climate.

The monitoring and evaluation of irrigation effects on household vulnerability to poverty and food insecurity require multi-integrated system approach which is essential to defend communities against the harmful effects of climate change and socioeconomic impacts (Essegbey et al., 2015). The concept of climate change mitigation and adaptation via the preservation and protection of nature's services is difficult. Governments, institutions, and societies should emphasise restoration theory and innovations, environmental protection, and multi-integrated process studies as the solution to establish climate-resilient economies. The conglomerate approach includes ecosystem-based adaptation (Wamsler et al., 2017; Guerbois et al., 2019; Busayo et al., 2022), learning-based planning (McDougall et al., 2013; Sood & Singh, 2021), information-based modelling (Sinyolo et al., 2014; Afuye et al., 2021), and the novel systems-based approach (Heckelman & Wittman, 2015; DeClerck et al., 2016), and is pivotal for ensuring household food security, and poverty reduction and eradication. As a result, the outlined approaches contributing to the effects necessitate a proactive solution in our modern time that will determine the standardisation role of farming techniques. This includes sustainable irrigation farming to reduce household vulnerability to poverty and improve food security and human livelihoods, and to promote biodiversity and sustainable land management. Ecosystem-based adaptation offers the potential for an all-inclusive, cost-effective, multifaceted and multifunctional strategy to natural resource management (Busayo et al., 2022; Kumar, 2022). EbA incorporates and promotes biodiversity, agroecosystem services as well as sustainable land management that may contribute to food security as a strategy for coping with climate change and mitigating disaster risk (Montagnini & Metzel, 2017; Busayo & Kalumba, 2021; Busayo et al., 2022). Learning-based planning (LBP) focuses on local knowledge bases that enhance institutional communication and landscape procedures with priorities and goals that are clearly defined for food security policies and poverty alleviation.

The information-based model was created to improve policy on environmental preservation and recovery to ensure natural resources management and agroecology following the crippling effects of climate change on food systems (Afuye et al., 2021). IBM provides a network for communications management details, with resilience and recovery phases for risk analysis when preparing, implementing, and evaluating effects from natural or human-induced activities to enhance sustainable planning outcomes (Afuye et al., 2021). Incorporating IBM through the novel systems-based approach, a family's susceptibility to hunger and poverty is strategic in strengthening the goals of the sustainable development agenda. The novel use of a systems-based strategy integrates natural and spatial solutions (Garcia et al., 2018; Frick, 2019), human and problem-based solutions (Munang et al., 2011; Bokelmann et al., 2015), and knowledge-based solutions (Lemma et al., 2012; Huang & Tsai, 2021), and is fundamental to addressing multiple environmental challenges. Therefore, the involvement of key policy formulation for sustainability in strengthening local and regional authorities to ensure effective food production systems and poverty alleviation is essential. As shown in Table 6, this research provides a few broad perspectives on how irrigation affects South African households' susceptibility to poverty and its impacts on food security.

Families' susceptibility to hunger and poverty is largely related to policy issues (Seaman et al., 2014). Poverty can have a negative impact on social determinants of health and can create circumstances in which people may experience unstable access to food (Friel et al., 2008; Jessiman-Perreault & McIntyre, 2017). Household poverty reduction and eradication present major components in policy on food security (Béné et al., 2016). This is due to poor households spending a large portion of their revenue on food, thereby countless poor people rely on agriculture for most of their income, leaving them prone to sharp drops in agricultural output. Consequently, food is available when individuals have physical and economic access to a consistent, secure, and highly nutritious supply that meets their nutrition requirements for living a healthy and active life (Nordin et al., 2013; Capone et al., 2014). Having access to enough food is an obligatory prerequisite for food security, with a large focus on policy based only on the accessibility issue (Jones et al., 2013). A study reported that the accessibility of abundant food is not enough for household food security in total owing to the effects of poverty, famines, or drought (Allouche, 2011). For instance, based on the analysis, food accessibility mostly hindered by the issue associated with the denial caused the colonial government in Great Bengal who prioritizes food importation (Daoud, 2018). This is associated with the most serious famines documented – including the Sahelian famines in the 1970s, when there was an ample food supply, and the Great Famine of 1941 (De Waal, 2017; Daoud, 2018). As a result, households were unable to have access to food for many reasons, even when there was enough available. One of the core principles is that there is no assurance that a free market will produce an income distribution that will allow everyone to have enough money to buy the food they require. Realising universal food security depends on the World Bank's primary mission of eradicating poverty (Jarosz, 2011; Mugambiwa & Tirivangasi, 2017). Therefore, policies should be focused on safeguarding access to healthy food, instead of focusing on food availability, which frequently increases access-related risks and makes households more susceptible to food insecurity and poverty. Sustainable agriculture and smart or drip irrigation practices for climate-resilience agriculture ensures sustainable food systems. Climate-smart agriculture provides the platforms that integrate an irrigation farming strategy with managing landscapes, including cropland, livestock, forest, and fisheries, along with the connected issues of food security, poverty, and climate change (Scherr et al., 2012; Eshete et al., 2020). Drip irrigation is one of the most efficient types of micro-irrigation and allows for the gradual introduction of water into the soil over a long period, thereby helping in higher yields from plants for higher productivity and income generation (Phogat et al., 2013 Fang et al., 2018). A growing population will struggle to keep up with demand for food as crop yields level off due to declining rainfall, increasing temperatures, deficient soil nutrients, invasive crops and pests and biodiversity loss across many parts of the globe (Altieri et al., 2015; Elias et al., 2019). These challenges are further intensified by extreme agricultural vulnerabilities to climate change.

To further support the findings of this study, SDGs 1 (no poverty), 2 (zero hunger), 13 (climate action), and 15 (life on land) are highlighted together (Figure 1). The indicator framework therefore has been established to examine issues concerning the effects of climate change, food insecurity, hunger, and ecosystem biodiversity by researchers to investigate policy gas throughout the world in order to meet up with the set target by 2030. For instance, hunger and malnutrition in Sub-Saharan Africa, including South Africa, are caused by inadequate and unsteady food stocks at the domestic or intra-domestic levels (Conceição et al., 2011). Most farmers in the rural areas cannot support their families on their meagre crop yields, which leads to poverty and food insecurity. SDG 1 was introduced to reduce all high forms of poverty, including the lack of clean drinking water, food and sanitation, which can be attributed to the threats caused by climate change (Rylander et al., 2013). SDG 2 (zero hunger) is committed to ending hunger through improved food and nutrition security, as well as promoting sustainable agriculture (Mollier et al., 2017). Moreover, SDG13 was approved to implement immediate measures to boost resilience and adaptive capacity to battle extreme climatic events and incorporate climate crisis initiatives into policy and strategies for environmental protection and sustainable human habitation (Campbell et al., 2018). More specifically, SDG 15 (life on land) aims to prevent desertification, reverse degradation, and stop the loss of biodiversity, while also preserving, restoring, and promoting the sustainable use of terrestrial ecosystems (Briassoulis, 2019). The Sustainable Development Goals are committed to preventing desertification, repairing deteriorated land and soil, including drought-affected land, and creating a world without land degradation by 2030 (United Nations, 2017). Therefore, important and urgent action is required to lower the degradation of natural and human-induced activities to combat the destruction of the ecosystem's wildlife and threatened species (Shivanna, 2020). The integration of national ecological and wildlife strategies, including planning on a local level, development procedures, poverty-alleviation methods, and natural resources, in response to the sustainable development goals is very crucial. At the local level, there should be increased capacity-building for household inhabitants to pursue sustainable livelihood opportunities to fight land erosion, habitat destruction and biodiversity loss, and to ensure the benefits of land-based ecosystems. Nevertheless, government, environmental stakeholders and relevant institutions should implement principles for environmental preservation, restoration theory, and integrated system investigations into the integration of national strategies for sustainable outcomes and evolving future research development.

The information in Table 2.6 provides indicators for household vulnerabilities and impacts on irrigation, poverty, and food security through a conglomerate approach. Climate-smart agriculture and environmental management of household vulnerabilities to risk preparedness, response and recovery are fundamentals in employing the conglomerate approach through strategy development in the social, local, and governmental spheres (Wamsler et al., 2017; Busayo & Kalumba, 2020). The preservation, sustainability and restoration of crop and livestock management are important for guarding vulnerable household societies against the extreme impacts of poverty, food insecurity and climate vagaries. Therefore, the answers that integrate the possibilities of nature services to offer household food security, poverty reduction and efficient and sustainable irrigation farming and adaptation plans are recognised as a conglomerate approach. The principle of handling and adjusting by preserving and protecting nature's services that incorporate the prospect of food security and poverty alleviation is difficult, because communities favour hard engineering programmes as the answer, thereby restraining the execution of novel conglomerate actions, particularly at the community level.

Table 2.6. Indicators of household vulnerabilities and impacts on irrigation, poverty, and food security using a conglomerate strategy

Indicators	Solutions
Irrigation management	1. Access to irrigation practices can increase yields by lowering crop failure brought on by erratic or variable rainfall. 2. Irrigation grants an opportunity for multiple cropping that can lead to an increment in yearly production. 3. In regions with minimal rain-fed crop production, irrigation enables the use of a bigger area of land for crops. 4. Innovative implementation of the theory and practice of farm management through the outcomes of operational programmes. 5. Climate-smart agriculture can provide the platforms that integrate an efficient irrigation farming approach to manage landscapes and the interlinked difficulties related to poverty, climate change, and food security.
Poverty reduction and eradication	1. Cooperation between rural livelihoods, farmers' and the planning directorate in local communities and municipalities is crucial. 2. Determine the connection, protocols, and memoranda of understanding between rural poverty-reduction strategies and NGOs with support to vulnerable household communities from the government.

	3. Innovative low-water farming techniques, like climate-smart or drip irrigation systems, can eradicate household vulnerability to poverty. 4. Using agricultural land wisely can prevent the benefits provided by our ecological systems. 5 Designing appropriate relief and development interventions can alleviate poverty.
Household food security	1. The household's calorie consumption can be viewed as an important aspect of food security in terms of yearly production, usage, and income. 2. Coping capacity and response strategies to food insecurity. 3. Mainstreaming of the conglomerate approach to food security by municipalities and local communities. 4. Small-scale irrigation has the potential to improve rural food supply while also increasing resilience, reducing poverty, and ensuring adaptation to climate change. 5. Establish the concept of prevention and adaptation to climate change using the protection and conservation of nature's services.

2.6. Conclusion

Food insecurity is a significant global issue, with more people living in poverty and at risk of it. This study explores the impact of irrigation on household vulnerability to poverty and its effects on food security using South Africa as a case study. The study used documentary analysis and bibliometric techniques to analyze relevant documents, finding that irrigation applications produced better yields and increased farm incomes, reducing rural household poverty and vulnerability to poverty.

Based on the findings from the reviewed literature, the study suggests that more sophisticated and innovative methods, such as the proposed multi-level framework, conglomerate approach, and community-led solutions, need to be developed and implemented to foster household food dynamics, food system resilience, and governance in South Africa. The conglomerate approach has become a major strategy in incorporating the long-term viability of household agriculture, offering remedies to household vulnerability to poverty and food insecurity. Techniques for mainstreaming introduced by the conglomerate approach should be put into operation at the community level to improve existing practices, institutional and inter-institutional planning, and implement strategies in the real world.

The results of this study have significant implications for provincial, national and global strategies to reduce households' food insecurity and poverty, which are crucial for assessing the effectiveness of the Sustainable Development Goals (SDG) agenda. The authorities in South Africa need to devote more time to reliable and innovative methods like the conglomerate approach, community-led solutions, landscape management strategies, and enhanced institutional communication to prevent the collapse of the nation's food systems. Planning should also focus on learning regional knowledge for sustainable farm management practices through operational programs.

Lastly, lessons from the literature suggest that household food security governance should adopt a holistic ecological model, incorporating information-based approaches and novel systems-based solutions. This must consider residents, including farmers, alongside financial regionalization for local businesses. Additionally, the national government should actively promote alternative methods to address food insecurity, poverty, and natural resource management through empowerment of the local authorities to monitor developments periodically. Finally, the scientific overview of multidimensional structures, thematic trends, and future research directions is essential for advancing our knowledge in this field.

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CHAPTER THREE

EFFECT OF IRRIGATION FARMING INVOLVEMENT ON FOOD SECURITY AMONG RURAL HOUSEHOLD FARMERS: EMPIRICAL EVIDENCE FROM SOUTH AFRICA

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Abstract

The deteriorating welfare of rural household farmers is a matter of worry that necessitates prompt intervention. This situation has the potential to result in many adverse consequences for the food security status of these households. Nevertheless, there has been limited studies on the significance of engaging rural farming households in irrigation farming as a strategy to address the issue of food insecurity, particularly in the most impoverished regions of South Africa. This study investigates the factors that influence rural farmers' participation in irrigation farming and its impact on household food security. The study employed an endogenous treatment effect with ordered outcome model, and used Household Food Insecurity Access Scale approach to analyze the data extracted from the South African Vulnerability Assessment Committee (SAVAC) datasets to achieve the study objectives. The empirical results showed that rural households' food insecurity has a greater likelihood to reduce when they are involved in irrigation farming as this increases their productivity and access to food, particularly in the event of extreme weather-related shock such as drought. The findings also showed that household gender, size of household, unemployment status, market outlet, remittances and crop diversification (CDV) increase the likelihood of the rural farmers' participation in irrigation farming as well as reduce their food insecurity. Based on the findings of this study, we suggest a review of the government intervention policies, and a restructuring of rural operations to include more technological innovations such as advanced irrigation systems.

Keywords: food insecurity; irrigation farming, extended ordered probit regression

3.1. Introduction

Food security refers to the state in which individuals have consistent and unrestricted physical, social, and economic means to obtain a sufficient quantity of food that is both safe and nutritious, thereby fulfilling their dietary requirements and preferences, and enabling them to lead an active and healthy lifestyle. (FAO, 2017). It necessitates addressing the four key factors of food supply, access, use, and stability. Food security is crucial and shouldn't be compromised even during sudden shocks like economic crises since food stability aims to protect the four dimensions of food over time (Sinyolo & Mudhara, 2018). It is judged that food insecurity has occurred when one or more of these factors are ignored, leaving people without regular access to a sufficient amount of food that is both affordable and nutritious (Mazenda et al., 2022; Mudzielwana et al., 2022).

Millions of individuals around the globe struggle with food insecurity, especially those in developing nations (Nengovhela et al., 2022). Global hunger under the influence of the ravaging COVID-19 pandemic resulted in a spike, reaching about 9.9 per cent (FAO, 2020). Food insecurity predominantly affects populations in developing countries evidenced most in Africa and South Asia; however, this issue has global implications (Roser & Ritchie, 2019). On a daily basis, a substantial 830 million individuals globally experience hunger (Wudil et al., 2022). The prevalence of acute food insecurity has significantly increased from 135 million in 2019 to 345 million in 2022 as a direct consequence of the COVID-19 pandemic and the ongoing conflict in Ukraine (UNICEF, 2021). Food insecurity has been a subject of concern for many nations, especially within the rural communities' post Covid-19 pandemic. Globally, the pandemic incidence has affected the standard of livelihood caused by a shortage of food and disruption of the supply chain particularly in developing countries where rural households depend on agriculture production and seasonal jobs (Rahaman et al., 2021).

A household is said to be in a state of food security if all of its members have access to the food they need to survive and maintain a healthy lifestyle. This includes the capacity to obtain enough food by either producing or buying food for all household members (FAO, 2010). In this regard, food insecurity at the household level is posing a problem in South Africa since the majority of households experience a rise in food insecurity (Akinboade et al., 2016). Food insecurity in South Africa is attributed to various factors, including drought and other weather-related shocks (Southern African Development Community [SADC], 2019; Adetoro et al., 2022). As per the report by the African Union Commission (2020), the leading factors contributing to food insecurity in South Africa were economic contractions, recessions, and climatic disturbances. According to the World Bank (2022), there has been a notable rise in the incidence of food insecurity, with figures increasing from 17.5% to 18.2% in 2018 and 2019, respectively. This shows the susceptibility of most South African households and individuals to shocks-related food insecurity. This number is expected to increase as a result of numerous factors, including population growth, climate change, and economic instability. In addressing the issue of food insecurity, the use of irrigation farming has been well documented as a viable approach to enhance agricultural output, particularly in regions characterised by a semi-arid climate (Adetoro et al., 2020; Ogundeji, 2022).

Smallholder and commercial farming serve as the mainstays of South Africa's primary agricultural productivity and food security. Smallholder farmers utilise the most cultivable land in the southern African region (Livingston, Schonberger, & Sara, 2011). The agriculture sector's heavy dependence on rainfall renders it susceptible to the adverse effects of climate variability and change. Maleksaeidi and Karami (2013) suggested that the gradual decline of the viability and sustainability of rainfed cropping systems is a result of the increasing uncertainty in water availability. As a result, the productivity-boosting nature of irrigation farming has received interesting attention from many authors in the literature (You et al., 2014; Xie et al., 2014; Adetoro et al, 2020; Adetoro et. al, 2022).

In areas with insufficient or unpredictable rainfall, irrigation farming has been identified as a critical strategy for boosting food production and guaranteeing food security (Mhembwe et al., 2019). Irrigation farming is a major source of food production in many developing nations and supports millions of people's livelihoods. In regions with dry seasons, it increases the yields of particular crops and lengthens the effective crop-growing season, enabling multiple cropping (two or more crops per year) when just a single crop would otherwise be possible. The security that irrigation provides makes it economically feasible to add additional inputs (such as pest management, fertilizers, improved varieties, and better tillage) that are required to enhance productivity even further (Zhang et al., 2021).

Several literature sources (Adetoro et al., 2020; Christian, et al., 2019; Mhembwe et al., 2019) have documented that engagement in irrigation farming can potentially generate novel employment prospects, both within and outside the agricultural sector, and enhance rural incomes, food security, and poverty reduction, by enhancing farm productivity. Apart from the increase in food production brought about by the use of irrigation in farming techniques, irrigation farming also contributes some spillover effects to the overall contribution of Agricultural sector to the economic stability of developing countries such as in South Africa. The importance of this irrigation effects is evident through the assistance provided by South Africa's agricultural sector to increase farmers participation in irrigation farming (Devereux & Tavener-Smith, 2019). The government wants to encourage and improve small-scale irrigation in order to boost economic growth, create jobs, and decrease poverty. However, the number of South African farmers who experience food insecurity is on the rise (Mudzielwana et al., 2022). The question is whether the households' food insecurity situation is justified or aided by irrigation farming. At the level of farming production, many farmers' top priority continues to be food security. Investigating rural households' involvement in irrigation farming as an adaptability strategy to end food insecurity is crucial for this study.

This research offers novel perspectives on the effects of irrigation agriculture on rural household farmers in South Africa. The study's results have the potential to enhance the current knowledge base regarding the impact of irrigation farming on enhancing agricultural productivity, food security, and income levels among rural households. The study will provide policy implications for various stakeholders, including governments, development agencies, and others, who are involved in promoting food security and rural development in South Africa.

3.2. Methods

3.2.1 Household food security measurement approach

The phrase "food security" refers to having enough food to maintain an active and healthy lifestyle (Cafiero et al., 2018). One of the most important aspects of well-being is the ability of households and individuals to access food, but measuring this aspect is extremely challenging. For the sake of global food security, regardless of how difficult it may be to access food, it remains important to ensure that everyone can obtain enough food to sustain each individual or household. The state of households' food security is assessed using a variety of metrics. These include the household coping strategy index (HCSI), the household hunger scale (HHS), the household food insecurity and access scale (HFIAS), the food consumption score (FCS), the household dietary diversity score (HDDS), and the household coping strategy index (FCS). The Household Food Insecurity Access Scale (HFIAS) is a tool that uses a survey to measure food access at the household level. It is designed to assess the prevalence of household food insecurity and to detect changes in the food insecurity situation of a population over time. The HFIAS is based on the idea that the experience of food insecurity causes predictable reactions and responses that can be captured and quantified through a survey and summarized in a scale. The HFIAS is composed of a set of nine questions. Each question is posed with a 30-day recall period. The respondent is initially queried with an occurrence question, specifically inquiring whether the condition mentioned in the inquiry occurred within the preceding four weeks (answered with either a yes or no response). If the respondent affirms the occurrence of a condition, a frequency-of-occurrence question is posed to ascertain if the condition happened infrequently (once or twice), occasionally (three to ten times), or frequently (more than ten times) within the past four weeks. The highest possible score for a household is 27, which occurs when the household answers "often" to all nine frequency-of-occurrence questions (coded as 3). On the other hand, the lowest possible score is 0, which happens when the household responds "no" to all occurrence questions and the frequency-of-occurrence questions are skipped by the interviewer and coded as 0. As the score increases, the household's experience of food insecurity (access) also increases. A household's level of food insecurity (access) decreases as their score decreases. According to Coates et al. (2007) in the FANTA project, the continuous HFIAS variable can be categorized into four food insecurity levels: Food security, mildly food insecurity, moderate food insecurity and severe food insecurity. However, the study modified the categorization into three namely, food security to mild food insecurity, moderate food insecurity and severely food insecurity. The HFIAS has been utilized in various nations and demonstrates the ability to differentiate between households that are food insecure and those who are food secure, regardless of cultural differences (Coates et al., 2007).

For instance, according to Salman et al. (2023), HFIAS yielded important information on food security at household level. The information generated by the HFIAS can be used to measure the impact of food security programs on the access component of household food insecurity. The study following the validity report of Kolog et al. (2023) who compared HFIAS and Household Hunger Scale (HHS) and found that both HFIAS and HHS techniques produces reliable results of household food security, which also depends on the construct of each approach. According to the report of Maxwell et al. (2012), no food security proxy is able to record all of the various sections of food security, although a detailed indicator of food security is valid, reliable, and comparable across time and space (Maxwell and Coates, 2013). In order to assess the level of food security in households within the study region, this study uses the HFIAS as a food security indicator. The HFIAS is based on a brief questionnaire that, like some other experience-based metrics, measures the habits and psychological effects of insecure food access, such as having to reduce the number of meals consumed or lower the quality of the food due to a shortage of resources. The purpose of using the HFIAS approach is because the metric is distinctive when it comes to analysing food insecurity because it may uncover both the physiological and psychological components of food insecurity, which can harm health and well-being.

3.2.2 Empirical specifications and analytical approach

The estimate of the impacts of irrigated farming on the levels of food insecurity necessitates the use of econometric models that go beyond binary models. Impact assessment models, which employ non-observational or non-experimental data, are necessary for the study (Mabe, Mumuni, & Sulemana, 2021). The issue one is likely to encounter with such data is sample selection bias (Heckman, 1967). The problem of sample selection bias needs to be addressed so that innate traits do not give certain households a special privilege over others regarding food security, regardless of whether they engage in irrigated farming. When examining irrigated farming's effect on food insecurity, it is also vital to consider the likelihood that it is endogenous (Ogundeji, 2022). According to Wooldridge (2010), measurement errors, reverse causality (simultaneity bias), and missing variables are all possible sources of endogeneity.

Many approaches, including propensity score matching (PSM), Heckman sample correction, generalized propensity score (GPS) matching in continuous treatment framework, and endogenous switching regression model, can be used to address sample selection and endogeneity issues (Asfaw, Battistab, & Lipper, 2016; Gregory, 2015; Wooldridge 2008; Hirano & Imbens, 2004). The aforementioned models are effective for outcome variables that are not in a specific sequence. This study applied the endogenous treatment effect model with an ordered outcome variable (in the case of this study, food security, moderate food insecurity and severe food insecurity), as described in Gregory (2015).

This approach is predicated on the idea that the factors affecting the ordered result are distinct between the treated and untreated groups. Gregory (2015) stated that the selection equation, or treatment model, assessing the factors influencing the use of irrigated farming, is as follows:

$$IRF_i = \begin{cases} 1 \ if \ IRF_i^* = Z_i \hbar + \nu_i > 0 \\ 0 \ if \ IRF_i^* = Z_i \hbar + \nu_i \leq 0 \end{cases} \qquad (1)$$

In equation (1) IRF_i = Irrigation farming (for households that are involved in irrigation farming is 1 and 0 otherwise); Z_i = vector of explanatory variables and $\hbar$ is estimated parameters. v_i = error term for the ith household.

The treatment-effects model assumes that there is one regime for the outcome. In this model, the outcome variable (food security/insecurity categories) could be explained by the ordered discrete format and equation (2) can be specified as:

$$Y_i = \begin{cases} 1 & if -\infty < X_i\beta + \varepsilon_i \leq \psi_1 \\ 2 & if \psi_i < X_i\beta + \varepsilon_i \leq \psi_2 \\ 3 & if \psi_i < X_i\beta + \varepsilon_i \leq \psi_3 \\ & \cdots \\ K-1 & if \psi_{K-1} < X_i\beta + \varepsilon_i \leq \psi_K \\ K & if \psi_K < X_i\beta + \varepsilon_i \leq \infty \end{cases} \quad (2)$$

where ψ 1, ψ 2, . . ., ψ *k* denote cut parameters to be estimated, k = 1, 2, 3 represent thefood insecurity categories, and *Yi* is the latent food security variable for the *i*th household. *Xi* is an independent variable explaining variation in household food insecurity status and β is a parameter to be estimated. ε_i is the error term for the outcome equations.

Water right and water security were employed as an instrument for the treatment variable (IRF) in Equation (1) in addition to the vector of explanatory factors. The underlying principle is that while farmers' access to water and security has no direct effect on food insecurity, they can directly impact farmers' decisions to participate in IRF. Water rights and water security were thus considered in the IRF equation but not in the calculation for the outcome of food insecurity. As previously noted, we employed a treatment estimator with ordered outcomes. In this instance, any joint normality violations in the error terms, vi and ui, created by a factor structure in the treatment and outcome equations, are handled using a latent factor framework (Mabe, et al., 2021). The underlying principle of this approach is that the factors affecting the ordered outcome are different for the treated and untreated groups. However, if this fundamental presumption is not totally true, it may lead to estimations that are inconsistent. To overcome this, Halton-based sequences, as proposed by (Jaworowaska et al., 2013) and taken from the distributions of latent components, were utilized (factors that are unobserved but affect the involvement in irrigation farming and food insecurity levels). According to Deb, & Trivedi (2006), the benefits of Halton sequences include the distribution domain, a decrease in variances, and a decrease in processing time. Using the likelihood simulation approaches, the estimators of the two Equations (1) and (2) were estimated.

3.2.3 Marginal effects: Average treatment effect on the treated and untreated (ATT and ATE)

The effect of the treatment (irrigation) on the outcome variable (food insecurity) was quantified in terms of its impact. The average treatment effect in this study compares the effect of adopting irrigation to the effect of not adopting it on the levels of food insecurity for randomly chosen household heads in the study region. The average treatment effects on the household (ATE), which indicate the difference in the response variable of the household with and without treatment, were estimated, as they were found in many impact evaluation studies (Mabe et al., 2021; Ogundeji, 2022).

Following Gregory (2015), the ATE specification with a treatment-effect ordered probit structure can be given as:

$$ATE_J^T = \frac{1}{N}\frac{I}{S}\sum_{i=1}^{N}\sum_{s=1}^{S}[\phi\{\mu_k-(X_i\beta+\delta+\lambda\eta_{is})\}-\phi\{\mu_{k-1}-(X_i\beta+\delta+\lambda\eta_{is})\}] \\ -[\phi\{\mu_k-(X_i\beta+\lambda\eta_{is})\}-\phi\{\mu_{k-1}-(X_i\beta+\lambda\eta_{is})\}] \tag{3}$$

The treatment of the households that utilise irrigation refers to the average effect of treatment on the treated (ATT) parameter. Hence, ATT estimates the variation in the response variable (outcomes related to food insecurity) between the treated group (applied irrigation) with treatment and without treatment. This can be specified as:

$$ATT_J^T = \frac{1}{N}\frac{I}{S}\sum_{i=1}^{N}\frac{1}{E\{\phi(Z_i\gamma)\}}\begin{pmatrix}\sum_{s=1}^{S}\phi(Z_i\gamma+\eta_{is})\chi[\phi\{\mu_j-(X_i\beta+\delta+\lambda\eta_{is})\}-\phi\{\mu_{j-1}-(X_i\beta+\delta+\lambda\eta_{is})\}\\ -\phi\{\mu_j-(X_i\beta+\lambda\eta_{is})\}+\phi\{\mu_{j-1}-(X_i\beta+\lambda\eta_{is})\}]\end{pmatrix} \tag{4}$$

Given that δ is the coefficient of the endogenous treatment dummy variable, S is the simulation draws, γ is the loading factor, Φ is the standard normal cumulative distribution, k = 1, 2, 3 and K = J + 1 and J are the number of choices (three as in this study), and *N* is the number of observations.

3.2.4 Description of the study area and data collection techniques

This section describes the characteristics of the study area, much of which has been documented in the previous study (see Adetoro et al., 2022). The local municipalities in the Mthatha River basin in the province of Eastern Cape, represented by the King Sabata Dalinyebo and Nyandeni local municipalities (part of the OR Tambo District Municipality), were the subject of this study (Figure 3.1). The district is essentially rural, has a low level of education, and is primarily an agriculturally productive area. The Mthatha River serves the population of the catchment area with drinking water and water for irrigation. A total area of 5 520 km^3 makes up the catchment of the Mthatha River, which is roughly 100 km long and 50 km wide. North of Coffee Bay (Mankosi settlement) flows the 250 km long Mthatha River, which has two significant tributaries. These areas fall within the Comprehensive Rural Development Programme (CRDP) locations and were selected purposely for this study because they are situated in the centre of rural area, where historical poverty have been reported previously in the post-apartheid era.

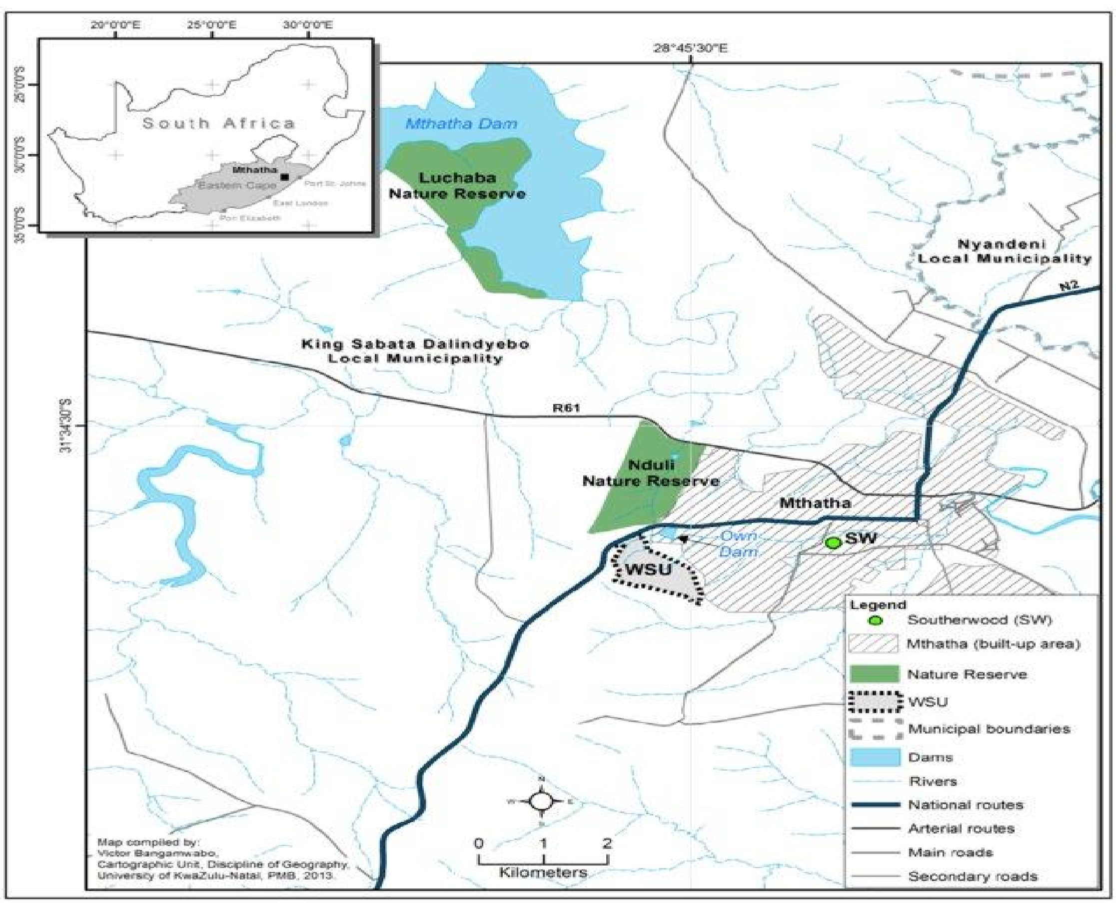

Figure 3.1. Map of the study area showing the geographical features of the area

The data for this study was obtained from SAVAC datasets. The data collection method used was a multistage sampling strategy. According to the location of the source of the Mthatha River, the basin was divided into four sections using a purposive sampling technique. These are the coastal region, the lower region, the peri-township region, and the upper region. Data were collected from ten randomly selected villages from each area, and 11 respondents representing each village were randomly selected based on the relevance of the current study to the survey. A total of 400 data outcomes were selected for analysis, which were deemed credible for this empirical study and followed the outcome of the pretesting of the survey dataset. The main purpose of this study was to gain holistic insight into the livelihood settings and the level of food insecurity in Eastern Cape, South Africa. This current study focuses on evaluating how irrigation farming involvement by rural farmers in Eastern Cape affects the food security status of rural farmers.

3.3 Results and discussion

3.3.1 Household descriptive statistics

This section describes the socioeconomic characteristics of the households in the study area.

The gender variable depicts that male represent 0.70 while the female respondents represent 0.65. The rural household farmers size who was involved in irrigation farming constitute 3.1 while those not involved represent 3.3. The mean age for the rural farmers age was 46 (Irrigation involved) and 45 (Non-involved in irrigation farming) years, representing the expected age range for the agile farmers who are known as a working group. Farmers who experienced flooding in their farm due to irrigation involvement equals 35% while non-involved farmers were 25%. Remittances were higher for farmers who engaged in irrigation farming (0.27) while it was 0.15 for non-involved farmers. Access to a wider market outlet was higher for farmers involved in irrigation farming while it was 2.73 for non-involved farmers. As expected, irrigating farmers who owned had higher mean value compared to the mean for non-involved farmers which was 0.086.

The result shows that a greater percentage of the rural farmers had water rights (about 51%) while 31% had water security, indicating their rationale to be involved in irrigation farming. The treatment variable selection is explained in Equation 1. According to Sinyolo et al. (2014), water security means the ability to access adequate and reliable water by irrigating households to achieve agricultural productivity objectives. Water right on the other hand, refers to control and guaranteed access to sufficient water use by the rural households for agricultural production (Kemerink et al., 2011). Due to the historical background of water rights and security following post-Apartheid era in South Africa, these two variables were considered important factors especially for the rural households (Kemerink et al., 2011). The inclusion of crop diversification, market outlet, land variables in our model recounts its importance in ensuring a comprehensive understanding of the association between variables in our analysis of irrigation participation impact on food security. Crop diversification can help stabilize productivity of cropping systems and reduce negative environmental impacts and loss of biodiversity. Marke outlet variables can help to identify factors that determines the demand for agricultural products and the cost for the products (Hufnagel et al., 2020; Rodriguez et al., 2021). For land, the type of land ownership was captured as a binary response, to understand how land ownership whether rented or other types could determine irrigation participation by the rural households. The focus was not to capture the land size but how the ownership influences the decision to participate in irrigation farming. The land variables can help to identify the factors that influence the availability of land for irrigation and agricultural production (Ijaz et al., 2019).

Table 3.1. Household descriptive statistics

Variables	Description	Involved (n=180)	Noninvolved (n=220)	Mean difference
Severe food insecurity	Yes =1; otherwise 0	0.560	0.116	-0.444
Moderate food insecurity	Yes=1' otherwise 0	0.196	0.218	-0.022
Food secure to mildly food insecure	Yes=1; otherwise 0	0.757	0.662	0.094
Age	Age of household head (years)	45.740	44.950	0.794***
Gender	1 if household head is male, 0 if female	0.697	0.651	0.046**
Household size	Number of persons living in the household	3.156	3.368	-0.213***
Unemployment	1 if the household is unemployed, 0 otherwise	0.350	0.250	0.100***
Adequate water supply	1 if households have access; otherwise 0			
Livestock holding	1 if income was generated from livestock sales, 0 otherwise.	0.756	0.714	-0.042**
Water right	1 if households have rights to water; 0 otherwise.	0.51	0.24	0.27
Water security	1 if households have water security; 0 if otherwise.	0.31	0.35	-0.040
Full-time farming	1 if the households engage in full-time farming; 0 if otherwise.	0.67	0.33	0.34
Education Expenses	1 if the household spends on education, 0 otherwise	0.878	0.886	0.009**
Remittances	1 if the household received remittances, 0 otherwise	0.272	0.15	-0.122*
Nonfarm activity	1 if the household engaged in other nonfarm activity, 0 otherwise	0.414	0.414	

Engage in seasonal farming	1 if the households practice seasonal farming, 0 if otherwise	0.606	0.505	0.101**
Market outlet	1 if the household has access to various market outlets, 0 otherwise	3.183	2.773	0.411**
Crop diversification	The number of different food crop types cultivated by the households.	5.339	5.005	0.334**
Education (years)	Years of education of household head	6.480	5.701	0.779***
Rented land	1 if the household rented land for farming, 0 otherwise	0.289	0.241	-0.048***
Owned land	1 if the household owns the land for farming through inheritance, 0 otherwise	0.094	0.086	0.008***
Communal land	1 if household farm on communal land, 0 otherwise	0.033	0.114	0.081*
Access to the credit facility	1 if households have access, 0 if otherwise	0.536	0.129	0.410
Leased land	1 if the household use leased land for farming, 0 otherwise	0.089	0.041	0.048***
Farm-based organization	1 if the household belongs to a farm organization, 0 otherwise	1.967	2.045	-0.079***
Treatment variable				
Water right	1 if households have rights to water; 0 otherwise.	0.51	0.24	0.38
Water security	1 if households have water security; 0 if otherwise.	0.31	0.35	

3.3.2 Determinants of households' involvement in irrigation farming and households' food insecurity

The results in Table 3.2 present the estimates of the probit regression analysis, showing the significant variables that determine irrigation farming. The likelihood ratio (LR) chi-square statistics, the probability of the chi-square, and the pseudo-R-square values reported in Table 3.2 indicate that the model specification reasonably fits the data.

Table 3.2. Determinants of households' involvement in irrigation farming, a probit regression analysis

Irrigation	Coef.	Std. Err.	P-value
Age	-0.0042	0.0064	0.508
Gender	0.8677	0.1966	0.000***
Household size	-0.2210	0.0601	0.000***
Unemployment	-0.9197	0.3153	0.004***
Adequate water supply	-0.1402	0.0632	0.027**
Livestock holding	-0.5058	0.2128	0.017**
Water rights	0.3047	0.1005	0.002***
Water security	0.1823	0.0739	0.014**
Full-time farming	-0.0287	0.1836	0.876
Education expenses	-0.2336	0.2867	0.415
Remittances	0.7413	0.2068	0.000***
Non-farm activity	0.0314	0.1769	0.859
Seasonal farming	0.9949	0.2033	0.000***

Market outlet	0.2907	0.0603	0.000***
CDV	0.2471	0.0768	0.001***
Farming on rented land	-0.0276	0.1871	0.883
Farming on inherited land	0.3299	0.2725	0.226
Farming on borrowed land	-0.1876	0.2666	0.482
Farming on communal land	-1.0077	0.3467	0.004***
Farming on leased land	0.6764	0.3180	0.033**
Access to road	-0.0285	0.1267	0.822
Extension contact	0.5602	0.2061	0.007***
Government support	0.3146	0.1986	0.113
Access to the credit facility	0.4367	0.2207	0.048**
Farmer-based organisation	-0.9948	0.2036	0.000***
Number of observations = 400			
Prob > chi^2 = 0.0000			
Pseudo R^2 = 0.2526			
Log likelihood = -205.72155			

*** = $p < 0.01$, ** = $p < 0.05$.

The gender variable exhibits a positive correlation with participation in irrigation farming. One possible explanation for this relationship is that female farmers may exhibit a reluctance to adopt new innovations and improved irrigation technologies, while male farmers tend to be more adaptable and enthusiastic about implementing irrigation tools in order to enhance farm productivity. The estimated coefficient for household size is negative and statistically significant for the probability of participation in irrigation farming. The partial effect of a unit increases in household size on the probability of participating in irrigation farming is – 0.2210, which suggests that participation in irrigation farming decreases by around 22% with an additional individual in the household. The reason for this could be ascribed to the fact that larger households often spend more on household consumptions rather than invest on farming practices like irrigation tools thus making the probability of participation in irrigation agriculture very low. This result is consistent with that of Oluwatusin et al. (2020).

The variable unemployment of households was significant and negatively affected the probability of irrigation involvement. The case of extensive unemployment limits the financial capacity of households to invest in irrigation tools, hence reducing the likelihood of being involved in irrigation farming. This in turn negatively translates to food insecurities of households in the rural areas of South Africa. The result is consistent with that of Altman and Ngandu (2010), who explained the role played by extensive unemployment as well as low wage levels of households which contribute to food insecurity in South Africa. In addition, the high unemployment levels in South Africa expose households to a battle to achieve food security, hence confirming the negative influence of unemployment on the propensity to households' involvement in irrigation farming (Ngema et al., 2018).

The livestock holding variable shows a negative and significant influence on households' involvement in irrigation farming as a means to eliminate food insecurity. This result implies that there is a lesser likelihood for households with more livestock to be involved in irrigation farming because the livestock business provides a substantial profit for households which serves the same purpose of reducing food the problem of food insecurity. In line with the results of this study, Regassa (2015), and Mekore and Yaekob (2018) also found that a household with livestock could have less probability to be involved in irrigation farming. Contrary to the finding of this study, Anteneh (2016) examined the influence of small-scale irrigation schemes on household income in Ethiopia and reported that livestock holding significantly and positively determined rural farmers' involvement in irrigation practice.

The empirical result shows that farmers who have water rights have a positive impact on farmer's probability of being involved in irrigation farming. A farmer's water right, often obtained by paying a fee for water consumption, indicates that farmers who pay a premium could have a secured water supply to carry out their irrigation practices. The study of Zhang et al. (2013) emphasized that in China, the water usage fee is significantly associated with water distribution services which in turn impact the irrigation of the farm as well as farm productivity of the water users. Our empirical results further reveal that timely water supply, adequate water availability and water availability at critical stages of rice production exert positive impacts on yields.

Similarly, the right obtained from being a member of the water association is positive and statistically significant, indicating that rural farmers who have sufficient knowledge about water allocation and understanding of the decision made regarding water have an increased probability of being involved in irrigation farming. According to Fan et al. (2018), farmers' water rights are linked to their involvement in water associations which enhanced farmers' insights from a water user point of view and determine their involvement in irrigation farming.

The estimated water security variable revealed a positive and statistical association with irrigation involvement, as having secured water sources influences the decision to practice irrigation farming. This is particularly linked to the fact that farmers with water security are more likely to be motivated to be involved in irrigation farming, particularly owing to the possibility of an increase in farm yields and productivity, therefore, improving the food security of their households. This is contrary to the study of Sharaunga and Mudhara (2018) who found that farmers who are faced with limited water sources are more likely to participate in irrigation farming. This study suggests that resource adequacy may influence user participation, especially if it reduces the food insecurity of rural farming households.

The positive value and significant impact of variable Seasonal farming show the importance of irrigation to achieving improved farming production, especially during the dry season. This is particularly important in shaping the decision of rural farmers to be involved in irrigation practice. This is correlated with the study of Ndlovu et al. (2022) who found that access to irrigation enabled farmers to grow crops in more than one season and that improved their food security status because of increased production, income, and consumption.

The market outlet variable is positive and statistically significant in determining irrigation farming involvement by rural households. It is expected that when there are numerous marketing opportunities to carry out farm sales of products, it could influence decisions to invest in products or strategies that could improve farm production such as irrigation practices. In an event where there is a lack of market outlets, farmers tend to self-consume farm products, leading to low earnings and a lack of financial capacity to invest in irrigation facilities. Similar to the findings of this study, the study of Yaméogo et al. (2022) emphasized that inadequate market outlets not only result in the self-consumption of farm products, but it also limits the financial resources of farmers to reinvest in their farm production.

CDV is statistically significant and shows a positive impact towards the irrigation involvement of rural household farmers. Irrigation adoption motivates farmers to practice multiple crop production which helps to increase yield and improve their food security regardless of the season. The practice of crop diversification is also identified in the literature as a coping strategy against weather instability and price shocks, especially among rural farm households whose main economic activity is agriculture. The result agrees with the study of Mofya-Mukuka and Hichaambwa (2018) who found a positive association between CDV and irrigation, as it helps rural farmers to cultivate a variety of crops throughout the year regardless of the seasonal change.

Farming on communal land shows a negative correlation to involvement in irrigation farming in the study area. This could be attributed to the nature of communal land, being a piece of land controlled by a group of people or farmers, hence making it difficult to make a sole decision on how to operate on the land. This type of land tenure system is critical in determining the decision-making of the farmers. The negative association of land tenure systems such as the communal land being used to farm has been reported to shape farmers' long-term investment in irrigation infrastructure decisions owing to property rights and insecurity factors (Meinzen-Dick, 2014).

Contrary to the result of communal land, the variable farming on leased land shows a positive association with involvement in irrigation farming. This implies that farmers who farm on land leased to them could obtain the right to carry out an irrigated farming system with the intention of increasing productivity and sales, which could enhance the ability of the farmers not only to reduce food insecurity but also increases the potentials of paying for the land charges. This is in cognizance with the study of Ndlovu et al. (2022) who found that farmers with leased land have an increased household income and as a result, have more access to food.

The extension contact variable positively and significantly influences the choice of farmers to practice irrigation farming in the study area. This result indicates that farmers in the study area have a higher probability of accessing agricultural extension services. Agricultural production based on an irrigation system sometimes requires experts' guidance and advice on the relevant irrigation settings as well as the irrigation schedule necessary to increase farm productivity and increase households' food security. This is consistent with the study of Awotide et al. (2016) who found that frequent contact with extension officers increases rice yields in Nigeria, as a result of an increase in irrigation practice, highlighting that an increase in farm yields plays a significant role in farmers' household food security.

Access to credit facilities is statistically significant at a 5% level, which shows a positive influence on farmers' involvement in irrigation practice as a means to eliminate food insecurity. This implies that farmers who have access to credit are in a better position to cultivate with the aid of irrigation and in turn, are empowered to be food secured. Credit is essential to purchasing irrigation tools which are necessary to achieve the desired farm productivity outcome. Farmers with a lack of credit have been reported to be faced with a key impediment towards being involved in irrigation practice and as such, face consequences of being food insecure (Tesfaye et al., 2021).

The results show that farmers who are members of farm-based organizations (FBOs) have a lower probability of being involved in irrigation practice and hence risk the consequences of food insecurity. The decreasing probability of farmers' participation in irrigation farming could be attributed to their access to several other options for eliminating food insecurity in their household, with a large possibility of getting motivated to engage in some off-farm activities for additional income (Danso-Abbeam et al., 2020).

3.3.3 Determinants of rural household food insecurity

The results in Table 3.3 present the factors that influence the food security status of rural households in relation to rural household farmers' involvement in irrigation farming. The significant variables are discussed in the order of farmers' involvement and non-involvement in irrigation farming, with their influence on household food insecurity. The empirical results indicate a positive and statistical association between household age and food security in the study area. Farmers' age plays an important role in identifying and understanding the means to reduce the likelihood of food insecurity, through the utilization of farming experience to increase farming outputs. Farmers who are involved in irrigation are more likely to improve their food security status while those who are not involved in irrigation have a lower chance of reducing their food insecurity status.

Table 3.3. Factors influencing food insecurity: An extended ordered probit regression

Variables	Coefficient		Standard Error		P-Value	
	IRR-IV	**IRR-N**	**IRR-IV**	**IRR-N**	**IRR-IV**	**IRR-N**
Household Head age	0.0333	-0.0137	0.0077	0.011	0.003***	0.074*
Gender	-0.7206	-0.3308	0.2996	0.2493	0.016**	0.185
Household size	0.2185	0.1345	0.0862	0.0795	0.011**	0.091*
Unemployed	0.3030	0.1525	0.5135	0.3113	0.555	0.624
Adequate water supply	-0.0256	-0.0567	0.0908	0.0792	0.778	0.474
Livestock holding	0.7241	0.0431	0.4299	0.2717	0.092*	0.874
Education expenses	0.5464	0.3600	0.3718	0.3562	0.142	0.312
Remittances	-0.2607	-0.2754	0.3194	0.2987	0.414	0.357
Non-farm activities	-0.2794	-0.0773	0.3212	0.1985	0.384	0.697
Seasonal farming	-1.1571	-0.1071	0.3607	0.2878	0.001***	0.710
Market outlet	-0.1932	-0.0753	0.1021	0.1288	0.095*	0.377
Rented land	0.0345	-0.0417	0.2426	0.2196	0.887	0.849
Inherited land	-0.4372	0.1500	0.3587	0.3271	0.223	0.646
Borrowed land	-0.3378	0.0377	0.3566	0.3136	0.343	0.904
Communal land	0.1887	0.4001	0.6448	0.3417	0.770	0.242
Leased land	0.1174	-0.0744	0.4154	0.4748	0.777	0.875
Road accessibility	-0.0275	-0.0880	0.1761	0.1944	0.876	0.651
Extension contact	-0.0372	-0.0301	0.2366	0.3471	0.914	0.899

Government support	0.5109	-0.3599	0.3508	0.2370	0.145	0.129
Credit access	-0.9595	-0.4369	0.3657	0.2762	0.009***	0.114
Farm-based organisations	1.029	0.3675	0.3092	0.2961	0.001***	0.215

Number of obs = 398

Prob > chi2 = 0.0241

Log likelihood = -504.81565

Wald $chi^2(44)$ = 64.39

*** = $p < 0.01$, ** = $p < 0.05$, * = $p < 0.1$ (IRR-IV means irrigation involvement, IRR-N means no irrigation involvement)

The empirical result shows a negative relationship between gender and rural household food insecurity, which implies that households with more male heads increase the chances of the household being food secured. Although the determinants of food insecurity are the same for both men and women, the gender variable shows a decreasing effect on the food insecurity event because a household with more males could serve as farm labour and contributes to the overall farm productivity. This is supported by the study of Grimaccia & Naccarato (2022) who reported that households with a higher percentage of males have a lower probability of experiencing events of food insecurity.

The study showed that the variable household size is statistically significant and positively influences irrigation involvement at less than 5% significance level. This implies that household heads with larger family sizes possess higher likelihood to have more labor to engage in irrigation practices. A study such as Mume et al. (2023) found that family labour represents a reliable and productive inputs for farm productions under irrigation in Ethiopia. Thus, this agrees with the finding of this study that a larger household size with a larger labor force is more likely to engage in irrigation farming.

Livestock is known to contribute to the means of livelihood through income generation by most rural household farmers. The earnings from the livestock are usually used as part of the investment fund for installing an irrigation system on the farm with the aim of increasing the overall farm productivity, which plays a significant role in combating food insecurity. The income from livestock has been reported to be used to purchase farm inputs which then allows the smallholder farmers to be able to demonstrate financial stability (Ogundeji, 2022), enabling them to participate in irrigation farming and thus reduce food insecurity.

Seasonal farming is statistically significant and negatively associated with food insecurity when rural household farmers are involved in irrigation farming. This is expected because, against weather shocks event, farmers are still able to produce and make food available owing to the advantage of irrigation. It has been argued by Dzanku (2019) that the seasonality of agricultural production and household consumption cannot be separated, meaning that households could have access to food when it can be produced even when the weather variability for instance during drought.

The empirical shows a positive correlation between market outlets and involvement in irrigation which directly influences household food security status. Access to the markets to carry out sales of farm products whether through wholesale, retail or direct sales at the farm gate encourages farmers' involvement in irrigation farming. This could result in an increase in farmers' productivity, increase farmers' income and households' food resources. According to Dzanku (2019), food insecurity is not only a question of if a farmer can increase productivity but other factors such as the ability to distribute food after it's been produced and making it available at the market where it can be sold to buyers or users. Thus, the market outlet is a major factor contributing to improving food security, especially for rural households.

The significance and statistical correlation of the credit access variable to food insecurity is expected as rural households who have access to loans could invest in irrigation technology and improve farm productivity, thereby improving the households' food security status. This is supported by the study of Salima et al. (2023) who found that access to credit improves household food security in Malawi.

The rural household farmers functioning within FBOs networks in the study area tend to have easy control and access to markets in terms of updated products prices, which in turn enhances their welfare, in terms of their food security status. According to Unver et al. (2021), irrigation farmers who are also FBOs members in developing countries often have access to profitable information and gain access to networks which help them to improve their household welfare.

3.3.4 Impact of Irrigation farming on food security

The average difference in mean food (in)security between those who engaged in irrigation farming and those in their non-adoption state and if they had engaged in irrigation farming is called average treatment effect on the treated and the untreated (ATT and ATE, respectively) indicated in Table 3.4.

Table 3.4. Treatment outcomes showing household food security status

Food security categories	**Mean**	**ATT**	**t-stat**	**Mean**	**ATE**	**t-stat**
Food secure to mildly food insecure	0.6875	0.6842	87.8587***	0.3169	0.3104	94.4597***
Moderately food insecure)	-0.2125	0.2147583	54.5656***	0.1641	-0.1583	55.5336***
Severely food insecure.	-0.1	0.101034	0.0853533	0.0842	-0.0836	0.1563***

*** denote significant level at 1%.

The ATT results indicate that engaging in irrigation farming increases the “food secure to mild insecure” status of the study population by 68%. On average, the probability of those who irrigate of being in the moderate food insecurity category is about 21% higher than those who did not irrigate their farm. However, if non-irrigated farmers had irrigated, they would have had more than 15% of being within the moderate food insecurity category. The result also reveal that involvement in irrigation farming reduces the likelihood of rural households in the study area of experiencing severe food insecurity by around 10% while if the non-irrigated households had irrigated, it would have declined their food severity status by 8%. The results agree with that of Sinyolo et al. (2014) who reported a significant impact of household food security.

3.5. Conclusion and policy implications

Evaluating the impact of irrigation as a means for alleviating poverty and increasing food security is important for ensuring an expected standard of living for the rural households in South Africa. This study investigated the impact of involvement in irrigation by rural household farmers on the food security status of households and shows the level of vulnerability of farming households to food insecurity in South Africa. The study employed an endogenous treatment effect model with ordered outcomes. The econometric result suggests that food security was improved as a result of irrigation involvement, thereby justifying the need for enhancing access to irrigation for rural households. Factors such as gender, household size, adequate water supply, water rights, remittances and CDV influenced the rural household farmer's decision to be involved in irrigation farming and decreased the food insecurity status of the households.

Based on the findings of this study, we suggest a review of the government intervention policies and a restructuring of rural operations to include more technological innovations such as advanced irrigation systems. We also recommend that the government provide more financial assistance to increase the capabilities of rural farmers to engage in irrigation farming. This will aid agricultural production and reduce food insecurity, as well as eradicate the incidence of vulnerability to food insecurity. Additional measures to improve the food security status of the rural households would place South Africa within the targets of meeting the zero-poverty agenda set by the World Bank and would be of critical importance in eliminating potential vulnerability to poverty.

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CHAPTER FOUR

TOWARDS THE GLOBAL ZERO POVERTY AGENDA: EXAMINING THE MULTIDIMENSIONAL POVERTY SITUATION IN SOUTH AFRICA

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Abstract

The vulnerability of smallholder farmers to multidimensional poverty in the Eastern Cape province of South Africa was assessed using the Alkire Foster multidimensional poverty index developed by the Oxford Poverty and Human Development Initiative and aligned with the Sustainable Development Goals (SDGs). The findings show that the deprivation indicator ranges from 5% to 90%, revealing that access to a flush toilet is an imperative factor in a households' standard of living (SDG11). Also, 66% and 55% of households were deprived of food security (SDG2) and education (SDG4), respectively. The probit analysis revealed that gender, remittances, crop diversification (CDV), education, seasonal farming and market outlets significantly influence the multidimensional poverty and vulnerability poverty of rural households in the Eastern Cape province. For instance, factors such as household size showed that an additional unit increase in the size of a household would result in a 5% increase in the household's vulnerability to multidimensional poverty. Similarly, a unit increase in extension contact resulted in 49% in the households' vulnerability to multidimensional poverty. The study suggests that policies related to improving education, increasing crop diversification, promoting farmer groups and the effectiveness of extension contact, and increasing market stability for sales of farm products, could contribute to reducing the multidimensional poverty level and the vulnerability of households.

Keywords: Multidimensional poverty; Sustainable Development Goals; Poverty vulnerability; Eastern Cape

4.1. Introduction

Poverty reduction remains a primary goal of policy development in developing countries around the world, and is consistent with the Sustainable Development Goals (SDGs), which aim to eliminate global poverty in all forms by 2030 (United Nations, 2015). According to World Bank (2020) reports, the impact of the COVID-19 pandemic has resulted in massive reversals of previous advances in poverty alleviation, with an additional 150 million people globally projected to be living in poverty by the end of 2021. This is a growing concern for many developed and developing countries, as the goal of alleviating global poverty by 3% now seems harder, with the number of people worldwide living below the international poverty line falling from 741 million to 689 million (OPHI & UNDP, 2020). The alleviation of poverty has increasingly been investigated through a multidimensional approach to establishing poverty alleviation policies, strategies and programmes (Gebrekidan et al. 2021). Even though poverty is a global social issue, it is the most difficult and pressing public concern in many developing countries, particularly countries in Sub-Saharan Africa, where a significant proportion of residents live in poverty and 36% of the population is considered to be poor (Alkire & Robles 2017; Motuna et al. 2020).

In South Africa, about 39.8% of the population lives under intense multidimensional poverty, with 12.2% of the population reported to be vulnerable to multidimensional poverty, and 39.5%, 13.1%, 47.4% contributing to deprivations related to health, education and standard of living, respectively (OPHI & UNDP, 2020). To reduce the poverty levels in South Africa, a National Development Plan (NDP) was drawn up to enhance the development of the country through a holistic approach linked to the SDGs to achieve synergies across multiple development goals (National Planning Commission, 2013; Cumming et al., 2017). The aim of the NDP is to address issues such as job creation, inequality, water security, food security, climate change, disaster risk reduction, infrastructure development, human settlements, and health challenges, as well as the sustainable use of natural resources (Cumming et al., 2017). Relative to the NDP, the SDGs highlight the need to end hunger, achieve food security, improve nutrition and promote sustainable agriculture (Food and Agriculture Organization [FAO], 2016). Poverty in terms of food security shows that around 26% of South Africans are food insecure and 28% are at the edge of facing food insecurity (Tibesigwa & Visser, 2016). While poverty assessments have been carried out at the country level, a more rigorous assessment at the multidimensional level has been reported to force provincial policy development that is necessary to enhance poverty alleviation and improve rural livelihoods (Mushongera et al., 2017).

The Eastern Cape province has consistently ranked in the top two positions of poverty-stricken (67.3%) provinces in South Africa after Limpopo (Statistics South Africa, 2017). According to Mthethwa and Wale (2021), the Eastern Cape province represents one of the two provinces facing chronic poverty and severe food insecurity, which affect the livelihood standards of rural households. Among the causes of the rising level of poverty in the Eastern Cape is the high rate of unemployment (Ngumbela et al., 2019). The report by the World Bank (2018) highlights that the Eastern Cape alone has the 20 poorest municipalities, indicating the post-effect of the apartheid era, which caused a decline in development in the homelands. Despite the high rate of poverty in the province, the efforts of the government are committed to promoting anti-poverty measures to improve the welfare of the people, and also to achieve the SDGs through various means such as improvements in skills and education and increasing social transfers. The social transfers have contributed to improved health and increased education levels of the people, thereby reducing the poverty headcount rate and declining the poverty gap by 7.9% and 29.5% respectively (World Bank, 2018). To address the dimensional poverty of the people, an innovative approach that separates different types of deprivation is required, hence a multidimensional poverty approach was considered for this study.

A significant shift in the measurement of poverty is the vulnerability to multidimensional poverty, which describes the increased tendency of a household to become poor (Feeny & McDonald, 2016). Several studies have also measured the vulnerability to multidimensional poverty using various approaches (Azeem et al., 2017). While the approach has been used extensively in other countries, there is a gap in the body of knowledge where traditional poverty analysis has mostly been adopted rather than using the multidimensional poverty approach to investigate the multiple deprivations in rural areas that are facing abject poverty, such as the selected study area, the Eastern Cape. The other important research gap identified was that previous studies carried out in South Africa have relied on national data, which only provides an overall overview of the country, thereby excluding the possibility of examining the grassroots causes of the growing poverty level of the households, particularly in rural areas. The fact that the understanding of a grassroots cause is the most instrumental strategy for generating and arriving at a sustainable solution creates the need to examine the multidimensional poverty of rural households at the provincial level in South Africa (Mkhize & Mutereko, 2022). Against this backdrop, this current study investigates the multidimensional poverty of households in the Eastern Cape province with many linkages to the SDG poverty-alleviation goals. The results of this research will contribute to the body of literature by presenting the determining factors of the multidimensional poverty and vulnerability levels of the households, as well as help devise the important policy recommendations that are necessary to improve the livelihoods of the rural households in the study area.

4.2. Empirical literature

4.2.1 Multidimensional poverty approach

A multidimensional approach has been developed to analyse a wide range of poverty levels involving severe deprivation of basic human needs, such as health, education and living standards, which are not captured by the monetary approach to poverty (Alkire et al. 2017) Previous studies have employed the multidimensional poverty approach proposed by Alkire and Foster in various countries, regions and sectors (Alkire & Seth, 2015; Dehury & Mohanty, 2015; Wang, 2016; Alkire et al., 2017; Megbowon, 2018; Santos et al., 2018; Dagunga et al., 2021). Similarly, other studies also employed multidimensional poverty, with much focus on inequality, health, education, vulnerability, and rural poverty in developing and developed countries (Leisher et al., 2013; Krishnamurthy et al., 2014; Mert & Kadioglu, 2016; Vukojevic et al., 2017). It is important to note that most of these definitions of poverty involve different dimensions. The above studies highlight the importance of the multidimensionality of poverty, as they combine entire and relative poverty. While poverty is assessed on a broader dimension consisting of some indicators, previous studies on poverty in developing countries such as South Africa focus mostly more on unidimensional monetary poverty using income or consumption levels, thereby excluding other important aspects such as child poverty.

4.2.2 Anti-poverty measures in south africa

In South Africa there is increasing recognition of government policies initiated as anti-poverty measures to tackle the rising poverty levels of many households across the nation. Given the strategy of reducing poverty in South Africa, which was estimated to be between 40% and 56% of the total population in 2015 (Hirschl et al., 2021), anti-poverty measures such as social capital, employment creation, strengthening food security, a basic income grant, a family poverty grant, a social auxiliary workers scheme, the scale-up of social welfare, a massive food production programme (MFPP) (Hebinck, 2014) and other development programmes have been established to reduce poverty in the country (some of which are targets set for 2030). Another anti-poverty policy that exists to combat poverty is the South African land expropriation without compensation bill, found in Section 25 of the South African Constitution, to reduce the number of people living below the poverty line, as lack of access to land was identified as one of the factors contributing to multidimensional poverty (Mubecua & Mlambo, 2021). While significant anti-poverty mechanisms play a role in poverty reduction and in improving the welfare of vulnerable rural households, there is still inadequate information on and evidence for how these strategies reduce multidimensional poverty and the vulnerability of these households to multidimensional poverty in South Africa. Therefore, the significance of this study is that it contributes a novel insight into the determinants of multidimensional poverty and how there directly affect the vulnerability of rural households to multidimensional poverty. This analysis provides critical policy recommendations that help to evaluate the existing antipoverty measures against the continental and global poverty-eradication targets, such as Agenda 2063 and the SDG goals.

4.3. Materials and methods

4.3.1 Description of the study area and data collection

This study was conducted in the King Sabata Dalinyebo and Nyandeni local municipalities, which fall under the OR Tambo District Municipality, representing the local municipalities in the Mthatha River basin in the Eastern Cape province (Figure 1). The district is functionally rural, characterised by low educational levels, and is predominantly an agricultural production area (Eastern Cape Socio-Economic Consultative Council, 2017). Demographically, it has been documented in the literature that the dominant age group is 10 to 14, representing 11.5% of the total provincial population of 6 667 million people. The majority of the population is female (52.8%), whilst males represent 47.8% (Statistics South Africa, 2022). The official unemployment rate in the Eastern Cape was 47.4% in the third quarter of the 2020/2021 fiscal year. Considering that the study area is ranked as having the highest official and expanded unemployment rates in the nation, the Eastern Cape has been dubbed the poorest province in South Africa. This, directly and indirectly, reflects the standard of living in the study area and therefore proves that it is essential to investigate and assess the multidimensional poverty and vulnerability to poverty of rural households.

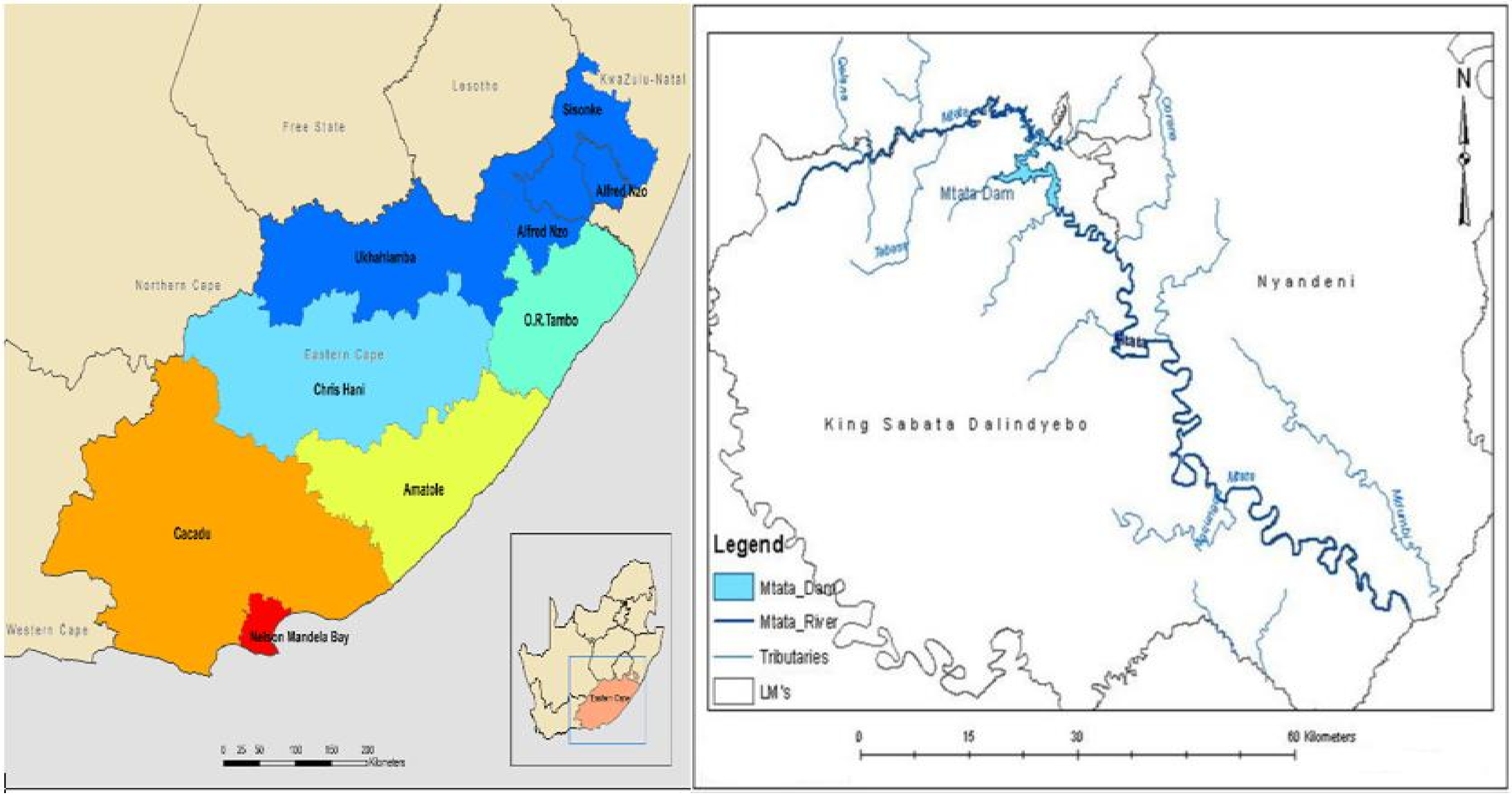

Figure 4.1. Map of South Africa showing the district in which the selected local municipalities are located

A multi-stage sampling technique was employed for data collection. A purposive sampling technique was used to separate the catchment into four regions, within the Mthatha River basin. These are the upper region, the peri-township region, the lower region and the coastal region. In each of the areas, ten villages were chosen at random, from which 11 respondents were randomly chosen based on the consent of the interviewees. In total, 440 households were interviewed, but only 402 were considered credible for analysis due to some uncompleted questionnaires. The sample size was determined following Slovin's procedure (Tejada & Punzalan, 2012), expressed as:

$$n = \frac{N}{1 + N * e^2} \quad , \tag{1}$$

where n = sample size, N represent the total population, and e is the margin of error. The sample size was determined using a 95% confidence level, with a margin error of 5%.

For this study, N = 6, 712, 276, e = 0.05

$$n = \frac{6712276}{1 + 6712276 * (0.05)^2} \tag{2}$$

Hence n = 400. This indicates that the study's minimum sample size should be 400.

Unlike the data from the 2001 population census, which most studies have used to analyse multidimensional poverty in South Africa (for example Megbowon, 2018), this study employed more recent primary data in order to closely assess the multidimensional poverty of rural households at a provincial level. The study employed a quantitative method for the collection of data using a survey questionnaire. The survey questionnaire was prepared in English and then translated into a local language (isiXhosa), as it was assumed that people would feel more at ease speaking to others in their language, which improves the accuracy of information obtained and the survey's dependability. The important sections of the questionnaire focus on the respondents' use of irrigation, farm activities, source of finance, water access and challenges associated with household food security. The questionnaire's other major component was designed to find out about households' demographic profiles and consumption patterns.

4.3.2 Empirical technique

4.3.2.1 Alkire-Foster multidimensional poverty index (MPI)

The MPI was generated using the Alkire-Foster multidimensional poverty approach to investigate the various deprivations that subject people to different levels of poverty. While there has been extensive use of a monetary measure as an official poverty indicator (Roelen et al., 2012), many researchers, as well as some policymakers, consider poverty to be a complex phenomenon that cannot be measured entirely by income or consumption expenditure, but is better analysed using multidimensional poverty indicators (Tran et al. 2015; Roelen 2017). The use of multidimensional poverty is supported by the findings of Kim (2019), who emphasises the need to go beyond the traditional monetary poverty measure not only to understand the dynamics of child poverty and well-being, but also to better inform policy. For this study, the multidimensional poverty indicator was preferred to capture the SDGs targets that align with the objectives of this study and the non-monetary indicators that were analysed in this study.

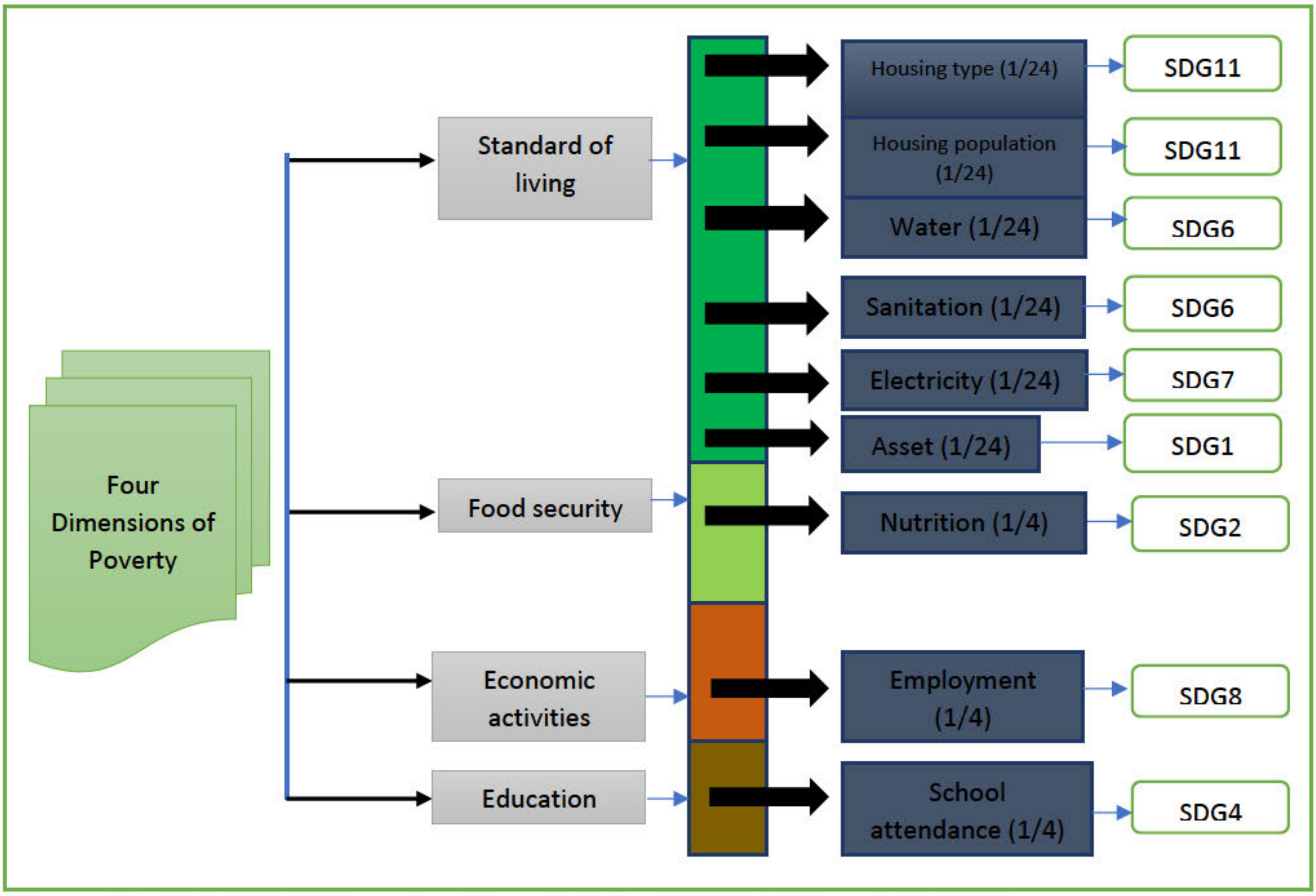

Figure 4.2. Global Multidimensional Poverty Index (OPHI) (Alkire et al., 2020)

The MPI framework, as shown in Figure 4.2, is useful for presenting the magnitude and details of the poverty of households and was applied to measure household poverty levels that are directly linked to the first goal of the SDGs, that is, putting an end to all forms of poverty everywhere around the world. The MPI framework consists of nine indicators (*d*) (nine indicators were preferred, as they better suit the South African case study, as explained by Mushongera et al., 2017) and grouped into four dimensions (*T*), which were equally weighted, with the indicators also assigned equal weights based on the weight of the dimensions that are attached to the indicator *j* (j equals 1, 2, … d), as showing in Equation (3).

$$w_j^d = \frac{1}{T} \cdot \frac{1}{d} \tag{3}$$

In Table 4.2, the study links each indicator from the MPI framework to the related goal of the SDGs. For example, goal number 4 of the SDGs was linked to the education dimension. The deprivation cut-offs for the nine indicators are presented in Table 2. We determined the poverty incidence (multidimensional headcount ratio [H]) and intensity (A), which is the average deprivation score of multidimensionally poor persons, using Alkire and Foster's (2011) methodology. According Alkire et al. (2021), the Oxford Poverty and Human Development Initiative (OPHI) definition of a household who is considered multidimensionally poor is if a household found to be deprived of at least 1/3 of the weighted indicators, meaning the household poverty cut-off (k) is equal to 33.33%. The incidence of poverty, often known as the headcount ratio (H), is the fraction of the population that is multidimensionally poor. This is calculated as:

$$H = \frac{n}{t}, \tag{4}$$

where n represents the number of poor households and t denotes the total number of households.

The intensity of poverty, on the other hand, is defined as the average proportion of indicators in which poor individuals are deprived (A). The intensity of poverty was calculated as:

$$A = \frac{\sum_1^n c}{n}, \tag{5}$$

where *c* denotes the overall weighted deprivations experienced by the poor household.

The MPI is calculated by multiplying incidence and intensity: $MPI = H \times A$ (6)

4.3.2.2 The probit model analysis

This study employed the probit model to estimate the determinants of multidimensional poverty in the Eastern Cape province, South Africa. As described earlier, a poor household is considered to be deprived of at least 33% of the weighted indicators and therefore takes a value of 1, and 0 if otherwise. We first take $\hat{y}$ to be an underlying continuous latent variable that causes a household to be poor, as the dependent variable is dichotomous and a household is either poor or not. The latent variable could be described as:

$$\hat{\varpi} = x\beta + \varepsilon , \quad (7)$$

where x represent the vector of the household socio-economic and institutional variables assumed to influence households' multidimensional poverty. Therefore,

$\varpi = 1$ if $\hat{\varpi} > 0$ and $\varpi = 0$ if $\varpi < 0$.

The probit model is then expressed as:

$$P_i = \Psi(\hat{\varpi}) = \Psi(x\beta + \varepsilon) = P_i = F(x\beta + \varepsilon) , \quad (8)$$

where F represents the standard normal cumulative distribution function, which can be written as:

$$F(x\beta) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x\beta} e^{-z\frac{2}{2}dz} . \quad (9)$$

For the poverty vulnerability estimates, we followed the OPHI approach (OPHI, 2021). For every person with a score for c of between 0.2 and 0.3, such a person is identified to be part of a group of people who are still vulnerable to multidimensional poverty. Also, every individual with a score of 0.5 or more is classified as living in severe multidimensional poverty (both MPI poor). The MPI statistics for a final cut-off of 40% are also reported. Subsequently, the determinant factors influencing the vulnerability of the grouped individuals were investigated following a similar process as that in Equations (7) to (9).

4.3.2.3 Description of variables and a priori expectations of the determinants of multidimensional poverty and drivers of household vulnerability to poverty

This study followed the approach of Dagunga et al. (2021) to determine the socio-economic and institutional variables that could probably influence the multidimensional poverty level of households in the study area. The socio-economic variables that were generated included household age, household size, household head gender, non-farm activity, remittances and engagement in seasonal farming. For the institutional variables, extension contact, market outlet and government credit support were considered.

Table 4.1. Descriptive statistics

Variables	Description of variables	Mean (SD)
Household age	Age of respondent (years)	45.30 (12.81)
Household size	Respondents' household size (number of family members provided for by the household head)	3.27 (1.51)
Gender	1 if the respondent is male, otherwise 0	0.63 (0.48)
Non-farm activity	1 if the respondent engages in a non-farm activity, otherwise 0	0.42 (0.49)
Extension contact	1 if the respondent receives extension services, otherwise 0	0.77 (0.41)
Remittances	1 if the respondent has received remittance, otherwise 0	0.20 (0.40)
CDV	1 if the respondent practises crop diversification, otherwise 0	5.15 (1.15)
Farmer association	1 if the respondent belongs to a farmer association, otherwise 0	0.77 (0.41)
Education	1 if respondents attended formal education, otherwise 0	0.86 (0.34)
Government credit support	1 if the respondent has used government credit, otherwise 0	0.27 (0.44)
Engage in seasonal farming	1 if respondents engage in seasonal farming, otherwise 0	0.55 (0.49)
Market outlet	Different types of market outlets available for the sale of products	2.95 (1.61)
Consumption status (log)	Total amount spent on food items (in rand)	3.26 (0.21)

The age of respondents, which was measured in years, showed a mean value of 45 years for the total population sample. The respondent's age could have a mixed effect on multidimensional poverty in South Africa. This could be because an individual's age does not necessarily translate into poverty, but instead into the number of assets owned by the household and the kind of income-generating activities they are involved in. Therefore, a negative or positive sign could be reported. For household size, an average of three individuals per household was reported, indicating an expected decrease in multidimensional poverty depending on the household characteristics in terms of employed vs. unemployed (Dagunga et al., 2021). In addition, a household with more individuals could translate into faster usage of household facilities (such as electricity and water) and cause overcrowded dwellings. The gender of the household head could also have a negative or positive effect on the probability of multidimensional poverty. Given that 63% were male, there is a higher possibility that a negative influence could be revealed, because households with more manpower could have more labourers to work and generate more resources, thereby improving the living standards of the households.

There was an expected positive or negative result from the non-farm activity variable, as the magnitude of the influence could be based on the characteristics of the activity in question. Regardless of the influence, a marginal level of non-farm activity is expected to significantly improve household livelihoods. Households that receive remittances are expected to experience a decline in their multidimensional poverty level, indicating that a negative effect is expected. Likewise, engaging in crop diversification (CDV) is expected to have a negative influence on household multidimensional poverty. Seasonal farming and market outlet were other variables included in the poverty model. These variables are expected to influence the probability of being poor, either positively or negatively. This is because seasonal farming helps farmers to grow climate-specific crops, with some crops requiring more water and others less water, to avoid issues related to crop loss and a decrease in yields. Also, market availability for sales of farm products is expected to negatively influence the likelihood of households being poor. Credit access was postulated to negatively affect households' tendency of becoming poor, as credit allows households to invest in several income-generating businesses. This aligns with the study of Olarinde et al. (2020), who also found that credit access, whether formal or informal, significantly decreases the probability of households becoming poor in Nigeria.

Lastly, the consumption per capita expenditure of the respondents could reveal a negative or positive outcome, as household consumption status varies based on several factors, such as employment, household size and so on.

4.3.2.4 Multidimensional poverty and SDGs

Table 4.2 shows a list of the indicators, the respective weights based on equal weighting of dimensions, as well as the related SDGs. For example, the housing indicator directly fits into SDG11, which reflects the importance of providing adequate, safe, and affordable housing, which serves as a means to end poverty of all forms.

Table 4.2. The dimensions, indicators, deprivations, and weights of MPI of households relative to SDGs

Dimensions of poverty	Indicators	Deprived if …	Weight	Associated with
Standard of living	Housing type	A household dwelling is a shack/ informal dwelling (floor, roof or walls)	1/24	SDG11
	Housing population	Overcrowded: two or more persons per room	1/24	SDG11
	Water	No access to piped water (safe) in a dwelling or yard	1/24	SDG6
	Sanitation	No access to a flush toilet facility	1/24	SDG6
	Electricity	No access to electricity for lighting or cooking facilities	1/24	SDG7
	Asset	A household has no more than one radio, TV and telephone	1/24	SDG1
Food security	Nutrition	At least one household member had to skip a meal	¼	SDG2

Economic activity	Employment	No one in the household is employed	1/4	SDG8
Education	School attendance	Respondent has five or fewer years of schooling	1/4	SDG4

Other indicators, such as sanitation, under the standard of living dimension, fit directly into SDG6, which explains the need to achieve adequate and equitable sanitation and hygiene for all by 2030. Similarly, the water MPI indicator also fits into SDG6, highlighting the need to achieve universal and equitable access to safe and affordable drinking water. Aligning the indicators with the SDGs is important for understanding the progress achieved in the delivery of these services, which is key for improving livelihoods from a policy perspective, especially given that wide gaps still exist in the provisions of housing and basic services in South Africa (Mushongera et al., 2017).

4.4. Results and discussion

The results in Table 4.3 present the estimated percentage of people facing deprivation in each of the nine indicators.

Table 4.3. Percentage deprivations of households for various indicators

Dimensions of poverty	**Indicator**	**Weight**	**Percentage of deprivation**
Standard of living	Household's dwelling is a shack/ informal dwelling	1/24	63.50
	Overcrowded: two persons per room	1/24	51.25
	No access to piped water	1/24	60.25
	No access to a flush toilet facility	1/24	90
	No access to electricity	1/24	33.75

	A household has no more than one radio, TV and telephone	1/24	5.25
Food security	At least one household member has had to skip a meal	1/4	66.25
Economic activity	None of the household members is employed	1/4	15
Education	Respondent has five or fewer years of schooling	1/4	55

Table 4.3 reveals that the deprivation percentages are quite similar among some of the indicators, although they vary for other indicators. The results show that the households in the study areas experience substantial deprivation in access to flush toilets. Access to a flush toilet, which is generally used to measure the living standard of people, has been used as an indicator to measure concerns related to water and sanitation (Alkire & Santos, 2014). Overall, the standard of living is the largest contributor to the MPI in the study area, and it varies between different indicators. This is consistent with the study of Megbowon (2018), who found that the standard of living of households in the Eastern Cape province contributed extensively to the MPI and was significantly influenced by access to electricity and education attainment.

The households also suffer considerable deprivation in dwellings in terms of people per room, estimated to be over 63%. The households are better off in deprivations associated with electricity, as the results show deprivation of as low as 33.75%. Similar to the findings of this study, high levels of deprivation were also found in the study of Espinoza-Delgado and Klasen (2018), although they found low deprivation for electricity and water. The results also show high deprivation in the area of access to water resources in the study area, with the result estimated to be 60.25%. This is not surprising, as water is generally a scarce commodity in South Africa, given the country's semi-arid climate (Adetoro et al., 2020). A very minimal percentage of households (5%) suffer deprivation in assets in terms of access to mobile phones, television sets and radios. Access to communication tools like phones and TV has experienced some growth in the last few years owing to the social wage implemented by the South African government, with expanded public works programmes forming a section of the social wage (Statistics South Africa, 2017).

Deprivations from the perspective of household food and nutrition security showed that around 66.25% of the respondents were deprived of food at some specific point in time. In other words, the percentage of households that skipped a meal was 66.25% (in a month), indicating that they could be living below the poverty threshold set by the World Bank (2009). Similar to the study of Rogan (2016), the food nutrition indicator contributes nearly the most to multidimensional poverty in South Africa. According to Dagunga et al. (2021), when a household skips at least one meal it could translate into not having enough capacity to provide food in terms of the financial status of the household. This, in turn, also affects the capacity of such a household to participate effectively in society. In addition, this indicates the propensity of households to be susceptible to violence, and it could as be translated into "living in marginal or fragile environments" (Dagunga et al., 2020).

The rate of unemployment and low enrolment in educational institutions also contribute a significant amount to multidimensional poverty, by 15% and 55%, respectively. The increase in unemployment could be associated with the increase in population, which has been found to have a positive influence on household poverty. This is consistent with the study of Aloosh et al. (2019), who found that an increase in population caused an increase in unemployment and household poverty levels in Iran. The findings of this study agree with those of Fransman and Yu (2019), who found that unemployment and years of schooling were the indicators that contributed most to multidimensional poverty in the Eastern Cape and KwaZulu-Natal provinces of South Africa.

4.4.1 Determinants of multidimensional poverty

The results in Table 4.4 present the factors that drive the MPI of rural households. Factors that significantly cause households to experience multidimensional poverty include gender, non-farm income, remittances, CDV, seasonal farming and market outlet.

Table 4.4. The drivers of the MPI and the estimates of the marginal effects

MPI_poor	**Coef.**	**Std. err.**	**P > z**	**Marginal effects**	**Std. err.**	**P > z**
Age	-0.0005	0.0069	0.943	-0.0001	0.0016	0.943
Household size	-0.0005	0.0564	0.994	-0.0001	0.0128	0.994
Gender	-0.4234	0.1804	**0.019****	-0.0903	0.0357	**0.011****
Non-farm income	0.2826	0.1748	0.106	-0.0628	0.0377	**0.096***
Extension service	-0.0113	0.2178	0.959	-0.0026	0.0492	0.959
Remittances	-0.5374	0.1971	**0.006*****	-0.1423	0.0581	**0.014****
CDV	-0.1223	0.0680	**0.072***	0.0278	0.0154	**0.071****
Farmer association	-0.1469	0.2127	0.490	-0.0319	0.0443	0.471
Education	-0.0796	0.2631	0.762	-0.0175	0.0560	0.754
Credit support from govt	-0.0813	0.2004	0.685	-0.0188	0.0473	0.690
Seasonal farming	-0.3220	0.1941	**0.097***	-0.0720	0.0423	**0.089****
Market outlet	-0.2785	0.0557	**0.000*****	-0.0633	0.0124	**0.000*****
Consumption expenditure (log)	0.7098	0.4369	0.104	0.1613	0.0988	0.103
Constant	-0.3809	1.4451	0.792			
Number of observations	398					
Pseudo R^2	0.1298					
LR chi^2 (13)	46.86					
Prob > chi^2	0.000					

Significance at * = 10%, ** = 5% and *** = 1% level.

The result shows that gender is an important variable in explaining the multidimensional poverty of households in the study area. Gender is negative and statistically significant in influencing the MPI, which indicates that male-headed households are more likely to experience less multidimensional poverty than female-headed households. The study of Cheteni et al. (2020) emphasises that gender plays a significant role in household decision-making and consequently can affect the level of multidimensional poverty in rural households. The marginal effect of the gender variable implies that a 1% increase in male-headed households among the population could decrease multidimensional poverty by 3%.

The marginal effect of non-farm income reasonably reduces household poverty. A unit increase in non-farm income is estimated to reduce multidimensional poverty by around 0.06%. As shown by Danso-Abbeam et al. (2020), non-farm income significantly improves smallholder farmers' welfare through poverty reduction. Thus, increasing off-farm employment opportunities could serve as a feasible way of alleviating poverty in rural areas.

Remittances, which are a form of financial support from relatives of various households, showed a negative and significant effect on household multidimensional poverty. This implies that households that receive financial support from relatives are more likely to reduce deprivation in terms of multidimensional poverty. Several studies have reported the significance of remittances in contributing to household poverty reduction through an increase in household spending, especially in rural areas (Awuse et al., 2020; Wang et al., 2019). The marginal effect of remittances shows that a unit increase in foreign monetary inflow reduces households' multidimensional poverty.

Crop diversification offers several benefits to rural households, such as improved income from agricultural activities, with results showing a negative association with household multidimensional poverty. This indicates that households that practise crop diversification are more likely to reduce their level of poverty and minimise deprivations associated with various basic amenities. Engagement in crop diversification has been reported to generate more farm income for farmers and improves household resilience against climate change for smallholder farmers who are in poverty (Ponce, 2020), and thereby can be considered a key factor for improving the livelihoods of rural households. From a marginal effect perspective, the results show that increasing crop diversification could further contribute to reduced multidimensional poverty. This is consistent with the study of Tesfaye and Tirivayi (2020), who found that increased crop diversity in Uganda increased household welfare through increased productivity and farm income.

Seasonal farming is a climate-smart agricultural system that allows farmers to adapt to climate changes, which in turn produces high yields and increases productivity. Our empirical findings show that seasonal farming practices tend to reduce household multidimensional poverty in the study area. Climate change causes variability in precipitation and temperature, which may affect crop growth and decrease yields if not planted in the right season. Some crops are more tolerant than others of certain types of stresses, and at each phenological stage, different types of stresses affect each crop species in different ways, which is the reason for choosing a suitable season for farming (Eshetu et al., 2021). Likewise, the marginal effect of seasonal farming had a negative influence on poverty reduction, indicating that increasing the period of practising seasonal farming would result in a reduction in multidimensional poverty and an improvement in household livelihoods. Thus, seasonal farming can be considered as a means for increasing yield and farm income and reducing the multidimensional poverty of rural households.

The empirical results show that having access to a market outlet contributes to a reduction in multidimensional poverty, being negative and significant of 1%. There is a strong correlation between market access and farm household income, which implies that farmers who can channel their products to markets could significantly reduce their multidimensional poverty and improve their livelihoods. Similar to the findings in the literature, Nandi et al. (2021) found that market access contributes to poverty reduction for rural households, owing to an increase in farm income generated as a result of reliable market access. An increase in market outlets by a unit would lead to around a 0.06% decrease in multidimensional poverty of the households.

4.4.2 Determinants of vulnerability to multidimensional poverty

The results in Table 4.5 present the factors that determine the vulnerability of rural households to multidimensional poverty. The estimated results also include the marginal effect of the significant factors on vulnerability to multidimensional poverty of rural households in the study area.

Table 4.5. The factors influencing household vulnerability to MPI (VMPI) and its marginal effect estimates

VMPI	**Coef.**	**Std. err.**	**P > z**	**dy/dx**	**Std. err.**	**P > z**
Age	0.0176	0.0170	0.300	0.0068	0.0065	0.300
Household size	0.4205	0.2214	**0.058****	0.1618	0.0858	**0.059****
Gender	0.4947	0.5223	0.344	0.1822	0.1808	0.313
Non-farm activity	-0.1383	0.4355	0.751	-0.0528	0.1647	0.748
Extension contact	-1.3446	0.6887	**0.051****	-0.4978	0.2137	**0.020****
Remittances	-1.7458	0.7397	**0.018****	-0.6172	0.2009	**0.002*****
CDV	-0.6431	0.1714	**0.000*****	-0.2475	0.0686	**0.000*****
Farm-based association	-2.2654	0.8382	**0.007*****	-0.6673	0.1157	**0.000*****
Education	-2.4298	0.9285	**0.009*****	-0.4813	0.0799	**0.000*****
Government credit support	-0.5791	0.7292	0.427	-0.2091	0.2400	0.384
Seasonal farming	-0.6420	0.5225	0.219	-0.2455	0.1969	0.212
Market outlet	-0.2066	0.1627	0.204	-0.0795	0.0630	0.207
LnY	0.4122	1.1527	0.721	0.1586	0.4437	0.721

Significance at the * = 10%, ** = 5% and *** = 1% level.

Household size was statistically significant and contributes positively to household vulnerability to multidimensional poverty. This implies that a larger household size would lead to a household being more vulnerable to multidimensional poverty. This is most likely because larger households require more food to feed all the household members, putting a strain on household income. The results of this study are consistent with those of Gebrekidan et al. (2020), who found that the size of a household correlates positively he with vulnerability to poverty, implying that the larger the household the more vulnerable such household would be to multidimensional poverty. This is also reflected in the marginal effect of household size on vulnerability to multidimensional poverty, with the results showing that a unit increase in household size would result in a 0.05% increase in the chances of the household being vulnerable to multidimensional poverty.

Consistent contact with extension agents showed a negative and significant association with vulnerability to multidimensional poverty. Contact with extension agents provides real-time information necessary for improving farm productivity and increasing farm income. Similar to our findings, Ambaye et al. (2021) revealed that household contact with extension agents was statistically significant and negatively associated with the household's vulnerability to multidimensional poverty in Ethiopia. The marginal effect indicates that, as contact with extension agents increases by one unit, the vulnerability to multidimensional poverty decreases by 0.49%. Remittance shows a negative and significant relationship with household vulnerability to multidimensional poverty. This indicates that foreign incomes received by farm households as remittances contribute directly to a reduction in the vulnerability of households to poverty. This is possible because households that receive constant remittances from relatives abroad often invest in businesses that generate a sustainable income flow for the rural household. Similar to the study of Ekanayake and Moslares (2020), the remittances variable was found to have a negative influence, suggesting that workers' remittances seem to reduce the poverty rates in Latin America. Likewise, the marginal impact may increase the multidimensional poverty of rural households if not used to improve livelihoods. Findings from the literature show that remittances have a negative association with poverty vulnerability and pose the possibility of reducing multidimensional poverty (Hagen-Zanker & Himmelstine 2016).

CDV is an important variable in the mitigation of multidimensional poverty in rural households. The results show that CDV may contribute to a reduction in household vulnerability to multidimensional poverty. The negative association could be ascribed to multiple incomes that can be obtained from growing various crops that provide households with improved consumption expenditure and enhanced livelihood standards. In line with the study of Feliciano (2019), diversification in crop production aligns well with the sustainable development goals, particularly in the aspect of poverty alleviation for farm households. Similarly, the marginal effect of involvement in CDV reveals that farmers who plant diverse crops are more likely to further reduce their vulnerability to multidimensional poverty, by 24%.

Being a member of a farm-based association is statistically significant and poses a negative association with vulnerability to multidimensional poverty. This implies that participating in a farm-based organisation could provide farm households with important information that is necessary for improving farm productivity and subsequently improving farm income, hence reducing household vulnerability to multidimensional poverty. Empirical evidence available in the literature, such as in Ojo et al. (2021), posits that involvement in farm organisation provides farmers with some important information that helps their innovation, production and marketing through social and farmer-to-farmer networks. This information can also enhance farmers' decision-making and thus eliminate potential vulnerability to multidimensional. poverty. Other aspects of belonging to a farm-based organisation could be linked to the opportunity to be exposed to a savings group (such as a farmers' cooperative organisation), which has been reported to contribute to a lower probability of being poor compared to those who do not belong to any organisation or a savings group. This is because savings serve as a cushioning mechanism that encourages farmers to invest in other activities, as well as to respond to unexpected events that could threaten the financial stability of rural households (Dagunga et al., 2021).

The years of education of the household head had negative coefficients, thus supporting the hypothesis that increased years of education decrease the probability that a household will be vulnerable to multidimensional poverty. Similarly, the marginal effect results revealed that a unit increase in years of education in the rural household would lead to a 0.48|% reduction in vulnerability to multidimensional poverty. This points to a need for an increase in training for farm households that could allow enhanced application of new technologies to improve farm income and livelihoods. This corroborates the findings of Padda and Hameed (2018), who found that education reduces multidimensional poverty in Pakistan.

4.5. Conclusions

This study investigated the multidimensional poverty of rural households in the Eastern Cape province of South Africa. Using cross-section data collected from 402 households in ten villages in the province, the study used the Alkire Foster multidimensional poverty index developed by the Oxford Poverty and Human Development Initiative (OPHI) to examine the multidimensional poverty situation in South Africa. We also employed the probit model to analyse the factors that could determine multidimensional poverty, as well as those that could influence household vulnerability to multidimensional poverty. The findings show that the deprivation indicator ranges from 5% to 90%, revealing that access to a flush toilet facility is an imperative factor in the standard of living (SDG11) of the households. Also, 66% and 55% of respondents were deprived of food security (SDG2) and education (SDG4), respectively. The findings of the probit analysis reveal that factors such as gender, remittances, crop diversification, seasonal farming and market outlets significantly influence the multidimensional poverty of households in the Eastern Cape. For instance, factors such as household size showed that an additional unit increase in the size of a household would result in a 5% increase in the household's vulnerability to multidimensional poverty. Likewise, the findings on extension contact reveal that, as contact with extension agents increases by one unit, the vulnerability to multidimensional poverty decreases by 49%. The study also suggests that policies related to increasing crop diversification, promoting farmer groups and enhancing the effectiveness of extension contact, as well as increasing market stability for sales of farm products, could contribute to reducing the level of multidimensional poverty and the vulnerability of households to multidimensional poverty. In addition, given the importance of education in the reduction of poverty to the SGDs and Agenda 2063 goals, this study suggests that policies that will motivate the rural community to embrace education should be implemented, as this could empower local populations to develop innovative solutions to reduce or eliminate challenges related to vulnerability to poverty South Africa.

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CHAPTER FIVE

IMPACT OF IRRIGATION ON WELFARE AND VULNERABILITY TO POVERTY OF SOUTH AFRICAN FARMING HOUSEHOLDS

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Abstract

Many empirical studies have documented the role of farm management practices such as irrigation in reducing poverty and improving household well-being. Few studies, however, have looked at the impact of irrigation farming on poverty vulnerability and the welfare of rural household farmers. This study examined the factors that influence farmers' participation in irrigation farming and the effects on farmers' food consumption expenditure per capita, the poverty gap, poverty severity and poverty vulnerability. To account for selection bias in both observed and unobserved factors, the study employed the endogenous switching regression model (ESR) model and analysed data collected through a survey in the northern and coastal regions in the Eastern Cape province of South Africa. The empirical results show that remittances, crop diversification, road accessibility, and access to water and extension services increased the household food consumption expenditure per capita, and reduced the poverty gap, severity of poverty, and the vulnerability to poverty of farmers who participated in irrigation farming. In addition, factors such as gender, household size, crop diversification, access to market outlet, and education, influenced farmers' decisions to practise irrigation farming. The findings suggest that improved education and training are required to strengthen and better understand the impact of irrigation sector reforms on poverty reduction and household welfare.

Keywords: Vulnerability to poverty, endogenous switching regression, irrigation participation, **poverty gap index**

5.1 Introduction

Poverty and hunger continue to be the most pressing issues facing the development of many nations around the world, particularly in the less-developed regions such as Sub-Saharan Africa (SSA). SSA remains the world's most food-insecure region, with nearly a quarter of the population (more than 230 million people), suffering from malnutrition (United Nations [UN], 2015; Food and Agriculture Organization [FAO], 2019). As a global goal, the 2030 Agenda for Sustainable Development has recognised the significant consequences of rising food poverty, which requires urgent attention. According to the World Bank (2018), poverty is defined as a multifaceted notion that includes low income and consumption, poor educational accomplishment, poor health and nutritional results, a lack of basic services, and a hazardous living environment. To categorise households based on the different levels of poverty, a poverty line of US$1.90 per day is used as an indicator of extreme poverty (World Bank, 2018).

Many extremely poor households live in rural areas and rely on agricultural production for a living (Gassner et al., 2019). To improve long-term food security and alleviate poverty, agricultural production systems have to be more productive and reduce output variability in the face of climate extremes and aspects such as land degradation. The stability of farmers' productivity is linked to the adoption of a resilient food production system that can withstand disruptive events (Olawuyi & Mushunje, 2020). Irrigated farming has been identified as a viable means of increasing agricultural productivity, farmers' revenue and household consumption as a mitigation strategy (Olawuyi & Mushunje, 2020). Irrigation aids in the stabilisation of food production by shielding it from the unpredictability of rainfall. Irrigation farming systems are a critical policy strategy for eradicating poverty and increasing food security (Fanadzo & Ncube, 2018). In addition, participation in irrigation is especially crucial in import-dependent developing countries, where agriculture employs the bulk of the population. Irrigation projects and existing schemes, despite their importance for economic growth and investment, are still underperforming in terms of realising their full potential (Mhembwe et al., 2019), particularly in a semi-arid country like South Africa.

In South Africa, farmers' participation in irrigation farming is generally low, with smallholder irrigation land area accounting for around 0.1 million hectares (8%) of the aggregate irrigated land (Sinyolo et al., 2014; DAFF, 2015). Despite the importance of smallholder farmers for economic development in South Africa because they possess potential for improving rural livelihoods, farmers participating in different irrigation schemes perform below suboptimal levels (Sinyolo et al., 2014; Fanadzo & Ncube, 2018; Christian et al., 2019; Mwadzingeni et al., 2020). Water management, access to financing, market access, poor infrastructure maintenance, and the farmers' age have been found to contribute to low participation in irrigation farming in many developing countries (Valipour, 2015; Ward, 2016). Christian et al. (2019) observed that irrigation participation in South Africa is influenced by farmers' age, family size, finance availability, extension contact, and membership of farmer groups. While factors determining participation in irrigation farming have gained some attention in South Africa, the impact of irrigation participation on household welfare, poverty and vulnerability to poverty has not been explored adequately. As a result, any untapped potential to enhance household welfare and reduce household poverty and vulnerability to poverty through smallholder irrigation participation in South Africa is critical. A lot of literature (Hussain &

Hanjra, 2004; Oni et al., 2011; Ndlovu et al., 2015; Mhembwe et al., 2019; Adetoro et al., 2020) has reported that participation in irrigation farming could serve as a way to create new job opportunities, both on and off the farm, and boost rural incomes, improve livelihoods, improve food security and alleviate poverty through an improvement in farm productivity. However, while there is evidence that irrigation development reduces poverty in several countries, the impact is determined by farm, irrigated technology and household variables. For the reasons stated above, it is vital to investigate whether irrigation users are significantly better off than non-users in terms not only of poverty status, but also of poverty incidence, depth, and severity, as well as the impact of irrigation on consumption levels. Moreover, the plethora of empirical studies on poverty has one major shortcoming: the failure to estimate treatment (use of irrigation) on vulnerability to poverty. It is critical to recognise the differences between poverty and vulnerability. The former is concerned more with one's immediate well-being, whilst the latter is concerned with one's long-term well-being. Thus, assessing poverty without considering vulnerability to poverty may result in insufficient information for future agriculture-related programme design and implementation. Thus, there is little empirical literature on the impact of irrigation participation on an extended outcome such as household welfare and household poverty, as well as vulnerability to poverty. As a consequence, the study hypothesised that smallholder farmers who participate in irrigation farming have higher consumption expenditure per capita, a lower poverty level, and are less vulnerable to poverty than non-participants.

This study brings out novelty in poverty-related studies in the following ways. First, we estimate the contribution of irrigation usage not only on poverty reduction, but also on the incidence and severity of poverty as well as the vulnerability to poverty among farming households in rural South Africa. Knowing who is poor, the intensity of their poverty and who is at risk of becoming poor is critical to inform farm-level policy initiatives and actions. Second, the study followed a rigorous technique used by the World Bank (2018) to measure poverty. Third, the study takes into consideration both observed and unobservable factors of irrigation participation through the use of the endogenous switching regression to account for selection bias and the potential endogeneity of participation in irrigation farming.

There is not much prior research in the country in this regard, making it difficult to draw conclusions. Changing sociocultural, political and economic factors entail the need for up-to-date research findings on which to base the formulation and implementation of various programmes to improve livelihoods. Through the provision of new empirical evidence, this study thus contributes to the efforts of government, international development organisations (e.g., FAO, International Water and Management Institute, etc.), and other stakeholders to strengthen and better understand the impact of irrigation sector reforms on poverty reduction and household welfare.

5.2 Methodology

5.2.1 Description of the study area and data collection

This study was conducted in the King Sabata Dalinyebo and Nyandeni local municipalities, which fall under the OR Tambo District Municipality, representing the local municipalities in the Mthatha River basin in the Eastern Cape province (Figure 1). The district is functionally rural, characterised by low educational levels, and is predominantly an agricultural production area (Eastern Cape Socio Economic Consultative Council, 2017). The Mthatha River provides drinking and irrigation water to the residents in the catchment area. The river catchment is approximately 100 km long and 50 km wide, with a total area of 5 520 km^3. The Mthatha River, which is 250 km long and has two big tributaries, flows north of Coffee Bay (Mankosi village). The Mthatha and Corana Dams, both on the Mthatha River's Corana branch, are major water-storage reservoirs in the Mthatha basin. The Mthatha Dam has an 886-kilometre catchment area and can store up to 254 million cubic metres of water while producing 14.5 million cubic metres of water per year (Hosu et al., 2018).

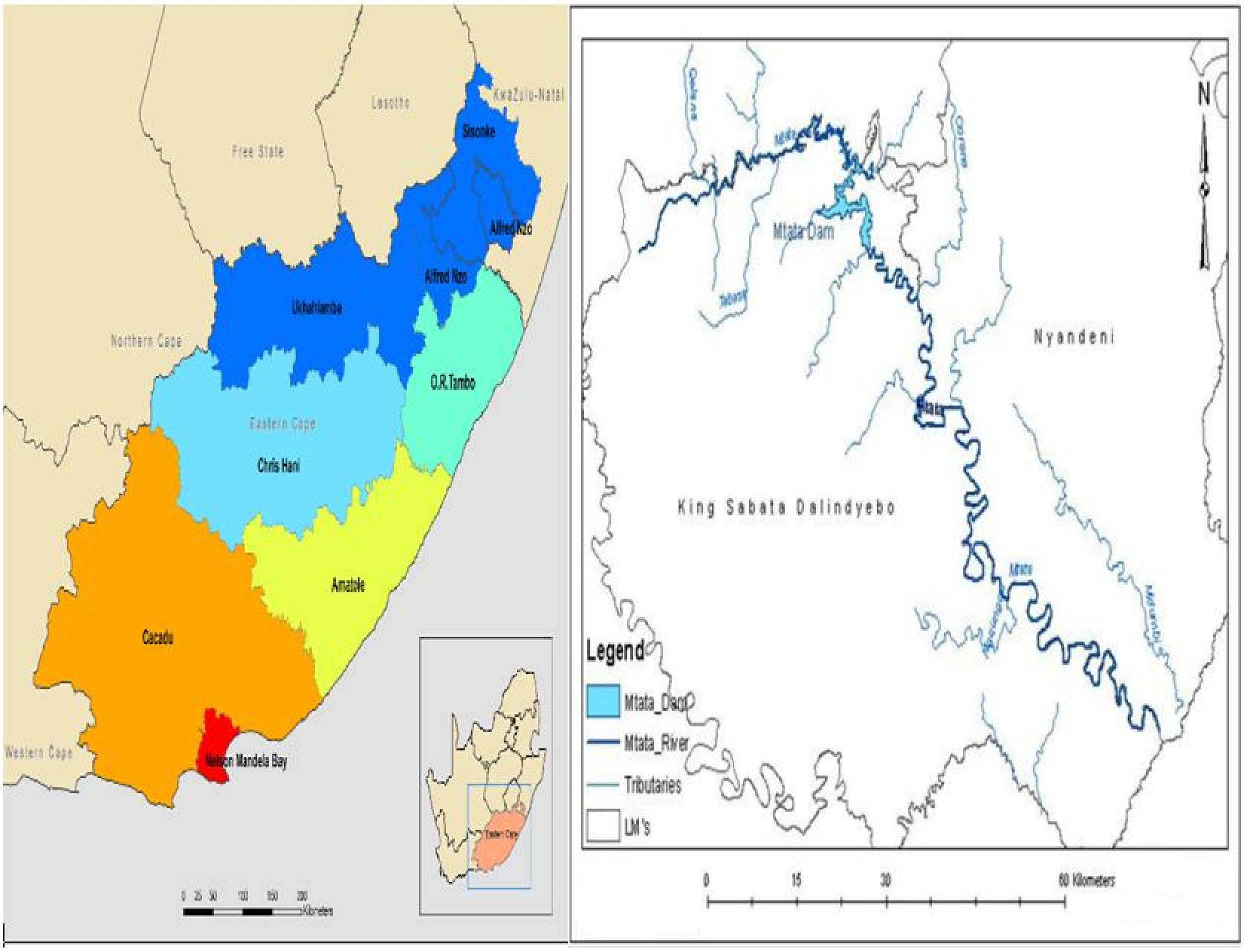

Figure 5.1. Map of South Africa showing the district where the selected local municipalities are located.

A multi-stage sampling technique was employed for data collection. A purposive sampling technique was used to divide the catchment into four regions in relation to the source of the Mthatha River. These are the upper region, the peri-township region, the lower region and the coastal region. In each of the areas, ten villages were chosen at random, from which 11 respondents were chosen randomly from each village, based on their desire to participate in the survey. In total, 440 households were interviewed, but only 400 were considered credible for analysis due to some uncompleted questionnaires.

The study employed a quantitative method for the collection of data using a survey questionnaire. The survey questionnaire was prepared in English and then translated into the local language (isiXhosa), as it was assumed that people would feel more at ease speaking to others in their home language, which improves the accuracy of the information obtained and the survey's dependability. Following Crossman et al. (2013), the quantitative method was used to compare responses between the participants and non-participants in irrigation farming, because all respondents were asked identical questions in the same order to allow for significant comparison. The important sections of the questionnaire focus on the respondents' use of irrigation, farm activities, source of finance, water access and challenges associated with household food security. The questionnaire's other major component was designed to find out about households' demographic profiles and consumption patterns.

5.2.2 Conceptual framework

This section presents the concepts employed to estimate the impact of irrigation participation on rural households' welfare outcomes. To achieve the objectives of this study, we assumed that the farm households make a binary decision on whether or not to participate in irrigation farming, based on certain factors such as their socioeconomic, farm-specific and other institutional characteristics. The farmers decide by comparing the expected utility of participating (U_i^P) with the expected utility of not participating (U_i^{NP}). Farmers' decisions are skewed toward participating in irrigation farming if the predicted outcome is favourable: $P_i^* = U_i^P - U_i^{NP} > 0$. This indicates that the benefit of participating in irrigation farming is greater than the benefits of not participating in irrigation farming. However, P_i^* is a latent variable, therefore it cannot be observed. It thus specified as a function of farmers' demographic characteristics, institutional factors, assets and farmer-specific factors, as follows:

$$P_i^* = \beta D_i + \alpha A_i + \partial M_i + \Phi I_i + \varepsilon_i, \qquad P_i^* = \{ \begin{smallmatrix} 1 & if\ P_i^* > 0 \\ 0 & if\ P_i^* \leq 0 \end{smallmatrix}, \tag{1}$$

where P_i is the binary parameter, given a value of 1 if a farmer is a participant of irrigation farming, and 0 if otherwise. The explanatory variables that are likely to influence participation are D_i, which represents a vector of farmers' demographic characteristics such as age, household size, gender, education and farming (which represents the primary occupation). A_i is the farmers' assets, such as livestock owned, non-farm income, and remittances, M_i represent other explanatory variables, such as water rights, water access and market outlet, while I_i represents the social network, such as membership of a farmer association. Lastly, ε_i is the error term with a mean of zero and variance of σ^2. The selection of the independent variables followed empirical evidence in the relevant participation and adoption literature (Dubbert, 2019, Danso-Abbeam et al., 2021; Ojo et al., 2021a).

As hypothesised, participation in irrigation farming is expected to improve farmers' welfare (measured on the basis of household consumption per capita) and reduction in poverty levels, which are the outcome variables, and the irrigation participation decision is linked to the outcomes using a linear function, expressed as:

$$Z_i^{cp} = \chi P_i + \beta D_i + \alpha A_i + \partial M_i + \lambda I_i + \mu_i \, , \qquad (2)$$

where Z_i^{cp} is the vector of welfare and poverty outcome variables, P_i is the participation indicator variable (1 if a household participates, 0 if otherwise), χ is the participation parameter to be estimated, and μ_i is the error term. Following Sinyolo et al. (2020) and Danso-Abbeam et al. (2021), the direction of the participation parameter, χ, would be estimated correctly, provided that farmers are randomly assigned to treatment and non-treatment groups. The analysis of participation choices, especially using cross-sectional data with non-randomised treatment groups, tends to have issues of endogeneity and sample selection bias. The participation status of farmers is described as endogenous when there is a correlation between the error term of the participation equation (i.e., Eqn. 1) and the error term of the outcome equation (i.e., Eqn. 2). Policy-relevant variables such as extension contacts and off-farm work engagement are possible endogenous variables that are reported to explain farmers' participation in irrigation farming (Owusu-Sekyere et al., 2021). Failure to address the issues of endogeneity and selection bias leads to underestimation or overestimation of the true impact of irrigation participation on welfare and poverty indicators. Hence, we employed the endogenous switching regression (ESR) model to estimate the impact of irrigation participation on welfare and poverty outcomes. This approach was preferred because it addresses both the observed and unobserved heterogeneity. In addition, the ESR model was used because it has the capability to control for every possible bias that has the potential to affect the outcomes (Ojo et al., 2021b). The ESR has been used in many previous empirical studies (Ojo et al., 2021a; Owusu-Sekyere et al., 2021).

5.2.3 Empirical approach: ESR

As stated above, we used ESR, which has been applied in many impact-evaluation studies. The ESR uses outcome variables, with farmers being faced with two different regimes, namely participation in irrigation farming (Regime 1) and non-participation in irrigation farming (Regime 2). The two regimes are expressed using the following equations:

$$P_i^* = \beta D_i + \alpha A_i + \partial M_i + \Phi I_i + \lambda I_i + \mu_i \qquad (3)$$

Regime 1: $Z_{1i}^{cp} = \beta D_{1i} + \alpha A_{1i} + \partial M_{1i} + \Phi I_{1i} + \varepsilon_{1i}$ if $P_i = 1$ (4a)

Regime 2: $Z_{2i}^{cp} = \beta D_{2i} + \alpha A_{2i} + \partial M_{2i} + \Phi I_{2i} + \varepsilon_{2i}$ if $P_i = 0$, (4b)

where Z_i represent the outcome variables (consumption per capita and poverty levels). D_i, A_i, M_i and I_i are the exogenous variables expected to influence the outcome variables. Hence, Equations (4a) and (4b) link the exogenous variables to the outcome variables in each of the regimes. The parameter to be estimated are β, α, ∂ and Φ for the vectors D_i, A_i, M_i and I_i, respectively. The μ_i and ε_i are the stochastic disturbances with zero mean and variances σ_μ^2 and σ_ε^2. We specified the covariance as:

$$Cov(\varepsilon_1, \varepsilon_2, \mu_3) = \begin{pmatrix} \sigma^2{}_{\varepsilon 1} & . & \sigma_{\varepsilon 1 \mu} \\ . & \sigma^2{}_{\varepsilon 2} & \sigma_{\varepsilon 2 \mu} \\ . & . & \sigma^2{}_{\mu} \end{pmatrix}, \qquad (5)$$

where σ^2 represent the variance in the disturbance term in Equation 1. According to Greene (2008), the coefficient, σ^2, is assumed to be equal to 1 because it can only be approximated up to a scale factor. $\sigma^2{}_{\varepsilon 1}$ and $\sigma^2{}_{\varepsilon 2}$ denote the terms of the variance in the welfare outcome variables in Equation (4a) and (4b), while $\sigma_{\varepsilon 1 \mu}$ and $\sigma_{\varepsilon 2 \mu}$ represent the covariance of μ_i, ε_{1i} and ε_{2i}. The covariance between ε_{1i} and ε_{2i} is difficult to define, because Z_{1i}^{cp} and Z_{2i}^{cp} are unobservable at the same time (Maddala, 1983).

One hurdle that is critical in impact evaluation using instrumental variable (IV) procedures such as ESR is the identification of the selection equation. Four instruments were selected for identification, namely farm-based organisation, credit support from the government, land leased and land held communally. These four variables are hypothesised to be correlated with the participation model, but not with the error terms of Equations (4a) and (4b). We followed relevant empirical studies (Issahaku & Abdul-Rahaman, 2019; Danso-Abbeam et al., 2021) in which the four variables were used as selection instruments. In addition, a simple falsification test recommended by Di Falco (2011) was used, which is also applied in empirical studies (e.g., Mmbando et al., 2015; Martey et al., 2020, Danso-Abbeam, 2021) to statistically ascertain the validity of the four instruments.

To accurately measure the impact of participation in irrigation farming on the outcome variables, we followed the framework applied by many impact studies to the treated and the control group, such as those by Mmbando et al. (2015), Sinyolo (2020), Martey et al. (2020) and Danso-Abbeam et al. (2021), among others. This was done by estimating the average treatment effect on the treated (ATT) and average treatment effect on the untreated (ATU) by comparing the expected outcome values in the actual and counterfactual scenarios. The condition expectations of the participation decision were estimated from the ESR, as follows:

Participants with participation (observed in the sample) – actual scenario

$$E(Z_{1i}^{cp} / P_i = 1) = \beta_1 D_{1i} + \alpha_1 A_{1i} + \partial_1 M_{1i} + \Phi_1 I_{1i} + \sigma_{\varepsilon 1 \mu} \lambda_{1i} \quad (6a)$$

Non-participants without participation (observed in the sample) – actual scenario

$$E(Z_{2i}^{cp} / P_i = 0) = \beta_2 D_{2i} + \alpha_2 A_{2i} + \partial_2 M_{2i} + \Phi_2 I_{2i} + \sigma_{\varepsilon 2 \mu} \lambda_{2i} \quad (6b)$$

Participants had they decided not to participate (not observed) – counterfactual scenario

$$E(Z_{2i}^{cp} / P_i = 1) = \beta_2 D_{2i} + \alpha_2 A_{2i} + \partial_2 M_{2i} + \Phi_2 I_{2i} + \sigma_{\varepsilon 2 \mu} \lambda_{1i} \quad (6c)$$

Non-participants had they decided to participate (not observed) – counterfactual scenario

$$E(Z_{1i}^{cp} / P_i = 0) = \beta D_{1i} + \alpha A_{1i} + \partial M_{1i} + \Phi I_{1i} + \sigma_{\varepsilon 1 \mu} \lambda_{2i} \quad (6d)$$

The above equations show the actual expectations observed by the researcher from the sample, as in Eqn. (6a) and (6b), and the counterfactual expected outcomes, as in Eqn. (6c) and (6d).

The predicted change in the outcome variables of the participants, which is the effect on the treated (participants), is called ATT. If the attributes of participants and non-participants have equal advantages, or participants have similar characteristics to non-participants, then ATT indicates the mean of the participant’s outcome. The ATT can be estimated as the difference between Equation (6a) and (6c):

$$ATT = Equation(6a) - Equation(6c) = E(Z_{1i}^{cp} / P_i = 1) - E(Z_{2i}^{cp} / P_i = 1) \quad (7)$$

Similarly, the effects of the treatment on the untreated, termed the ATU, was expected to change the welfare and poverty outcomes of the non-participants. In other words, the ATU can be described as the expected change in the consumption per capita and poverty levels of the non-participants if the characteristics of non-participants had the same advantage as the participants, or if the non-participants had the same characteristics as the participants. The ATU is specified as the difference between Equation (6b) and (6d):

$$ATU = Equation(6b) - Equation(6d) = E(Z_{2i}^{cp} / P_i = 0) - E(Z_{1i}^{cp} / P_i = 0) \quad (8)$$

5.2.4 Estimation of poverty and vulnerability to poverty

This study used the Foster, Greer and Thorbecke (FGT) poverty measure (Foster et al., 1984) to estimate the poverty gap, poverty gap index and poverty severity, while the vulnerability estimation followed the study of Chaudhuri et al. (2003). The incidence of poverty (headcount index) is a metric that gauges the percentage of the population living below the poverty line. For this study, we used the World Bank poverty line of $1.91 per day (World Bank, 2018). On the other hand, the poverty depth index (poverty gap) measures the household distance from the poverty line. The poverty severity index, also termed the poverty gap squared, considers both the poverty gap and the disparity between the poor. This means that a higher weight is assigned to households that are far from the set poverty line. For this study, we used food consumption per capita expenditure of households for the measurement of poverty, as it contains information, material deprivation and work intensity (United Nations Economic Commission for Europe, 2017). The FGT poverty index was estimated as:

$$P_\alpha = \frac{1}{n} \sum_{i=1}^{q} \left[\frac{(z - Y_i)}{z} \right]^\alpha , \quad (9)$$

where P_α represent the FGT poverty index, n denotes the household sample size, Y_i is the consumption per capita expenditure for each adult for the i^{th} household, z is the poverty line, q denotes the number of households below the poverty line, while α is the parameter for poverty aversion (that is, the level to which a poverty metric is sensitive to inequality among impoverished households). A poverty aversion takes values of 0, 1 or 2, with the values explaining the level of sensitivity of the poverty measure to inequality among the poor.

Following the World Bank approach (World Bank, 2018) to estimating the poverty gap index, we estimated the total number of households that fall below the poverty line and expressed it as the percentage of the poverty line. The poverty gap function, G_i, was first generated (in Equation (10)), after which the poverty gap index was calculated in Equation (11), as:

$$G_i = (z - x_i) \qquad \text{(with } G_i = 0 \text{ when } xi > z\text{)}, \tag{10}$$

where z is the poverty line and x_i represents the value of consumption expenditure per capita for the *i*th person's household. Next, we calculated the poverty gap using Equation (11):

$$P_{gidx} = \tfrac{1}{n} \sum_{i=1}^{n} \frac{G_i}{z}, \tag{11}$$

where P_{gidx} represent the poverty gap index, G_i denotes the index function, and z is the poverty line.

The poverty severity index was calculated by squaring the poverty gap index, which takes into account the inequality among poor households given the assigned weights. Therefore, the poverty severity, P_{svidx}, is calculated as:

$$P_{svidx} = \tfrac{1}{n} \sum_{i=1}^{n} \left(\frac{G_i}{z} \right)^2 \tag{12}$$

For the estimation of household vulnerability to poverty, we followed the approach of Chaudhuri et al. (2002). We defined poverty vulnerability as a household's likelihood of falling into poverty at least once in the next few years. Then we calculated the probability that a farm household, *hd*, will be vulnerable to becoming poor at a time *t* as:

$$V_{hd,t} = prob\left(InC_{hd,t+i}^{f} < Inz \right), \tag{13}$$

where $V_{hd,t}$ represents the household (*hd*) vulnerability to poverty at time t, and $C_{hd,t+i}^{f}$ denotes the food consumption of farm household *hd* at a time *t+i*. The *Inz* represents the natural log of the poverty line of farm household *hd*. Several observable and unobservable home variables influence a farm household's food consumption expenditure. The expression for household food consumption expenditure is based on the assumption that the relationship is linear, and the influencing factors are estimated as:

$$InC_{hd}^{f} = \vartheta X_{ihd} + \varepsilon_{hd}, \tag{14}$$

where X_{ihd} is the vector of the farm household's participation in irrigation farming and other observable individual features, ϑ is the vector of variables of interest, and ε is the error term that is associated with the idiosyncratic attributes that are normally distributed, with the mean zero and constant variance. By incorporating the coefficient estimates stated in Equation (14), we estimated the vulnerability to poverty as:

$$\hat{V}_{hd,t} = prob(InC^{f}_{hd,t+1} < Inz \mid X_{hd,t}) = \Psi(Inz - \hat{\vartheta}\hat{\gamma}X_{hd,t}), \quad (15)$$

where $\hat{V}_{hd,t}$ represents the estimated vulnerability to poverty (likelihood of a farm household falling below the poverty line in subsequent years), which depends on an individual's participation in irrigation farming and other attributes. The Ψ denotes the cumulative distribution function of the Gaussian distribution, and $\hat{\gamma}$ represents the estimated standard error from Equation (14).

To account for the possibility of heteroskedasticity, which is often caused by the violation assumption of constant variance, Chaudhuri et al. (2002) proposed a linear linkage of deviation in the food consumption function to individual attributes, which is denoted as:

$$\gamma^{2}_{\varepsilon,hd} = \sigma X_{hd} + \varpi_{hd} \quad (16a)$$

Given that participation in irrigation farming could be endogenous, it is important to correct the issue of endogeneity using a relevant instrument. For this study, we used irrigation participation as the instrument variable, and the recommended standard three-stage feasible generalised least square (FGLS) method to correct for heteroskedasticity (Amemiya, 1977). To achieve this, we estimated Equation (14) using ordinary least squares (OLS), and then used the residuals estimated in Equation (16b).

$$\hat{\gamma}^{2}_{OLS,hd} = \hat{\sigma} X_{hd} - \hat{\varpi}_{hd}, \quad (16b)$$

where $\hat{\varpi}_{hd}$ is the stochastic error term.

Using the FGLS estimate, we transformed Equation (14) so as to derive Equations (17a) and (17b), expressed as follows:

$$\hat{\gamma}_{\varepsilon,hd} = \sqrt{X_{hd}\hat{\sigma}_{FGLS}} \quad (17a)$$

$$\frac{InC_{hd}^{f}}{\hat{\gamma}_{\varepsilon,hd}} = \vartheta\left[\frac{X_{hd}}{\hat{\gamma}_{\varepsilon,hd}}\right] + \frac{\varepsilon_{hd}}{\hat{\gamma}_{\varepsilon,hd}} \tag{17b}$$

Equation (17b) was derived by dividing Equation (13) by the standard error obtained in Equation (17a). The estimate, ϑ, is an asymptotically reliable and efficient coefficient. Subsequently, we estimated the projected log of food consumption per capita expenditure and its deviation by employing ϑ_{FGLS} and $\hat{\sigma}_{FGLS}$, expressed in Equation (18a) and (18b):

$$E\left\{\left[\frac{In\hat{C}_{hd}^{f}}{X_{hd}}\right]\right\} = \hat{\vartheta}X_{hd} \tag{18a}$$

$$E\left\{\left[\frac{In\hat{C}_{hd}^{f}}{X_{hd}}\right]\right\} = \hat{\gamma}_{hd}^{2} = \hat{\sigma}X_{hd} \tag{18b}$$

Lastly, we assumed that the log of food consumption per capita expenditure follows a normal distribution, and the vulnerability to poverty was estimated as:

$$\hat{V}_{hd,t} = prob\left(InC_{hd,t+1}^{f} < Inz \mid X_{hd,t}\right) = \Psi\left\{\frac{Inz - \hat{\vartheta}_{FGLS}X_{hd}}{\sqrt{\hat{\sigma}_{FGLS}X_{hd}}}\right\} \tag{19}$$

We chose a vulnerability poverty threshold of 0.5, as recommended by Dey (2018) because it is more appropriate. As a result, farm households with a 50% or higher chance of slipping into poverty in the future were considered vulnerable to poverty.

5.3 Results and discussion

5.3.1 Definition of variables and summary statistics

Table 5.1 presents the descriptive statistics and statistical test of differences in characteristics for participants and non-participants in irrigation farming. The proportion of male-headed households in the participant and non-participant groups was 0.70 and 0.65, respectively. Farmers had an average age of 45, which is within the age range of the working population. The average age of participant and non-participant household heads was 46 and 45 years, respectively. This is similar to the average age of 52 years for the Eastern Cape province found in the study of Akinyemi and Mushunje (2019).

Table 5.1. Descriptive statistics of the respondents

Explanatory variable	Description	Participant (n = 180)	Non-participant (n = 220)	Mean difference
Gender	1 if household head is male, 0 if female	0.697	0.651	0.050**
Household age	Age of household head (years)	45.740	44.950	0.794***
Household size	Number of persons living in the household	3.156	3.368	-0.213***
Flooded farm plot	1 if household experienced flood on farm plot, 0 otherwise	0.350	0.250	0.100***
Income from livestock production	1 if income was generated from livestock sales, 0 otherwise.	0.756	0.714	-0.042**
Education expenses	1 if household spends money on education, 0 otherwise	0.878	0.886	0.009**
Remittances	1 if household received remittances, 0 otherwise	0.272	0.15	-0.122*
Non-farm activity	1 if household engaged in other non-farm activities, 0 otherwise	0.414	0.414	-0.031***
Engage in seasonal farming	1 if household practised seasonal farming, 0 otherwise	0.606	0.505	-0.101**
Market outlet	1 if household had access to various market outlets, 0 otherwise	3.183	2.773	0.411**
Crop diversification	The number of different food crop types cultivated by the household	5.339	5.005	0.334**

Education (years)	Years of education of household head	6.480	5.701	0.779***
Rented land	1 if household rented land for farming, 0 otherwise	0.289	0.241	-0.048***
Owned land	1 if household owned land for farming through inheritance, 0 otherwise	0.094	0.086	0.008***
Communal land	1 if household farmed on communal land, 0 otherwise	0.033	0.114	0.080*
Leased land	1 if household used leased land for farming, 0 otherwise	0.089	0.041	0.048***
Road accessibility	1 if household had access to good road network, 0 otherwise	1.967	2.045	-0.079***
Treatment variable				
Irrigation farming	1 if household participated in irrigation farming, 0 otherwise	0.45		

, **, and * represent significance at the 10%, 5%, and 1% level, respectively.*

As indicated in Table 5.1, the household size of the participants in irrigation farming was lower than that of the non-participants. A higher proportion of the participants in irrigation farming experienced flooded farms over the 12 months preceding the survey than the non-irrigation participants. Furthermore, the statistics show that more respondents among those participating in irrigation farming obtained income from livestock sales and also had fewer expenses for education. This is similar to the study of Mwangi and Crewett (2019), who found that participation in irrigation farming was driven by the number of years of education of the farmers. Participants in irrigation farming receive more financial support through remittances than the non-participants, with many of the participants preferring to engage in seasonal farming. The majority of the farmers who practised crop diversification were participants in irrigation, with most of them having more education years than the non-participants in the study area. The statistics show that leased and communal land were important variables for assessing irrigation farming participation, given that the land tenure system in South Africa, especially for communal land, prohibits the purchase/sale of land, for instance as in the case of KwaZulu-Natal (Sinyolo et al., 2014; Parplies et al., 2016).

The treatment variable used in the study was irrigation farming, and the results show that about 45% of the households participated in irrigation farming, while the remainder represent the non-participants.

5.3.2 Discussion of the outcome variables

The information in Table 5.2 presents a summary of the statistics and description of the outcome variables, which are household consumption per capita expenditure, poverty levels and poverty vulnerability.

The food consumption per capita expenditure of households that participated in irrigation farming is significantly higher than that of households that did not participate in irrigation farming. This implies that households that participate in irrigation farming are more likely to increase their consumption per capita expenditure. Findings from the literature (Kuwornu & Owusu, 2012) confirm that participants in irrigation have a higher potential to obtain greater farm yields and generate more income, which consequently influences the level of household consumption. The poverty gap and poverty gap index variables show that participants in irrigation farming have a lower poverty gap and poverty gap index, indicating that households that practise irrigation farming have a lower poverty status than the non-participants. In line with our findings, Beshir (2018) found that participation in irrigation farming reduces poverty and increases food security in Ethiopia.

Table 5.2. The summary statistics of household consumption, poverty and vulnerability to poverty

Variables Outcome variables	Description	Participation (n = 180)	Non-participation (n = 220)	Mean difference
Food consumption expenditure per capita	Natural log of food consumption expenditure per capita as a welfare indicator.	3.26	3.25	0.003***

Poverty gap index	The index of household poverty gap away from the poverty line	0.057	0.058	0.0007***
Poverty severity index	The extent of the poverty situation of households	0.011	0.0159	0.0045***
Poverty status	Poverty headcount of sampled households	0.394	0.377	0.017***
Poverty vulnerability	The exposure to poverty of households that are above the poverty line	0.984	0.991	0.013***

, **, and * represent significance at the 10%, 5%, and 1% level, respectively.*

The household statistics show a lower poverty severity for the irrigation participants relative to the non-participants. This implies that non-participants constitute a larger proportion of households experiencing severe poverty, perhaps due to lower farm productivity and relatively low income obtained from farm activities. This is consistent with the study of Itichia (2019), who found that participants in irrigation farming have a higher tendency to reduce the severity of poverty.

The poverty status of the irrigation participants is reasonably better than that of the non-participant, which correlates with the hypothesis that irrigation farming improves rural household poverty status and food security. For poverty vulnerability, the non-participants in irrigation farming have a higher tendency to slip into poverty in the next year if they are not already poor.

5.3.3 Determinants of participation in irrigation farming

The results in Table 5.3 present the determinants of participation in irrigation farming by the farming households in the study area. The key variables that significantly explain the decision of farmers to participate in irrigation farming are discussed in this section.

Table 5.3. Determinants of participation in irrigation farming (Probit model analysis)

Irrigation	**Coefficient**	**Standard error**	**P-value**
Age	-0.002	0.007	0.825
Gender	0.848	0.223	**0.000***
Household size	-0.210	0.060	**0.000***
Flooded farm plots	-0.123	0.064	**0.054*
Income from livestock production	0.443	0.237	**0.061*
Education expenses	0.015	0.425	0.973
Remittances	0.749	0.220	**0.001***
Non-farm activity	0.065	0.182	0.722
Seasonal farming	1.062	0.207	**0.000***
Market outlet	0.377	0.078	**0.000***
Crop diversification	0.244	0.084	**0.004***
Inherited land	0.334	0.281	0.234
Leased_land	0.655	0.326	**0.044**
Access to road	-0.060	0.124	0.628
Extension service	0.720	0.218	**0.001***
Accessed credit facility	0.443	0.219	**0.043**
Farm-based association	-1.022	0.220	**0.000***
Education	0.394	0.232	**0.090*
Rented land	-0.106	0.195	0.587
Communal land	-1.087	0.341	**0.001***
Water right	0.378	0.115	**0.001***

Water access and satisfaction	0.181	0.081	**0.026****
Full time farmer	-0.355	0.219	0.104

****, ** and * represent significance at the 1%, 5% and 10% level, respectively.*

The gender variable was positive and statistically significant in explaining farmers' decisions to irrigate. This implies that male farmers are more likely to participate in irrigation farming than female farmers, possibly because men have greater access to resources such as water institutions and water-related training than women. This is consistent with the findings of Mudege et al. (2017) and Dlangalala and Mudhara (2020), who found that women are perceived as providers of home care and thus have less access to agricultural resources than male farmers. Household size significantly reduces the probability of participation in irrigation farming. This could be attributed to the fact that larger household size is expected to be associated with higher consumption expenditure than a smaller household size. According to Ngema et al. (2018), there is a higher chance for large households to be poor owing to a larger number of people that have to be fed. Consequently, a larger household size could redirect resources to household consumption rather than irrigation investment. The empirical findings also suggest that farmers who experience flood on their farm plots are less likely to participate in irrigation farming than farmers who did not experience flooding on their farm plots. This result agrees with the findings of Jordán and Speelman (2020), who concluded that frequent flood incidences on farms discouraged farmers from adopting an irrigation farming strategy as a climate change adaptation measure. Farmers who have excess water on their farm plots may find it unnecessary to participate in irrigation farming, as enough water is available for the cultivation of crops. Although some farmers suffer from flooding caused by closeness to the riverbank, they also benefit by directly taking advantage of the excess water to irrigate their crops and improve their farm productivity. The results show that income from livestock production was statistically significant and positively influenced participation in irrigation farming. This is because the income generated from livestock sales could serve as capital to invest in irrigation activities. This aligns with the study of Zwedie et al. (2020), who found that households with large livestock holdings are expected to have more income, which will increase their tendency to participate in irrigation, since livestock serves as wealth and can easily be converted into cash when necessary.

The importance of internal remittances (funds sent by relatives from other areas or regions within the country) to farmers was established, as indicated by the results. While remittance could increase the likelihood of participation in irrigation farming, other studies have reported that remittances are subject to global market volatility, making them potentially more vulnerable in the long run (Parajuli et al., 2021). Seasonal farming is statistically significant and positively influences farmers' decision to participate in irrigation farming in the study area. This could imply that farmers who only engage in farming activities on a seasonal basis may as well be involved in some other non-farm businesses, which could translate into more income and more capital to invest in irrigation operations. The reduced seasonality effect on farm production could motivate farmers to consider participating in irrigation farming, as this could help them achieve higher yields through reduced crop failure (Asayehegn, 2012).

Market outlets were positively signed and statistically influence participation in irrigation farming, with market availability key for the sale of farm produce. The result implies that farmers who have access to various marketing channels have a higher probability of selling a large proportion of their farm produce, and consequently have a higher probability of participating in irrigation farming. Thus, the estimated results suggest that market access could motivate farmers to participate in irrigation farming. This is in line with previous studies (Fikirie, 2017; Nonvide et al., 2018), which found a significant positive relationship between market channels and irrigation participation.

The results show that diversification in crop production was statistically significant and positively influences the likelihood to participate in irrigation farming. Practising crop diversification could allow farmers to engage in irrigation farming, as more water resources are required to sustain the different crop types. This result supports the findings of De Sousa et al. (2017), who reported that farmers who practise crop diversification often require more water to sustain the different crops, which may serve as motivation to invest in irrigation infrastructure.

In addition, access to leased land leads to a higher probability of participating in irrigation farming. In contrast to our findings, Fanadzo and Ncube (2018) emphasise that some landowners are afraid of losing their land, causing them to pull it out of production. This results in enormous swaths of land lying idle and reduced land available for irrigation farming.

The adoption of farming practices such as irrigation is sometimes limited by the availability of information and access to funding to finance irrigation projects. Farmers may lack adequate information about the cost of and access to irrigation infrastructure and its benefits. Extension services provided to farmers were statistically significant and have a positive effect on explaining farmers' participation in irrigation. This is not surprising, as extension officers provide technical and managerial support on farm practices such as irrigation. This is in line with the study of Christian et al. (2019), who concluded that access to extension services increased the likelihood of adoption of irrigation technology in the Eastern Cape province of South Africa. However, farmers' associations negatively and statistically influenced farmers' decision to participate in irrigation farming. The negative association with the probability of participating in irrigation farming could be attributed to the active irrigators, who might discourage other local farmers by making them aware of the high cost and negative impacts of the construction of irrigation infrastructure on the natural watercourses and the ecological system (Chuchird et al., 2017). The study of Osewe et al. (2020) established a negative association with the adoption of farmer-led irrigation, confirming the results of this study. Access to credit facilities is an important variable in explaining the probability of farmers participating in irrigation farming in the study area. Credit access could allow farmers to purchase irrigation facilities and afford the maintenance costs associated with irrigation farming. Similar to the study of Adekunle et al. (2015), farmers with reliable access to credit have a higher probability of engaging in irrigation farming compared to household farmers who are faced with irrigation constraints.

Educational attainment positively and statistically influences smallholder farmers' decision to practice irrigation farming. The result on the education variable supports the premise that better-educated farmers are more likely to engage in farming technology such as irrigation. This finding agrees with the study of Owusu-Sekyere et al. (2021), who found that farmers with more knowledge would understand the benefits associated with participating in irrigation farming, such as an increase in net income.

The results further indicate that farmers who cultivate on communal land are less likely to participate in irrigation farming. This highlights the fact that a lack of land ownership may impede large investments in irrigation infrastructure because communal land is allocated to a specific group of farmers for a specific type of farming, and inputs are mostly supplied by the government or the allocating organisation. In Ethiopia, for example, communal land allotted to young farmers is strictly to be used for tree planting, agroforestry, fodder collection for livestock, and apiculture (Oniki et al., 2020). As a result, people lack decision-making authority over the use of communal lands, and the decision to participate in irrigation is beyond the control of individual farmers.

Farmers with water rights are more likely to participate in irrigation farming. The water right creates reliable access to water resources, and this significantly contributes to improving farmers' living conditions or to reducing poverty. This is supported by other studies, such as those of Corral et al. (2017) and Nonvide et al. (2018), who found that water rights contribute to poverty alleviation, enhance the standard of living and could motivate farmers to irrigate their farms.

Similar to a water right, the empirical results show that water access and satisfaction have a significant positive impact on the likelihood of farmers to practise irrigation farming in the study area. Increased access to water could encourage rural household farmers to consider irrigation farming, as well as provide a sense of satisfaction with various water-related uses. Water access improves agricultural diversity, crop yield and smallholder income, while also reducing vulnerability to climate variability. This is consistent with the findings of Speelman et al. (2010), who found that water access is strongly related to irrigation and the income of smallholder farmers in Limpopo, South Africa.

5.3.4 Influence of determinants of irrigation participation on outcome variables

The results in Table 5.4 show the estimates of the outcome variables for both participants and non-participants in irrigation farming. The first part of the estimated results presents the effects of variables on the outcomes for the participants, and the second part shows the estimates of the variables with the switching indicators on the outcomes for non-participants.

The last rows of Table 5.4 show the correlation coefficients ($\rho 0$ and $\rho 1$) of covariance terms between the error terms of the first- and second-stage estimations of the ESR model. The consumption outcome has a statistical significance of 1%, indicating the possibility of self-selection bias in participation decisions. This means that unobserved factors that influence farmers' decisions to participate in irrigation could also influence food consumption expenditure per capita income.

An increase in household size improves household welfare and reduces the poverty gap, poverty gap index, poverty severity and vulnerability to poverty for irrigation participants. However, it increases the vulnerability to poverty of the non-irrigation participants. This could be due to the possibility of using the larger household size to their advantage by increasing the number of farm labours, thereby increasing farm productivity and, consequently, improving their welfare.

The results further indicate that household heads who are educated have a higher probability of reducing their poverty level and eliminating vulnerability to poverty. This is consistent with the study of Nigussie et al. (2016), who found that education increased productivity and subsequently led to higher levels of welfare for the household.

Table 5.4. The impact of irrigation participation and non-participation on outcome variables (2nd-stage ESR)

Outcome variables	Consumption (per capita expenditure) log		Poverty gap		Poverty gap index		Poverty severity		Poverty vulnerability	
Participation	**Coef.**	**Std. error**	**Coef.**	**Std. error**	**Coef.**	**Std. error**	**Coef.**	**Std. error**	**Coef.**	**Std. error**
Age	0.0015	0.0012	-0.0091	0.0134	-0.0004	0.0005	-0.0002	0.0002	0.0009	0.0006
Gender	**-0.1019***	0.0376	**1.2560****	0.4976	**0.0499****	0.0198	0.0078	0.0050	-0.0067	0.0182
Hhsize	**0.0536*****	0.0111	**-0.4699*****	0.1330	**-0.0187*****	0.0053	**-0.0039*****	0.0015	**-0.0178*****	0.0053
Flooded farm plot	**0.0198****	0.0104	-0.1769	0.1190	-0.0070	0.0047	-0.0020	0.0014	**-0.0084***	0.0051
Income from livestock production	-0.0418	0.0521	**1.4143****	0.5865	**0.0562****	0.0233	**0.0150****	0.0063	**0.0634*****	0.0229
Education expenses	0.0519	0.0457	**-1.8874*****	0.5025	**-0.0750*****	0.0200	**-0.0146****	0.0059	-0.0251	0.0213
Remittances	**0.1350*****	0.0468	**-1.5445*****	0.4654	**-0.0614*****	0.0185	**-0.0156*****	0.0050	**-0.0424****	0.0184
Non-farm activity	**-0.0685***	0.0388	0.1730	0.4255	0.0069	0.0169	-0.0042	0.0049	0.0177	0.0178
Seasonal farming	**-0.1734*****	0.0454	**1.9226*****	0.6131	**0.0764*****	0.0244	0.0094	0.0063	**0.0607*****	0.0227
Market outlet	-0.0152	0.0142	-0.0135	0.1664	-0.0005	0.0066	-0.0009	0.0016	0.0074	0.0074
CDV	**0.0638*****	0.0133	**-0.6801*****	0.1524	**-0.0270*****	0.0061	**-0.0054*****	0.0016	**-0.0168*****	0.0057

Rented land	**0.0592****	0.0279	-0.2948	0.3044	-0.0117	0.0121	-0.0057	0.0037	0.0039	0.0134
Inherited land	-0.0398	0.0451	-0.0243	0.4881	-0.0010	0.0194	-0.0053	0.0058	0.0235	0.0212
Access to road	**0.0690*****	0.0209	**-0.9731*****	0.2221	**-0.0387*****	0.0088	**-0.0071*****	0.0026	**-0.0464*****	0.0097
Extension services	**0.1921*****	0.0405	**-2.3672*****	0.4321	**-0.0941*****	0.0172	**-0.0228*****	0.0048	**-0.0822*****	0.0176
Accessed credit facility	0.0251	0.0423	-0.3444	0.4368	-0.0137	0.0174	-0.0001	0.0052	0.0246	0.0193
Education	0.0202	0.0351	-0.1633	0.3982	-0.0065	0.0158	0.0003	0.0046	-0.0044	0.0169

Table 5.4 (contd.). The impact of irrigation participation and non-participation on outcome variables (2nd stage ESR estimates)

Non-participation

Age	-0.0004	0.0014	**0.0327****	0.0144	**0.0013****	0.0006	**0.0004****	0.0002	**0.0028*****	0.0006
Gender	-0.0540	0.0420	0.5968	0.4383	0.0237	0.0174	**0.0161****	0.0068	**-0.0742*****	0.0164
Hhsize	**0.0370*****	0.0136	-0.0915	0.1775	-0.0036	0.0071	-0.0010	0.0028	**0.0153*****	0.0055
Flooded farm plot	0.0166	0.0126	0.0260	0.1330	0.0010	0.0053	0.0005	0.0019	-0.0018	0.0053
Income from livestock production	**0.1691*****	0.0418	**-2.2537*****	0.4873	**-0.0896*****	0.0194	**-0.0210*****	0.0067	-0.0038	0.0185
Education expenses	**0.3440*****	0.0684	**-4.5553*****	0.7189	**-0.1812*****	0.0286	**-0.0798*****	0.0105	-0.0264	0.0266
Remittances	-0.0746	0.0515	**0.9804***	0.5728	**0.0390***	0.0228	0.0112	0.0085	**-0.1002*****	0.0216

Non-farm activity	**0.0671***	0.0400	**-0.9289****	0.3775	**-0.0369****	0.0150	**-0.0227*****	0.0054	-0.0121	0.0147
Seasonal farming	-0.0023	0.0415	-0.5252	0.4204	**-0.0209**	0.0167	-0.0059	0.0066	**-0.0472*****	0.0170
Market outlet	**-0.0403*****	0.0130	**0.5816*****	0.1399	**0.0231*****	0.0056	**0.0114*****	0.0020	0.0027	0.0059
CDV	**-0.0443****	0.0224	**0.4605****	0.2151	**0.0183****	0.0086	**0.0078****	0.0032	**0.0375*****	0.0091
Rented land	0.0412	0.0372	**-0.6661***	0.3997	**-0.0265***	0.0159	-0.0061	0.0056	-0.0169	0.0163
Inherited land	0.0309	0.0634	-0.5585	0.5915	-0.0222	0.0235	-0.0043	0.0083	-0.0247	0.0240
Access to road	**-0.0783****	0.0366	**0.7658****	0.3804	**0.0304****	0.0151	**-0.0122****	0.0051	-0.0159	0.0148
Extension services	0.0628	0.0473	**-1.3142*****	0.4415	**-0.0522*****	0.0175	**-0.0227*****	0.0063	-0.0107	0.0180
Accessed credit facility	**-0.1506*****	0.0471	**1.1611****	0.5197	**0.0462****	0.0207	0.0116	0.0080	-0.0087	0.0210
Education	0.0753	0.0530	**-0.9939***	0.5104	**-0.0395***	0.0203	**-0.0140****	0.0071	**-0.0557*****	0.0211
Generalised residuals ($\rho 0$)	0.408	0.407	-0.330	0.568	-0.091	0.224	0.431	0.262	**-0.187*****	0.156
Interacted generalised residuals ($\rho 1$)	-0.810*	0.630	-0.781	0.668	0.237	0.426	-0.608	0.521	-0.099	0.218
Wald $\chi 2$ statistic	2 262.58***		3 913.18***		1 339.65***		172.87***		186.78***	

* Significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level

The availability of adequate water on plots of land significantly and positively contributes to the consumption expenditure per capita of the participants. The reliability of access to water for irrigation implies that farmers who participate in irrigation farming could improve the conditions of crops to increase farm productivity.

The results further indicate that investing in education could translate into poverty reduction for households that participate in irrigation farming. As one of the multidimensional indicators of poverty as defined by the World Bank (2018), low education achievements contribute to household poverty and investment in education reduces the poverty gap and poverty severity of rural households.

Thus, investment in adult education programmes could translate into a substantial equalising effect owing to the impact of the returns generated by irrigation investments, and consequently lead to improved household welfare.

The empirical results show that an increase in remittances would improve household welfare while reducing the poverty gap, poverty gap index, poverty severity and vulnerability to poverty of the irrigation participants. The findings of this study agree with those of Musakwa and Odhiambo (2020), who found that access to remittances reduces the poverty of households.

Farmers' participation in non-farm activities showed a negative and significant relationship with the welfare outcome variable for the participants in irrigated crop production. This could be ascribed to the transfer of resources and labour hours necessary to increase farm outputs to other non-farm activities. This result concurs with those of other studies (e.g., Dubbert, 2019) that have found a negative association of non-farm activities with household welfare. In comparison to the non-participation in irrigation farming, the results show a significant and positive influence on household welfare, while decreasing poverty levels.

Engagement in seasonal farming by farmers participating in irrigation is negatively correlated with the welfare outcome variable. This suggests that farming households that participate in irrigation-and only engage in seasonal farming are less likely to improve their poverty status, including their probability of being vulnerable to poverty in the following year. The seasonality in farming could be affected by seasonality in prices and income, which may have negative consequences for the financial status of the household and its ability to improve its welfare and poverty status. Blackmore et al. (2021) have reported a negative influence of seasonal farming on vulnerability to poverty and food insecurity, concurring with the results of this study. For non-participation in irrigation farming, the results show a positive and significant effect on alleviating the poverty status of rural households. This is expected, because farmers who do not irrigate and only practise seasonal farming are indifferent, given the fact that they rely only on rainfall and produce during raining season, thus incur no debt on or investment commitments for irrigation assets. This argument is based on the assumption that the impact of climate change on the production of the participants and non-participants is negligible, otherwise they would not be comparable. Furthermore, crop diversification in relation to participation in irrigation farming is statistically significant and has a positive effect on household welfare. This might be because households that participate in irrigation could easily diversify and, as a result, become better off in terms of a reduction in their poverty level, as well as reducing the potential of becoming poor in subsequent years.

These findings are consistent with those of Michler and Josephson (2017), who investigated the effect of agricultural diversification on poverty dynamics. According to their results, growing a variety of crops reduces the likelihood of non-poor households becoming poor and poor households remaining poor. On the other hand, non-participants in irrigation who practise crop diversification are more likely to experience a decrease in welfare, because growing diverse crops may require irrigation support, especially given the impact of climate change. This has a negative effect on the households' vulnerability to poverty.

The importance of the effect of having access to rented land on poverty reduction has been examined in Kenya by Muraoka et al. (2018). The result of this study is consistent with our findings, as there is a positive and significant effect of rented land on the welfare of participants in irrigation farming. For the non-participants in irrigation farming, access to rented land showed a negative association with household poverty levels, indicating a reduction in the poverty gap and poverty gap index. This could be attributed to lower transaction costs paid to landowners, with the exclusion of costs for irrigation operations (Ricker-Gilbert & Chamberlin, 2018).

Road access is statistically significant and positively influences household consumption per capita income for rural household farmers who are in the group participating in irrigation. This implies that farmers who have road access could easily access irrigation facilities, improve farm productivity, and subsequently increase their household consumption. Access to motorable roads also resulted in a reduction in poverty and household vulnerability to poverty for the irrigators. The results further show that poverty severity among non-irrigators could still increase, despite them having access to roads. This could be ascribed to the fact that non-irrigators could have smaller yields for sale, which may not contribute to improving their welfare or reducing poverty levels. The findings are consistent with those of Bacha et al. (2011), who found that road access improves household welfare.

Contact with extension agents has a significant effect on household welfare and poverty reduction. According to the findings, if irrigators have access to extension officers it improves their welfare, while significantly reducing their poverty gap, poverty gap index, poverty severity, and vulnerability to poverty. Extension visits were only significant in explaining poverty reductions among non-irrigators. This is consistent with expectations, as non-irrigators could also benefit from learning how to improve farm productivity, potentially narrowing the poverty gap and severity. The finding is consistent with those of Sinyolo et al. (2014) and Wossen et al. (2017), who found that access to extension services increases household consumption while decreasing poverty.

5.3.5 The falsification test results

In order to better identify the model, the study set exclusion restrictions, as suggested by Di Falco and Bulte (2013), which is done through falsification tests. The falsification results (see Appendix A) show that four instruments are jointly statistically significant in the irrigation participation equation ($Chi^2 = 35.95$; $p = 0.0000$), but not in the outcome equation for the participants ($F = 1.56$; $p = 0.1883$) and for non-participants ($F = 0.76$; $p = 0.5499$) when household consumption per capita expenditure is used as an outcome variable. In relation to the poverty gap, the result for the participants was ($F = 1.31$; $p = 0.2671$), while for non-participants it was ($F = 0.34$; $p = 0.8541$). For the poverty gap index, the result for the participants was ($F = 1.31$; $p = 0.2671$), and for non-participants it was (F = 0.34; $p = 0.8541$). Under the poverty severity outcome variable, the result for participants was ($F = 1.19$; $p = 0.3156$), and for non-participants it was ($F = 0.35$; $p = 0.8443$). Lastly, for the vulnerability to poverty outcome variable, the result for participants was ($F = 0.74$; $p = 0.5670$), and for non-participants it was (F = 0.45; $p = 0.7386$).

5.3.6 Treatment effects of outcome variables

The descriptive statistics for welfare and poverty outcomes presented in Table 5.2 show that irrigation participants were better off compared to the non-participants in irrigation farming. However, these significant differences do not imply causality, as the differences in the outcome variables are subject to self-selection bias. Table 5.5 presents the impact or effect of participation in irrigation farming on the outcome variables using the endogenous switching estimator. The ATT and ATU were estimated after fitting the switching regression with endogenous treatment effects.[1]

Table 5.5. Average treatment effect of irrigation participation on outcomes

Outcome variables	Treatment type	Participation	Non-participation	Treatment effects
Household consumption per capita expenditure	ATT	4.33	3.87	0.45***
	ATU	3.04	3.27	0.23***
Poverty gap	ATT	2.73	3.64	-0.84***
	ATU	2.86	2.67	-0.19***
Poverty gap index	ATT	1.09	0.90	-0.20***
	ATU	0.11	0.05	-0.05***
Poverty severity	ATT	1.04	0.82	-0.22***
	ATU	0.33	0.16	-0.17***
Poverty vulnerability	ATT	1.79	1.54	-0.25***
	ATU	0.75	0.76	0.003
F-stat	0.23	0.45	0.93	

** Significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level*

The results suggest that there is a significant change in terms of participants in irrigation farming. The increase in food consumption expenditure per capita shows the impact of participation in irrigation farming, which also has a statistically significant impact on reducing households' poverty gap, severity of poverty and vulnerability to poverty. The results show that, due to farmers' participation in irrigation farming, food consumption expenditure per capita increased by 45%, while non-participants would have increased their consumption per

[1] ATT and ATU were estimated as a post-estimation after fitting the Stata command, *switch_probit*, for switching probit regression with endogenous treatment. The ATT estimated after *switch_probit* is the potential outcome mean, while ATU is the conditional treatment effect.

capita expenditure by 23% had they participated in irrigation farming. For the poverty gap and poverty gap index, participating farmers lowered their poverty gap and poverty gap index by 84% and 20%, respectively, while non-participation in irrigation-based farming could have resulted in a 19% and 5% reduction in poverty gap and poverty gap index, respectively, had they opted to irrigate their farms. Moreover, the ATT for participation resulted in a decrease of around 22% in poverty severity, and this could also have led to a reduction of 17% in poverty severity for the non-participants in irrigation farming had they chosen to participate. Lastly, vulnerability to poverty was reduced by 25% owing to participation in irrigation farming, while non-participants could have reduced their poverty vulnerability by 3% had they participated in irrigation farming. Overall, the results of the ATT and ATU suggest that participation in irrigation farming contributes to improving household welfare and alleviating poverty in the study area.

5.4 Conclusion and recommendations

This study employed the ESR technique and poverty vulnerability approach to empirically analyse the factors that influence farmers' decisions to participate in irrigation farming and the impact on households' welfare and poverty. The gender of the household head, education, crop diversification, access to credit, water access and extension services were some of the driving factors that significantly influenced farmers' decision to participate in irrigation farming. The analysis of the estimated impact showed that credit access, extension contact, land ownership type, membership of a farmers' association and education training have a significant effect on increasing household consumption per capita expenditure and reducing household poverty. This study demonstrates that irrigation participation has a favourable and significant treatment effect on household welfare, as well as contributes significantly towards a reduction in the poverty gap, poverty severity and vulnerability of household to poverty. Given the significance of irrigation participation in poverty reduction and household welfare, the government, agriculture water managers and policymakers should scale up irrigation technology facilities, especially for poor households, and create more awareness to improve rural households' livelihoods. In order to raise more rural households from poverty and improve livelihoods, this study recommends policy implementations that will provide financial support programmes such as increasing access to credit facilities to enhance farmers' willingness to participate in irrigation farming. The findings of this study suggest that improving access to credit facilities and re-examining loan repayments could practically encourage poor households to participate in irrigation farming and increase productivity, which in turn will reduce their vulnerability to poverty. More importantly, the findings of this study could be instrumental in driving the first goal of Agenda 2063 and the Sustainable Development Goals (UN, 2015) in the context of achieving self-sufficiency and eliminating poverty in all forms, respectively. This could be achieved by improving food security in Africa, increasing irrigation technology in African regions faced with drought, which could go a long way to lifting many Africans out of poverty, as well as eliminating the vulnerability of households to poverty (in terms of Agenda 2063). Moreover, policies are needed to increase access to education, which could motivate non-participating farmers to consider the option of irrigating their farms. This could subsequently improve the overall agricultural productivity of the study area, hence leading to gradual poverty reduction and improved welfare for rural households.

This study recommends that future studies should consider the use of the national poverty line to investigate whether there could be significant variations in the results when compared to studies that used the global poverty line.

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Appendix A

Falsification test results

Outcome variables	Participants	Non-participants
Household consumption per capita expenditure	F (4, 154) = 1.56; Prob > F = 0.1883	F (4, 194) = 0.76; Prob > F =0.5499
Poverty gap	F (4, 154) = 1.31; Prob > F = 0.2671	F (4, 194) = 0.34; Prob > F = 0.8541
Poverty gap index	F (4, 154) = 1.31; Prob > F = 0.2671	F (4, 194) = 0.34; Prob > F = 0.8541
Poverty severity	F (4, 154) = 1.19; Prob > F = 0.3156	F (4, 194) = 0.35; Prob > F = 0.8443
Poverty vulnerability	F (4, 154) = 0.74; Prob > F = 0.5670	F (4, 194) = 0.45 Prob > F = 0.7386

Appendix B

Abbreviations

ATT - average treatment effect on the treated

ATU - average treatment effect on the untreated

DAFF - Department of Agriculture, Forestry and Fisheries.

ESR - endogenous switching regression

FAO - Food and Agriculture Organization

FGLS - feasible generalised least square

FGT - Foster, Greer and Thorbecke

IV - instrumental variables

OLS - ordinary least square

SSA - Sub-Saharan Africa

UN - United Nations

CHAPTER SIX

GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 General conclusions

The intersection of irrigation, poverty, and well-being is a critical nexus deserving scholarly attention. This study undertook a general investigation of the impacts of irrigation on the vulnerability to poverty, food security and welfare of rural farming households in South Africa using various relevant quantitative and qualitative methodologies to analyse the primary and secondary data. Having carried out this important research and identified the need to explore farming operations, household welfare and food security status, attention is now directed to communicating the key lessons of the research to policymakers, users and future researchers. It was pinpointed in this study that several factors have contributed to the participation of rural households in irrigation practices, and issues of food security and the welfare of the farmers in the study area were highlighted. More importantly, certain significant factors, such as access to market outlets, unemployment status and access to credit facilities, among others, were pointed out as some of the critical factors that have intensified the issues faced by rural household farmers. There is significant evidence that there is a pressing need to focus on the food insecurity and welfare issues faced by rural households in the Eastern Cape province of South Africa. As shown in the study, food insecurity, multidimensional poverty and the welfare of rural households require urgent attention by policymakers and all other relevant organisations and bodies that are concerned with the issues reported. Despite the efforts by the South African government to implement several welfare alleviation programs, the vast majority of the population in the poorest provinces are still faced with food insecurity issues, multidimensional poverty, high vulnerability to poverty and low standard of living.

This disclosure as it has been shown in this thesis depends on the understanding of the impact of irrigation engagement on the food insecurity, multidimensional poverty, vulnerability and welfare of rural households, as a solution to enhancing household standard of living and meeting the SDGs and Agenda 2030 targets. Several conclusions were drawn from this study, and they are presented based on the order of objectives listed in Chapter one.

6.2 Objective one

This objective was to systematically evaluate the impacts of irrigation access on vulnerability to poverty and food security.

6.2.1 The impact of irrigation on household vulnerability to poverty, and effects on food security in Africa: A review

In this study, the intricate relationship between irrigation practices, household vulnerability, and food security within the context of South Africa was investigated. The findings of this study underscore the critical importance of addressing food insecurity, particularly among rural households. Below are the key lessons:

1. **Irrigation Impact**: The analysis revealed that irrigation applications lead to improved crop yields and increased farm incomes. This positive effect directly contributes to poverty reduction and mitigates vulnerability among rural households.
2. **Innovative Approaches**: Based on the findings, the results reveal the need for the adoption of sophisticated methodologies. Specifically, the proposed multi-level framework and the conglomerate approach hold promise. These strategies enhance household food dynamics, resilience, and governance.
3. **Policy Implications**: The results of this study have significant implications for provincial, national, and global strategies. Policymakers must prioritize food security and poverty reduction efforts, aligning them with Sustainable Development Goals (SDGs).

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6.3 Objective two

The focus of the second objective was to assess the impacts of irrigation on farming household food security to foster irrigation utilization and poverty alleviation plans.

6.3.1 Effect of irrigation farming involvement on food security among rural household farmers: Empirical evidence from South Africa.

In this study, an endogenous treatment effect with ordered outcome was employed to explore the impact of irrigation on food security within rural households in South Africa. The econometric results reveal a positive association between irrigation involvement and improved food security. The findings are specifically highlighted below:

1. **Irrigation and Food Security**: The study establishes that access to irrigation positively influences food security outcomes. Rural households benefit from enhanced agricultural production and reduced vulnerability to food insecurity owing to irrigation participation.
2. **Key Factors**: Gender, household size, water supply adequacy, water rights, remittances, and community-driven initiatives (CDV) significantly shape farmers' decisions regarding irrigation participation. These factors contribute to mitigating food insecurity risks.

Building on the study findings, the following recommendations are proposed:

1. **Government Support**: Policymakers should allocate additional financial resources to bolster rural farmers' capabilities in engaging with irrigation practices. Strengthening agricultural infrastructure and providing training will enhance productivity and resilience.
2. **Zero-Poverty Agenda**: South Africa must prioritize measures aimed at eradicating poverty and vulnerability. Aligning with the World Bank's zero-poverty agenda necessitates targeted efforts to improve food security at the household level.
3. **Holistic Approaches**: Implementing community-led solutions, sustainable water management practices, and inclusive policies will fortify food systems and empower rural households.

In summary, the study underscores the urgency of addressing food insecurity through multifaceted strategies. By investing in irrigation and fostering resilience, South Africa can pave the way toward a more equitable and secure future, particularly for those in the poor rural areas such as Eastern Cape.

6.4 Objective three

The third objective was focused on examining the determining factors that shows the impacts of irrigation on farming household multidimensional poverty.

6.4.1 Towards the global zero poverty agenda: Examining the multidimensional poverty situation in South Africa.

In this comprehensive study, the Alkire Foster multidimensional poverty index, a robust tool developed by the Oxford Poverty and Human Development Initiative (OPHI), was employed to delve into South Africa's multidimensional poverty landscape. The study also used the probit model to analyse the determinants of multidimensional poverty and household vulnerability within this context. The key findings from the study are presented below:

1. **Deprivation Spectrum**: The deprivation indicator spans a wide range, from 5% to 90%. Notably, access to flush toilet facilities emerges as a critical factor influencing household standards of living (SDG11).
2. **Food Security and Education**: A significant proportion 66% and 55% of households' face deprivation in food security (SDG2) and education (SDG4), respectively.
3. **Influential Factors**: The probit analysis result underscores the impact of gender, remittances, crop diversification, seasonal farming, and market access on multidimensional poverty among Eastern Cape households.

Recommendations

Drawing from the insights gained from the study, the following actionable recommendations are proposed:

1. **Crop Diversification**: Policymakers should prioritize strategies that encourage crop diversification. By promoting a variety of agricultural products, resilience against multidimensional poverty can be enhanced leading to a reduction in multidimensional poverty level.
2. **Farmer Groups and Extension Services**: Strengthening farmer groups and improving extension services is crucial. These mechanisms empower rural communities, foster knowledge exchange, and enhance sustainable practices.
3. **Education Empowerment**: Education remains pivotal. Policies that incentivize rural communities to embrace education will empower local populations to innovate and combat poverty vulnerability effectively.

In summary, this study advocates for holistic approaches that address poverty across multiple dimensions. By implementing these recommendations, South Africa can advance its commitment to the Sustainable Development Goals and Agenda 2063, ensuring a more equitable and prosperous future for all.

6.5 Objective four

The focus of the fourth objective was to evaluate and investigate the impact of irrigation on vulnerability of poverty and welfare of farming households.

6.5.1 Impact of irrigation on welfare and vulnerability to poverty in South African farming households.

This study rigorously employed the ESR technique and a poverty vulnerability approach to analyse the intricate factors influencing farmers' decisions regarding participation in irrigation farming. The empirical analysis reveal the impact of this participation on household welfare and poverty. The following key findings extracted from the study are presented below:

1. **Determinants of Irrigation Participation**: Factors such as the gender of the household head, education levels, crop diversification, access to credit, water availability, and extension services significantly influence farmers' choices to engage in irrigation farming.
2. **Positive Treatment Effect**: The estimated impact underscores that irrigation participation positively affects household welfare. It contributes substantially to narrowing the poverty gap, reducing poverty severity, and enhancing overall well-being.
3. **Policy Implications**: Policymakers, agriculture water managers, and government bodies must prioritize scaling up irrigation technology facilities, particularly for impoverished households. Awareness campaigns are essential to uplift rural livelihoods.

Recommendations

The following recommendations are drawn and presented below:

1. **Financial Support Programs**: Implement targeted financial support programs, including enhanced access to credit facilities. These measures will incentivize farmers and bolster their willingness to participate in irrigation farming.

2. **Revisit Loan Repayment Mechanisms**: Re-examine loan repayment structures to encourage participation among poor households. Practical adjustments can foster productivity gains and reduce vulnerability to poverty.
3. **Agenda 2063 and Sustainable Development Goals (SDGs)**: Aligning with global agendas, South Africa should leverage these findings to drive poverty reduction efforts. By empowering rural communities, this can collectively lead to a sustainable development.

In summary, this study advocates for evidence-based policies that elevate rural households from poverty and enhance their livelihoods.

This study recommends that future studies should consider the use of the national poverty line to investigate whether there could be significant variations in the results when compared to studies that used the global poverty line.

6.6 Recommendations

6.6.1 *6.6.1 Suggestions on way forward*

The prospective benefits of addressing the issue of food insecurity in the Eastern Cape province are critical for the welfare or standard of living of the rural households, which are important highlights of the Sustainable Development Goals as well as the agenda 2063. Worldwide, there is an increasing attention among the international organizations, institutions and scholars regarding the need to eradicate multidimensional poverty, especially those in the rural communities who are living below the poverty line. While several studies have attempted to tackle the food insecurity and multidimensional issues, there are still areas yet to be investigated. Findings from this study have shown that the welfare of rural households are badly impacted particularly for households who are non-participants in irrigation farming, as those who participated in irrigation farming had better farm outputs and access to food resources compared to their counterparts.

Global organizations such as World Bank and the United Nations, as well as other reputable organisations are well known for their efforts towards eliminating food insecurity and multidimensional poverty. These organisations provide supports, financial aids as well as research outputs aimed at achieving the "Development Goals" objectives across identified countries and regions such as South Africa. It is important to point out that healthy household and environment are required to serve as critical natural capital to form the basis for agricultural productivity and to contribute to the national economic growth of South Africa. The core objective of measuring irrigation impact on household welfare, investigating multidimensional poverty and vulnerability to poverty as well as exploring the determinants of food insecurity encompasses the identification of pathways towards poverty alleviation, promoting strategies for eliminating multidimensional poverty, and building household resilience against hunger caused by food insecurity. A clear understanding of the benefits provided by this thesis, from a perspective of "zero hunger" as well as the positive impact and advantage from participating in irrigation farming as a means to elevate household welfare revolves around the potentials of government to initiate support programs to monitor situations in the rural regions so as to align with the goal of this study. Additionally, this will foster the initiation of policy and innovative approaches among policyholders and stakeholders to achieve and promote the objectives of this study. To make the most of these combined effects, strategic development must start at the level of implementation.

6.6.2 Limitations of the study and future research suggestion.

This section presents the limitations of the study and future research suggestions. While this research contributes valuable insights, the limitations of the study are presented below, and future research recommendations are also presented:

1. **Omission of Existing Irrigation Schemes**:
    - The study did not explicitly consider existing irrigation schemes or assign farmers to specific schemes based on their locations.
    - By overlooking this aspect, the potential variation related to scheme-specific factors influencing farmers' decisions to participate in irrigation farming might have been excluded.
2. **Land Size Not Accounted For**:
    - The actual land size utilized by farmers was not a focal point in our analysis.
    - Consequently, there was a lack detailed information on production quantities and how land size directly impacts poverty status among farmers.

Recommendations for Future Research

To address these limitations and advance the scientific understanding, future research endeavors should consider the following:

1. **Scheme-Level Investigations**:
    - Conduct in-depth studies that delve into specific irrigation schemes. Analyse the dynamics, management practices, and socio-economic factors unique to each scheme.
    - Explore how scheme characteristics influence farmers' choices and overall welfare.
2. **Fine-Grained Land Analysis**:
    - Incorporate precise land size data into research designs. Investigate how variations in land holdings impact agricultural productivity, income, and poverty vulnerability.
    - Consider both small-scale and large-scale farmers to capture the full spectrum of land sizes.

Overall, while this study provides valuable insights, further exploration is needed to enhance the knowledge of irrigation's impact on poverty and household welfare.

7. Appendices

Appendix 1: Submitted article 1

Scientific African

The impact of irrigation on household vulnerability to poverty, and effects on food security in Africa: A Review

--Manuscript Draft--

Manuscript Number:	SCIAF-D-23-02182
Article Type:	Review Article
Section/Category:	Agriculture and Food Security
Keywords:	food security; poverty alleviation; vulnerability; irrigation
Corresponding Author:	ADETOSO ADEBIYI ADETORO University of KwaZulu-Natal Bloemfontein, Free State SOUTH AFRICA
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	Mjabuliseni Simon Cloapas Ngidi, PhD
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	Collins C Okolie, MSc
Abstract:	The importance of irrigation technology participating in eliminating vulnerability to poverty and improving wellness is directly associated with food security. This study examined the alleviation of household vulnerability to food insecurity and poverty in line with the emerging scholarship of synergising the impacts of irrigation and its implications for family susceptibility to poverty and food security and sustainability. This study employed the documentary analysis approach and bibliometric technique to mine and analyse relevant documents for evaluating facts and evidence, which largely concurs with the method of information gathering used in the qualitative study method. The study's findings have significant policy implications for national, provincial, and continental strategies for determining household susceptibility to food insecurity and poverty, which is essential for gauging the success of the Sustainable Development Goals plan. In the analysis period (1991-2022), the highest article on impacts of irrigation on household poverty was published in 2022, indicating the growing concern on depleting food resource access. Overall, the findings revealed that irrigation applications produced better yields and increased farm incomes thereby reducing rural household poverty as well as vulnerability to poverty. This study suggests that more sophisticated and innovative methods need to be developed and implemented such as the proposed multi-level framework, conglomerate approach, and community-led solutions, to foster the household food dynamics, food system resilience and governance in the context of South Africa (SA).

Appendix 2: Submitted article 2 (Under Review)

Journal of Agriculture and Food Research

Impact of irrigation farming involvement on food security among rural household farmers: Empirical evidence from South Africa.

--Manuscript Draft--

Manuscript Number:	JAFR-D-23-01244
Full Title:	Impact of irrigation farming involvement on food security among rural household farmers: Empirical evidence from South Africa.
Short Title:	Impact of irrigation farming involvement on food security
Article Type:	Full Length Article
Section/Category:	Agriculture
Keywords:	food insecurity; irrigation farming, extended ordered probit regression
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Abstract:	The decline in the welfare of rural household farmers is concerning and requires urgent management, which could lead to numerous negative effects on the household food security status. However, the importance of the involvement of rural household farmers in irrigation farming as a means to eliminate food insecurity has not been extensively explored in the poorest areas in South Africa. Therefore, this study investigates the factors that influence rural household farmers' involvement in irrigation farming and examined their impact on household food insecurity. The study employed probit regression and an extended ordered probit regression model to achieve the objectives of the study. The empirical results show that rural households' food insecurity has a greater likelihood to reduce when they are involved in irrigation farming as this increases their productivity and access to food, particularly in an event of extreme weather-related shock such as drought. The findings also show the household gender, size of household, unemployment status, market outlet, remittances and crop diversification (CDV) factors increases the likelihood of the rural farmers' involvement in irrigation farming as well as reduce their food insecurity. Based on the findings of this study, we suggest a review of the government intervention policies, and a restructuring of rural operations to include more technological innovations such as advanced irrigation systems.

Appendix 3: Published article 3

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ORIGINAL PAPER

Towards the global zero poverty agenda: examining the multidimensional poverty situation in South Africa

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Abstract
The vulnerability of smallholder farmers to multidimensional poverty in the Eastern Cape province of South Africa was assessed, using the Alkire Foster multidimensional poverty index developed by the Oxford Poverty and Human Development Initiative and aligned to the Sustainable Development Goals (SDGs). The findings show that the deprivation indicator ranges from 5 to 90%, revealing that access to a flush toilet facility is an imperative factor towards the households' standard of living (SDG11). Also, 66% and 55% were deprived of food security (SDG2) and education (SDG4), respectively. The probit analysis result revealed that gender, remittances, crop diversification (CDV), education, seasonal farming and market outlets significantly influence the multidimensional poverty and vulnerability poverty of rural households in the Eastern Cape province of South Africa. For instance, factors such as household size showed that an additional unit increase in the size of a household would result in a 5% increase in the chances of the household's vulnerability to multidimensional poverty. Likewise the extension contact, a unit increase resulted in 49% in the households' vulnerability to multidimensional poverty. The study suggests that policies related to improving education, increasing CDV, promoting farmer groups and the effectiveness of extension contact, and increasing market stability for sales of farm products could contribute to reducing the multidimensional poverty level and the vulnerability of households.

Keywords Multidimensional poverty · Sustainable Development Goals · Poverty vulnerability · Eastern Cape

Appendix 4: Published Article 4

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Impact of irrigation on welfare and vulnerability to poverty in South African farming households

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ABSTRACT

Many empirical studies have documented the role of farm management practices such as irrigation in reducing poverty and improving household well-being. Few studies, however, have looked at the impact of irrigation farming on poverty vulnerability and the welfare of rural farming household. This study examined the factors that influence farmers' participation in irrigation farming, as well as how it affects farmers' food consumption expenditure per capita (proxy for welfare), poverty gap index, poverty severity and poverty vulnerability. The study's data was collected from farming households in the northern and coastal parts of the Eastern province of South Africa. The endogenous switching regression (ESR) model was employed in the study to account for selection bias that could be caused by both observed and unobserved household factors. The empirical result shows that gender, household size, educational attainment, crop diversification, and market outlet among others influenced farmers' decision to practice irrigation farming. Farmers engaging in irrigation farming boosted their food consumption per capita by 44%, while non-participants would have increased their consumption expenditure per capita by 23% if they had participated. Moreover, participating farmers reduced their poverty gap index by 20% and poverty severity by 22%, whereas non-participating farmers could have reduced their poverty gap index and poverty severity by 5% and 17%, respectively had they engaged in irrigation farming. Participation in irrigation farming also reduced poverty vulnerability by 25%, while non-participants may have reduced poverty vulnerability by 3%. The findings suggest that enhancing farmers' access to irrigation is crucial to meeting the Sustainable Development Goals (SDGs), which aim to eradicate poverty in all its manifestations everywhere.

Appendix 5: Ethical Note

Some parts of the SAVAC datasets were used for this study, therefore the permission is provided.

agriculture, land reform
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Dear Dr Ngidi

RE: PERMISSION FOR USE OF SAVAC DATASETS

Thank you for your letter dated 29 January 2021, in which you request the Department of Agriculture, Land Reform and Rural Development (DALRRD) to **use the SAVAC datasets for PhDs, Masters and publication of papers.** Permission is granted expressly for use in the Masters and PHD as listed in your letter. The data remains the property of the South African Vulnerability Assessment Committee (SAVAC) as the originator. Users are expected to respect the intellectual property rights of the SAVAC. It is therefore expected that the analysis and insights emanating from the use of this data will be shared with the SAVAC Chairperson.

Yours Faithfully,

[redacted]

MR M MAMADI
DIRECTOR: SUBSISTENCE FARMING