

University of KwaZulu-Natal

The governance-institutions nexus in water management for climate change adaptation in smallholder irrigation schemes in Zimbabwe

By

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ABSTRACT

Smallholder irrigation schemes (SISs) are crucial for improving food and income security in rural communities in a changing climate. However, despite huge investments and substantial development, most of the schemes have been performing below expectations. This study synthesizes governance-institutional nexus in water management from climate change adaptation in SISs, highlighting the linkage between scheme management and climate change. This study used qualitative and quantitative surveys to collect data from 317 scheme farmers in Exchange, Insukamini and Ruchanyu irrigation schemes of Midlands province, Zimbabwe.

The overall objective of this study was to explore the governance-institutions nexus in water management for climate change adaptation in SISs. The specific objectives of the study were: (1) to assess livelihood vulnerability of households in SISs to climate change, (2) to assess the impacts of institutional and governance factors on the adaptive capacity of SISs, (3) to identify gendered perception on the prevalence and management of pests in SISs given climate variability and change, and (4) to assess the water footprint and nutrient content for the crops grown in the schemes. To achieve these objectives, different studies were conducted.

In the first component of the study, the Livelihood Vulnerability Index (LVI) and the Livelihood Vulnerability Index—Intergovernmental Panel on Climate Change (LVI-IPCC) was used to compare vulnerability to climate change in the Exchange, Insukamini, and Ruchanyu SISs in the Midlands Province of Zimbabwe. Results show higher exposure and sensitivity to climate change in the Insukamini irrigation scheme despite the higher adaptive capacity. Both LVI and LVI-IPCC show that households in Insukamini irrigation scheme are more vulnerable to climate change than in Exchange and Ruchanyu irrigation schemes, attributed to water insecurity, poor social networks, and droughts. The study recommends that development and investment in Insukamini and Ruchanyu should prioritize improving social networks while Exchange should primarily focus on improving livelihood strategies. Vulnerability analysis using LVI-IPCC is crucial to better understand the vulnerability of smallholder irrigation schemes farmers to climate change. For instance, it can be used to explore the contribution of socio-economic, institutional and governance factors to the vulnerability of the SIS communities. This will contribute to improved water management for climate change adaptation.

This chapter reveals factors that can be considered to increase the resilience SISs in a more variable climate.

In the second component of the study, socio-demographic, governance and institutional factors that influence adaptive capacity in Exchange, Insukamini and Ruchanyu irrigation schemes were explored. Questionnaire-based interviews, group discussions and key informant interviews were used for data collection. Adaptive capacity calculated using the livelihood vulnerability model was used as the dependent variable. Ordinary least square regression was used to assess socio-demographic, institutional and governance factors influencing adaptive capacity in the smallholder irrigation schemes. We accept the hypothesis that stronger institutions positively influence the adaptive capacity of smallholder irrigation systems. The study reveals that adaptive capacity was significantly ($P \leq 5\%$) influenced by a margin of 0.026 for age squared, 0.073 for gender, 0.087 for education, 0.137 for household size, -0.248 for satisfaction with irrigation committee, 0.356 for participation in irrigation water scheduling, and -0.235 for participation formulation of rules. This chapter reveals factors that can be considered to adaptation to climate change in SISs.

In the third component of the study, Mann-Whitney U test was employed to assess perception on the prevalence of pests between male and female farmers. Findings from this study depict that the females perceived a higher prevalence of cutworms (*Agrotis Ipsilon*) ($P \leq 0.01$), red spider mites (*Tetranychus urticae*) ($P \leq 0.01$), maize grain weevils (*Sitophilus Zeamais*) ($P \leq 0.01$), and termites (*Isoptera*) ($P \leq 0.01$) than males, while men perceive a higher prevalence of fall armyworms (*Spodoptera Frugiperda*) ($P \leq 0.01$), bollworms (*Helicoverpa armigera*) ($P \leq 0.01$) and whiteflies (*Aleyrodidae*) ($P \leq 0.1$) than females. Perception of the prevalence of pests was based on farmers' experience and shapes how they manage pests. Utilisation of gendered perception on pest in this chapter enables institutions and governance systems to consider gendered perception on climate change adaptation. Meanwhile, understanding water footprint is crucial to advise farmers to grow water use efficiency crops.

Lastly, water footprint approach was used to assess the water metrics and nutrient-water matrix of food crops grown in three SISs in Midlands Province, Zimbabwe. The nutritional matrix of food crops was calculated based on the study done in Exchange, Insukamini, and Ruchanyu Irrigation Schemes in Zimbabwe. Given that the average yield ranges from 1.04 t/ha for sugar beans (*Phaseolus vulgaris*) to 30.60 t/ha for cucumber (*Cucumis Sativus*), the water footprint ranges from

278.85 m³/t for cucumber to 4762.98m³/t for sugar beans. Maize (*Zea Mays*) and wheat (*Triticum Aestivum*) are energy and carbohydrates rich crops with lower water footprints. Sugar beans have a higher protein content and water footprint, okra have high zinc content and low water footprint, while wheat has higher iron content and low water footprints. Interventions should focus on improving water footprint and opt for crops with the higher nutrient value of key nutritional elements like protein, zinc, and iron to fight hidden hunger. Climate change adaptation in SISs needs understanding of water footprint and nutrient security of the scheme communities.

DECLARATION

I, Liboster Mwadzingeni, declare that:

1. The research reported in this thesis, except where otherwise indicated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other University.
3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
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Signed

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As the candidate's supervisors, we agree to the submission of this thesis:

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Dr. Raymond Mugandani (Co-Supervisor)

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DEDICATION

I dedicate this work to Phyllis, Kangamwiro and Learnmore.

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LIST OF ACRONYMS

AEZs – agro-ecological zones

AGRITEX - Agricultural Technical and Extension **Services**

CPRs – **Common**-pool resources

CSES – **Complex** socio-ecological systems

DANIDA – Danish International Development Agency

DIRR – Department of Irrigation

ESAP – Economic Structural Adjustment Program

FAO – Food and Agricultural Organization

FAW – **Fall** armyworm

GCMs – General Circulation Models

GFFW – Global Fund for Women

FGDs – Focus Group Discussions

FSA – Food Safety Authority

GDP – Gross Domestic Product

GMB - Grain Marketing Board

GoZ – Government of Zimbabwe

GVP – **Gross** value of production

HIV/AIDS – human immunodeficiency virus/ acquired immunodeficiency syndrome

HLPE – High Level Panel of Experts

IFAD – International Fund for Agriculture Development

IMCs – **Irrigation** management committees

IMT – **Irrigation** management transfer

IPCC – Intergovernmental Panel on Climate Change

IPPC – International Plant Protection Convention

IWRM – International Water Resources Management

KIIs – Key Informant Interviews

KW – **Kilowatt**

LIV – Livelihood Vulnerability Index

LIV-IPCC – Livelihood Vulnerability Index—Intergovernmental Panel on Climate Change

MLAWCRR – Ministry of Lands, Agriculture, Water, Climate and Rural Resettlement

MSD – Metrological Services Department

NAPs – National Adaptation Plans

NCSs – **Nutrient** content scores

NGOs – Non-Governmental Organisations

RCP – Representative Concentration Pathway

SDGs – Sustainable Development Goals

SIRP – Smallholder Irrigation Revitalization Programme

SISs – smallholder irrigation schemes

SMSs – Small Massaging Services

SSA – **Sub**-Sahara Africa

TVs – **Televisions**

UN – United Nations

UNESCO – United Nations Educational, Scientific and Cultural Organization

UNFCCC – United Nations Framework Convention on Climate Change

UNSCN – United Nations System Standing Committee on Nutrition

WHO - World Health Organisation

WRPID – Water Resources Planning and Irrigation Development

ZAPF – Zimbabwe Agricultural Policy Framework

ZIMSTAT – Zimbabwe National Statistics Agency

ZINWA – Zimbabwe National Water Authority

CHAPTER 1:

INTRODUCTION

1.1 Background to thesis

The contribution of the agricultural sector to the economies of most countries in sub-Saharan Africa (SSA) can never be exaggerated. The sector **directly employs 175 million people and** employs more than 50 % of the total labor, provides a source of livelihood for the majority of the smallholder farmers who own more than 80% of farms in the region (Rapsomanikis, 2015). In SSA, agriculture is important for national food and nutritional security and provides farmers with extra income (FAO, 2012). The sector is failing to guarantee the food and nutrition status due to low yields which have been attributed to heavy dependency on rain-fed agriculture and underutilization of available water resources to increase the resilience of farming systems in a changing climate (Mbira and Moyo., 2018). **In fact, SSA, faces an enormous challenge of feeding the projected 1.4 billion people by 2030 and 2.1 billion people by 2050 (UN, 2019).**

There is a **wide** gap between actual and yield potential due to insufficient moisture, low soil fertility, **poor crop management, and increased incidences of droughts** (Mueller *et al.*, 2012). The yields, which have stagnated or **declined** in the majority of the countries in the region, are expected to decline further as the majority of the General Circulation Models (GCMs) project that the frequency and severity of droughts are expected to increase across Africa (Pinto *et al.*, 2018, Freeman *et al.*, 2019), especially in SSA. **Resulting in region food insecurity** given the mismatch between population increase and food demand by 2050. Moreover, only about 4% of the land is under irrigation in SSA despite the huge potential in closing the yield gap that can be realized by expanding the area under irrigation (van Ittersum *et al.*, 2016). In the absence of adequate adaptation measures, especially in the water-related sectors, a majority of countries in SSA will fail to meet their food and nutritional security objectives. At the same time, an estimated 60% of the population in the region currently resides in the communal areas, depending on **rain-fed** agriculture for food, nutrition and income security (Githira *et al.*, 2020).

Irrigation schemes **complements other strategies** strategy to increase the resilience of smallholder rain-fed farming systems in the face of climate change **given that the area under irrigation in SSA**

is just too low, less than 5% (Cooper *et al.*, 2008). Governments, local and international aid agencies, have over the years made substantial investments in irrigated agriculture in the region. They present a huge opportunity for SSA where agricultural output has to increase by 60 – 70 percent in order to meet the food demands of a growing population (UN, 2019). However, despite the huge investments, SISs in SSA have failed to meet the food security and nutritional objectives due to their poor performance (van Ittersum *et al.*, 2016). This poor performance has been linked to climate-related challenges, including water stress, pests and diseases, poor water governance and weak institutions (FAO, 2011). However, there is cursory scholarship literature on the link between governance and institutional capacity and water resources management in irrigated areas in smallholder farming systems in SSA, particularly in Zimbabwe. Moreover, it is very difficult to achieve the intended outcome of reducing the vulnerabilities of smallholder farmers in the face of climate change without focusing on governance. Institutional frameworks and weak institutions for water governance can lead to frequent water shortages and conflicts among smallholder farmers.

Thus, a contextual and empirical understanding of governance and institutional frameworks in a changing climate is pertinent for the development of practical solutions that can configure the trajectory of smallholder irrigation schemes in SSA in general and Zimbabwe in particular. Accordingly, management systems need to be productive and resilient, where alternative approaches align short-term gains with long-term benefits that seek to reconcile economic and environmental goals (Shinbrot *et al.*, 2019). Smallholder farmers adopt a wide range of short-term tactics and long-term strategies with different environmental and economic outcomes (Rodriguez *et al.*, 2014). However, agricultural water management that includes a wide range of technical, infrastructure, economic and social factors is needed (Iglesias and Garrote., 2015). The additional problem of deep uncertainties resulting from climate change is likely to increase in the next decade (Campbell *et al.*, 2016); hence, there is urgent need to develop institutions that can cope with these challenges for sustainably increasing agricultural productivity especially in SISs. How rapidly governance and institutions in water management adjust to changes in their environment is a central question in climate change adaptation and is important for policy design across climate change adaptation domains.

According to Mubaya and Mafongoya (2017), the success of these adaptation efforts generally hinges upon the nature of existing formal and informal rural institutions. Therefore, climate change adaptation is a broader development challenge that can potentially be addressed through broader adaptation pathways within the development framework (Campbell *et al.*, 2016, Mubaya and Mafongoya, 2017). The rationale of this study is to link climate change adaptation to broader development efforts with the purpose of developing a link among governance, institutions nexus, and climate change adaptation.

1.2 Problem Statement

Irrigated agriculture, which allows smallholder farmers to grow crops all year round, might increase food security globally, especially SSA, where crop yields are constrained by erratic rainfall patterns (Pittock *et al.*, 2020). Thus, this is supposed to reduce vulnerability of smallholder farmers to climate change. However, the dismal failure of the SISs to improve food security, reduce poverty and improve national economic outlook due to well documented poor performance of these schemes shows that these farmers remain vulnerable to climate. Hence, **SISs**, which are complex socio-ecological systems (CSES), are experiencing economic loss in the face of worsening drought conditions in the region (Bjornlund *et al.*, 2018). However, much of this increased vulnerability does not fall from the sky (Pittock *et al.*, 2020), given the multifarious challenges faced by these CSES, something that has received less significant attention from designers, funders and managers of the **SISs** (Bjornlund *et al.*, 2018). In addition, factors that make these CSES has received less research traction. The effects of drought may not be eradicated among the rural poor if the livelihood vulnerability of smallholder farmers is not explored. Livelihood vulnerability varies spatially, temporary and among social groups; therefore, there is urgent need to explore the factors contributing to the current livelihood vulnerability of the smallholder irrigation scheme farmers.

The sustainability of **SISs** is being threatened by the worsening state of climate change **challenging water access** without management to cope with the existing magnitude of climate change (Berbel *et al.*, 2015, McCornick *et al.*, 2013). The poor performance of SISs has been attributed to a combination of socio-economic, climatic, political, institutional and design factors (Mutambara *et al.*, 2016).

In addition to the above, it is crucial to mention that the success of irrigation management transfer (IMT) depends on both collective action and institutionalization (Rahman *et al.*, 2012). Formal and informal institutions affect natural resource management by communities and local regulatory regimes, respectively (Rahman *et al.*, 2012). The complex institutional landscape can improve water productivity. Therefore, governance and institutions are critical factors of water management in adaptation and resilience to climate change. However, there is limited empirical research exploring how governance and institutions affect the adaptive capacity in smallholder irrigation schemes. This makes it difficult to establish the reasons for low and decreasing crop and water productivity in SISs, leading to continued poverty, unemployment, hunger and starvation (Mutambara *et al.*, 2016). Such risks need urgent actions to ensure the resilience of Zimbabwe's agricultural sector against climate change impacts. Therefore, there is a need to assess the response of governments and institutions to climate change to draw clear anticipation on the necessary adaptation measures.

Climate change will likely change the patterns of outbreak of pests and diseases, increase the frequency and severity of pest events, thus making agricultural systems at higher risk during the 21st century (Bebber *et al.*, 2013). Thus, smallholder irrigation scheme farmers need to effectively control pests to reduce crop losses and ensure food security. Pests are responsible for crop damages, accounting for more than 40% worldwide (Mafongoya *et al.*, 2019). The spread and outbreak of pest species are being facilitated by climate change and dynamic weather patterns (Mafongoya *et al.*, 2019). On the other hand, new microclimates as a result of irrigation together with monoculture practices, the introduction of higher-yielding varieties have been proffered as possible reasons for the worsening proliferation of new pests (Rathee & Dalal, 2018). Several inventions have been developed in the field of controlling pests like crop rotation, chemical pests and biological control, yet there is a persistent outbreak of pests in face of climate change. Food insecurity is likely to be more severe if there are no adequate measures to curb the outbreak of pests in the country and the region. Given that changes in pest outbreak is likely to be location specific depending on management, farming systems, and existing institutional capacity, one would expect the challenge of pests and diseases and solutions to such to be context specific. Although similar cases have been observed in the region, there is a knowledge gap on the current outbreak of indigenous and exotic pests among irrigation schemes in Zimbabwe. Knowledge about

the current state of emerging pests will help to map the vulnerability of **SISs** farmers to emerging pests in face of climate change.

Malnutrition, which is connected to rising illness, mortality and substantial healthcare costs, is an increasing world health concern (Vassilakou, 2021). The Covid-19 pandemic has increased global pressure of food security, poverty, hunger and undernutrition, thus, challenging achievement of SDGs 1, 2 and 3. The number of people facing hunger jumped from about 650 million in 2019 to 768 million in 2020 (FAO *et al.*, 2021).

SISs offer a real opportunity to address global malnutrition. However, given the narrow opportunity for readdressing food, hunger and nutritional insecurity due to increased water stress, there is urgent to identify nutrient-dense crops which have high water use efficiency in the alignment of the freshwater use planetary boundary of 4000 **km³/year** blue water consumption (Gleeson *et al* 2020). This threshold has already been surpassed (Leng and Hall, 2021, Sokolow *et al.*, 2019, Gleeson *et al.*, 2020). Despite accounting for a small component of the global water, renewable freshwater is the base in freshwater and terrestrial ecosystems (Jackson *et al.*, 2001). Thus, it is crucial to increase water productivity in SISs. Irrigation currently account for 70% of the global freshwater withdrawals (FAO, 2011, Damerau *et al.*, 2019). Thus, it is critical to address nutritional and water insecurity challenges using a nexus approach (Brewis *et al.*, 2020) for adaptation planning, particularly in rural areas (Bacon *et al.*, 2021). **However**, to the best of our knowledge, there is dearth of scholarship literature exploring the link between nutrient density and water footprint in SISs of Zimbabwe. Such information is crucial to inform decision makers on how to address **malnutrition** and water insecurity while improving environmental sustainability.

1.3 Justification

Prioritizing irrigation schemes in communal areas will ensure food and nutritional security at both household and regional levels; hence the detrimental effects of climate change will be scaled down (Muchara *et al.*, 2016). Governments in Africa support smallholder irrigation schemes to alleviate poverty, create jobs, boost pro-poor sustainable agriculture and economic growth (van Koppen *et al.*, 2017). Therefore, the promotion of smallholder irrigation is a strategy that paves the way to enhanced income generation, increases food security, and reduces persistent poverty among poor farmers in SSA (Burney and Naylor, 2012). This study is an instrument for the government, NGOs and policymakers to combat hunger and food and nutrition insecurity at household, national and

regional levels through the development of policies that promote operational efficiency of irrigation schemes in drought-prone areas. This will translate to the reduction of treasury expenditure on food security and increased government focus on the provision of public goods.

1.4 Research Questions

The main question governing the study is; what are the roles of water governance and institutions on climate change adaptation among smallholder irrigation schemes in Zimbabwe?

The research questions addressed by the study are:

1. How vulnerable are households in smallholder irrigation schemes to climate change?
2. What are the impacts of institutional and governance factors on the adaptive capacity of SISs?
3. What is the gendered perception of the prevalence and management of pests in smallholder irrigation schemes given climate variability and change?
4. What are the water footprint and nutrient content for the crops grown in the schemes?

1.5 Objectives

The aim of this study is to explore the governance-institutions nexus in water management.

The study, therefore, seeks to do the following:

- a) To assess livelihood vulnerability of households in smallholder irrigation schemes to climate change.
- b) To investigate the impacts of institutional and governance factors on the adaptive capacity of smallholder irrigation schemes.
- c) To identify gendered perception on the prevalence and management of pests in SISs given climate variability and change.
- d) To evaluate the water footprint and nutrient content for the crops grown in the schemes.

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CHAPTER 2

DYNAMICS OF VULNERABILITY IN SMALLHOLDER IRRIGATION SCHEMES TO CHANGING CLIMATE IN ZIMBABWE¹

Abstract

Irrigation have been portrayed as a panacea to **negative impacts of** climate change. However, there is an emerging discourse that established schemes are becoming vulnerable to increased climate variability and change. This paper reviews the existing knowledge on vulnerability to climate change and variability of smallholder irrigation schemes in Zimbabwe. In addition, this paper highlights adaptation options to climate change in smallholder irrigation schemes. Data for this review was collected systematically from peer-reviewed and published literature. The literature used for this study showed that smallholder irrigation schemes in Zimbabwe are beset with water stress, competing water needs and the outbreak of pests and diseases, which have been identified with climate change and variability. **Challenges related to governance-institutional nexus contribute to vulnerability of scheme farmers.** The existence of these challenges affects smallholder irrigation schemes' productivity and decimates the livelihoods of scheme farmers. The review suggests that for smallholder irrigation schemes to obtain a new state of resilience from adverse effects of increased climate variability and change, there is a need for increased absorptive, adoptive and transformational capacity. This review recommends the need to understand and prioritize vulnerability to climate change in smallholder irrigation schemes. In addition, there is a need to continuously monitor and address water stress, competing water needs and incidences of pests and diseases in smallholder irrigation schemes in the wake of climate variability and change.

Keywords: rainfall, drought, temperature, water stress, pests, diseases

2.1 Introduction

The physical science basis of climate change strengthened by huge financial research investments is now a mature discourse. The Intergovernmental Panel on Climate Change (IPCC) has concluded that human-induced climate change is unequivocal (IPCC, 2014), while 97% of climate experts

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agree about human-induced climate change (Cook *et al.*, 2016). The change in climate experienced world-wide already has negative implications for 21st-century agriculture in Zimbabwe (Gukurume, 2013). **Human-induced climate change are human activities that fundamentally result in global warming (Cook *et al.*, 2016).** Globally, the major abrupt influence of a changing climate in the agricultural sector will be through a more variable precipitation pattern, increased temperatures and an increase in the frequency and severity of extreme weather events, such as cyclonic activities, droughts and floods (Kotir, 2011). The impacts of climate change on water resources, including quantity and quality of water, are a growing concern in smallholder farming systems, particularly in those areas already experiencing water stress (Kotir, 2011, Muzari *et al.*, 2016, Benitez *et al.*, 2018). Some authors have documented the possible impacts of climate change on new and emerging pests and diseases (Mafongoya *et al.*, 2019, Kutwayo *et al.*, 2013, Brazier, 2015). However, addressing the impact of climate change must be considered in the broader picture of socio-economic conditions, including policies, institutional, investments, financial and technical factors which affect the vulnerability of systems to climate change.

There is mounting evidence that large investments have been made in Zimbabwe's smallholder irrigation schemes (SISs) in an attempt to depart from rain-fed agriculture through judicious harnessing of available water resources (GoZ, 2021a). However, there is a rising concern about need to build the resilience of these schemes to protect investments in light of a more variable climate.

In this article, climate variables and socio-economic factors are reviewed to inform decision-makers on possible action to build resilience with a particular emphasis on SISs in Zimbabwe. **This review seeks to explore vulnerability of SISs in Zimbabwe to climate change. The study hypothesizes that SISs in Zimbabwe are vulnerable to climate change.**

2.2 Development and investments in SISs, status and trends

Since pre-independence era, the development of SISs has been spearheaded using different management models (GoZ, 2021a). Over the past forty years, the Government of Zimbabwe (GoZ) has made significant investments in SISs. During the post-colonial era (1980 to date), the government intensified the development of SISs. In 1980, about 4 400 ha were under SISs (Rukuni, 1984, Rukuni, 1988). At the same time, 81 SISs were operational (Rukuni, 1984). In 2000, the total area under SISs rose to 11 860ha while the number of SISs increased to 187 (Makadho *et al.*,

2001). The area under SIS farming as a percentage of the total irrigated area rose from 3.4% in 1980 (Rukuni, 1984) to 9.8% in 2000 (Makadho *et al.*, 2001). Between 2000 and 2020, the area under SIS rose by about 119% to 26 000 ha (GoZ, 2021a). The land redistribution programme resulted in an increase in land under SIS farming as the land was acquired from large-scale commercial farmers and divided into smallholder irrigation plots (ADBG, 2011). According to GoZ (2015), Zimbabwe has a potential irrigable area of approximately 600 000 ha. As indicated in Table 1, the government proposed to develop 29 000 ha of SISs, increasing area under SISs by 112% to 55 000ha by 2025 (GoZ, 2021a).

Table 2. 1: Proposed smallholder irrigation development from 2021-2025

Year	Area (ha)	Percentage	Total area under SISs (ha)
Base year (2020)			26 000
2021	4 000	15.38	30 000
2022	5 000	34.62	35 000
2023	5 000	53.85	40 000
2024	5 000	73.08	45 000
2025	10 000	111.54	55 000

Adapted from (GoZ, 2021a)

Meanwhile, the GoZ has managed to mobilize funds for development and revitalization of SIS annually after independence (Zawe *et al.*, 2015).

Among its initiatives, the GoZ has bilateral agreements with Brazilian, Chinese and Indian governments towards the development of SISs. Ministry of Lands, Agriculture, Water, Climate and Rural Resettlement (MLAWCRR) mobilized a loan of US\$98 million from the Brazilian government for SIS development (Mosello *et al.*, 2017). The Government of China is focusing on transferring technology to SISs (Mosello *et al.*, 2017). International Fund for Agriculture Development (IFAD) initiated **Smallholder Irrigation Support Programme (SISP) and Smallholder Irrigation Revitalization Programme (SIRP)** to rehabilitate existing schemes and facilitate development of new SISs (IFAD, 2016).

In order to improve operational efficiency and guide the operation of SISs, Zimbabwe has developed strategies and policies since 1980. Currently, the SISs are mainly guided by Zimbabwe Agricultural Policy Framework (ZAPF) (1995-2020) (Zawe *et al.*, 2015). The National Water Act of 1998 is the basis for financing the management of water resources under the Zimbabwe National Water Authority (ZINWA) (Zawe *et al.*, 2015). At the same time, several national policies have sections devoted to SISs.

These policies are effective instruments for implementing and managing activities in SISs in Zimbabwe (Matsika, 2021). Policies are among the pathways of SIS development, considering the need for improved water utilization management across scales and sectors. Policies, that evolved over the years, have shaped the practice and performance of SISs in Zimbabwe (Mosello *et al.*, 2017). Despite the prominence of irrigation development on the government development agenda, little attention has been paid on scheme management (Moyo *et al.*, 2017). Recently, Zimbabwe unveiled the irrigation policy (Accelerated irrigation rehabilitation and development plan 2021 – 2025) (GoZ, 2021a) after years of relying on other policies/sector strategies shown in Table 2.2.

Table 2. 2: Policies, acts, programs and strategies relevant for SIS in Zimbabwe

Policy/Strategy	Relevance in the context of SISs	Reference
1998 Water Act	Gives authority to catchment council to allocate water to SISs. Gives regulations of how schemes operate.	GoZ (1998)
1998 Zimbabwe National Water Authority Act	Establishes the ZINWA as a parastatal agency – in charge of water permits and water allocations, including for SIS use.	GoZ (2000a)
2002 Environmental Management Act and 2003 Environmental Agency Act	Introduces mandatory environmental impact assessments for SIS development.	GoZ (2002) GoZ (2003)
2000 Land Acquisition Act	Empowers the government to compulsorily acquire land for SIS development purposes.	GoZ (2000b)
Zimbabwe's Agenda for Sustainable Socio-Economic	Used to set the objective of increasing the area under SIS through rehabilitation and modernisation of irrigation	GoZ (2013a)

Transformation Asset) 2013–2018	(Zim	schemes and increase of power available and affordable for irrigation.	
Zimbabwe’s Climate Response Strategy 2015	National Change	Mainstreaming climate change in all key sectors of the economy; calls for integrated management and development of agricultural water resources. Promotes rehabilitation of SISs	GoZ (2015)
Comprehensive Agricultural Framework 2012–2032	Policy	Includes provisions for rehabilitating and modernising SIS infrastructure, developing new irrigation infrastructure and strengthening research on irrigation development and new technologies (objective 7.3).	GoZ (2012)
Water Policy 2012		Ensure the availability of good quality and affordable water in adequate quantity for all at all times.	
Zimbabwe’s Agricultural Investment Plan 2013–2017		Aims to redesign and rehabilitate SIS infrastructure.	GoZ (2013b)
Medium-Term 2011–2015	Plan	Focuses on rehabilitation of existing SIS infrastructures and completion of irrigation projects to increase agricultural production.	GoZ (2011)
National Development Strategy 1 2021 - 2025		Intensification of construction and rehabilitation of SIS infrastructure including dams and funding of irrigation development	GoZ (2021b)
National Agricultural Framework (2018-2030)		Development of low-cost technology investment in SIS, capacitation and enhancing skills for irrigation technicians and promotion of low-cost finance for irrigation development, investment in irrigation development and water harvesting technologies	GoZ (2018)
Accelerated Rehabilitation and Development 2021 – 2025	Irrigation and	Rehabilitation and revitalisation of over 450 SISs in communal areas, on 26 000 ha and a concomitant farmer capacitation, governance overhaul and business model transformation to ensure viability and sustainability of these schemes. Development of various SISs in the Lowveld Green Zone Irrigation Development and projects linked to dams in communal and resettlement areas.	

To improve access to finance, inputs, markets and overcome governance and business systems at irrigation schemes.

Reliable market arrangements for produce from SISs

Investment in expanding SISs needs to be coupled with measures to allocate water effectively and equitably. The MLAWCRR is responsible for the development and implementation of agriculture and irrigation policies. The Department of Water Resources Planning and Irrigation Development (WRPID) is responsible for planning, identifying, designing, constructing, operating and managing SISs at the national, provincial and district levels (Mosello *et al.*, 2017). The MLAWCRR formulates policies for the utilization of water resources. The Water Law of 1998 emphasizes water management through decentralization and stakeholder participation in line with Integrated Water Resources Management (IWRM) (Zawe *et al.*, 2015). **Catchment Councils** manage water permits in seven catchments which are subdivided into sub-catchments. Governance structures of SISs vary with scheme type. GoZ partly operates and maintains jointly managed schemes. Farmer-managed schemes were developed by GoZ but owned and managed by farmers through irrigation management committees (IMCs) (Zawe *et al.*, 2015). However, the effectiveness of IMCs varies from one scheme to another. Traditional chiefs allocate land for scheme development. Multilateral and bilateral donors exclusively support SISs in communal areas by funding to ensure farmers' food security. The Food and Agriculture Organization (FAO) supports MLAWCRR in policy formulation and coordinates effort by donors and GoZ to partner in irrigation sector (Mosello *et al.*, 2017).

Both GoZ and donor communities have introduced some initiatives to improve the productivity of SISs. They have financed the maintenance of SISs to enhance their productivity. Moreover, GoZ injects input subsidies to enhance crop productivity (Moyo *et al.*, 2017). The GoZ prescribes the cropping program, which schemes depend on to sustain production (Mosello *et al.*, 2017).

Surprisingly, there is a minimal critical reflection in the literature on limitations of SISs as a climate change adaptation strategy in different contexts (Mosello *et al.*, 2017). However, the primary concern of this paper is the need to understand the impact of climate change on SISs. This

paper summarizes the impact of climate change and variability in Zimbabwe, an overview of implications of climate change on SISs and socio-economic conditions.

2.3 Potential impact of climate change on SISs

The potential impact of climate change on SISs **depends** on a combination of exposure, sensitivity and resilience of the system to potential water supply and demand changes, hence, vary considerably from one scheme to another. Agricultural communities are exclusively at risk due to reliance of their livelihoods on farming, the little scope of diversification **of livelihoods options** and their high exposure to climate variability (Palombi and Sessa, 2013). Zimbabwe is evidently experiencing effects of climate change through a notable increase in frequency and intensity of extreme weather events, **which lead to** chronic food insecurity (Mosello *et al.*, 2017). **Changes in climate** will result in water stress, rendering land marginal for agriculture, threatening the nation's economy and livelihoods. Agricultural **sector** in Zimbabwe **is among the** most vulnerable entities their dependence on natural resources (World Bank, 2020, IFAD, 2016) (Table 2.3). The relative dependence of SISs in Zimbabwe on surface water makes livelihoods of its communities more vulnerable to climate change and variability, as the existing resources often dry up (Chigumira, 2018), leading to water stress. The depletion of resilience sources increases the **SISs'** vulnerability in Zimbabwe through **loss of** revenue, poor access to credit due to weak tenure security and degradation of irrigation infrastructure (Hanusch *et al.*, 2019). Although the SISs are touted as a panacea to withstand impact of climate change and variability (Moyo *et al.*, 2020, Mosello *et al.*, 2017, GoZ, 2018), they face increasing water stress. This challenge is stimulated by **the decrease in** precipitation, increasing temperature leading to changes in evaporative demand, increase in the frequency of weather extremes and increased depletion of water resources. On the other hand, outbreak of pests and diseases, including new and emerging pests, is expected to increase due to changes in rainfall and temperature (**Mafongoya *et al.*, 2019**).

Table 2. 3: Natural hazards occurrence and damage in Zimbabwe from 1900 -2017

Natural Hazards	Subtype	Events Count	Total Deaths of People	Total Number of People Affected	Total damage (Million USD)
Drought	Drought	7	-	19 122 551	
Epidemic	Bacterial disease	17	4 900	111 349	-
	Parasitic disease	1	1 311	500	-
	Viral disease	2	55	1 338	-
	Others	2	71	10 102	-
Floods	Flash floods	1	3	1002	20
	Riverine floods	9	271	313 002	272.9
	Others	2	259	30 128	103.6
Storm	Convective storms	2	41	2.475	-
	Tropical cyclone	2	8	-	1.2
	Others	1	11	-	-

Adapted from World Bank (2020)

The impact is expected to vary across the five agro-ecological zones (AEZs) of Zimbabwe (World Bank, 2020, Mugandani *et al.*, 2012). The impact of all the above challenges will not be homogeneous given the heterogeneity in management and institutions; therefore, resilience and adaptive capacity are different in SIS.

2.3.1 Impact on rainfall

In Zimbabwe, the rainy season stretches from October to March (Mazvimavi, 2010, World Bank, 2020). The country's rainfall patterns are influenced by El Nino-Southern Oscillation events, which have a 30% chance of causing drought (Mazvimavi, 2010). Evidence of desiccation, below average, and increased rainfall variability has been noted in most parts of the country (Mazvimavi, 2010, Chamaillé-Jammes *et al.*, 2007, Mugandani *et al.*, 2012). Most parts of Zimbabwe, arid or semi-arid, are increasingly becoming drier due to climate change (Moyo *et al.*, 2017, World Bank, 2020). Besides, even AEZ II and III are becoming arid, as noted by a remarkable decrease by 49% and 14% of its precipitation, respectively (Manyeruke *et al.*, 2013, World Bank, 2020, Mugandani *et al.*, 2012, Manatsa *et al.*, 2020). Rainfall patterns and intensity are highly variable and are projected to be uncertain in the second half of the 21st century (Muronzi and Mukarwi, 2019). Zimbabwe's monthly precipitation is projected to decrease by 3.3mm, 5.1mm, 7.4mm, and 8.2mm in the 2030s, 2050s, 2070s, and 2090s under Representative Concentration Pathway (RCP) 8.5, respectively (World Bank, 2020, Ebi *et al.*, 2014). According to IPCC, seasonal rainfall

characteristics like onset, duration, dry spell frequencies, and intensity have changed significantly in the region (Ebi *et al.*, 2014). However, the recent decline in agricultural production is linked to more frequent and severe droughts (World Bank, 2020, Mazvimavi, 2010). Mazvimavi (2010) advocates for planning and managing water resource systems to adapt to changing climate.

2.3.2 Impact on temperature

There is variation in temperature across AEZs in Zimbabwe (Nangombe, 2015). The average annual temperature varies between 18°C and 25°C in areas with a higher altitude (approximately 1500m) in the Eastern Highlands and the highveld and between 22°C and 25°C in lower altitudes (northern and southern regions) (Nangombe, 2015, Manatsa *et al.*, 2020). The Metrological Services Department (MSD) of Zimbabwe has reported that the daily minimum temperature rose by approximately 2.6°C, while the daily maximum temperature rose by 2°C over the last century (Scoones *et al.*, 2019). The rise in temperature is attributed to the recent increase in the number of hot days and nights and decreasing the number of cold days and nights in recent decades. Temperature across the country is projected to rise in the 21st century and beyond. However, the increase in temperature will depend on greenhouse gas emission scenarios as Zimbabwe's monthly temperature is projected to rise by 1.2°C, 2.2°C, 3.4°C and 4.5°C in the 2030s, 2050s, 2070s, and 2090s under RCP8.5, respectively (World Bank, 2020, Ebi *et al.*, 2014). The highest temperature increases are projected from June to September (Ebi *et al.*, 2014).

2.3.3 Impact of droughts, cyclones, and floods

Droughts have devastating impacts on stream run-off and irrigation water availability, the nation's economy and contributes to the terminal vulnerability of the majority of its communities (Frischen *et al.*, 2020). Devastating droughts recently affecting Zimbabwe (January to March 2021) are strongly correlated to El Niño (FAO, 2016). Zimbabwe's agricultural sector, which contributes nearly 12% of the nation's Gross Domestic Product (GDP), is severely affected by droughts (Frischen *et al.*, 2020). Approximately 70% of the national population depends directly on agriculture (Frischen *et al.*, 2020). Climate-induced water stress has crippled agricultural and economic productivity, further resulting in an upward spiral of poverty and insecurities (Frischen *et al.*, 2020). Since 1990, severe incidences of droughts have been recorded in 1991 – 1992, 1994 – 1995, 2002 – 2003, 2015 – 2016, and 2018-2019 seasons (Nangombe, 2015, Frischen *et al.*, 2020). Isolated droughts patterns varied spatially in 2003 – 2004, 2006 – 2007, 2011 – 2012, and

2017 – 2018 farming seasons (Frischen *et al.*, 2020, Nangombe, 2015). Although droughts are a common feature in all the provinces, they are more severe in south-western provinces – Matabeleland North and South – and less severe in the eastern provinces – Manicaland and Mashonaland East (Manyeruke *et al.*, 2013). The bulk of droughts in the past century occurred in the past two decades, although most of them were mild (Nangombe, 2015). Droughts have culminated in the stagnation of rural livelihoods over the past three decades through hunger, decimating crops and livestock production, environmental degradation and a declining socio-economic status (Nangombe, 2015). In Zimbabwe, ad hoc measures to address drought focus on alleviating its impacts rather than encompassing the full cycle of drought management to ensure adaptation and coping at the individual, national and regional levels in the unforeseeable future (Muzari *et al.*, 2016).

Cyclones and extreme flooding have destroyed irrigation infrastructure in Zimbabwe over the years (GoZ, 2018). Cyclone Eline of 2000, Cyclone Dineo of 2017, and Cyclone Idai of 2019 are the most disastrous and fatal cyclones over the past two decades (Mavhura, 2020). The communication system, dwellings, and infrastructure were destroyed by cyclones and floods (Masasi and Ng’ombe, 2019, Mavhura, 2020). Cyclone Eline destroyed Mutema Irrigation Scheme infrastructure, including three boreholes, resulting in the scheme operating only at 10% capacity (Masasi and Ng’ombe, 2019). Cyclone Japhet destroyed a dam in the Chirume communal land in Shurugwi, making the community more sensitive to drought (Brown *et al.*, 2012). Cyclone Idai damaged ten SISs in Chimanimani district and eight SISs in Chipinge district (GoZ *et al.*, 2019). Specifically, 2 293.50 ha were damaged, affecting 5 041 scheme farmers (GoZ *et al.*, 2019). In addition to this, other support infrastructures like roads, power supply lines and schools were also damaged, while some crops under irrigation were also lost (GoZ *et al.*, 2019). According to estimates, a total of US\$4 890 000 will be required to rehabilitate the schemes (GoZ *et al.*, 2019).

2.3.4 Impact on water resources

Zimbabwe’s water resources, which amount to 20 000 million m³ per year, or 1 413 m³ per capita, are dominantly surface water resources since there are limited groundwater resources (FAO, 2016). The country has 2 200 dams, including 260 large dams with a total capacity of 99 930 m³ (FAO, 2016). The water resources in the country vary across five AEZs (Brazier, 2015). The impact of climate change is projected to severely reduce Zimbabwe’s water resources (Brazier,

2015). Rainfall simulations in the Odzi, Gwayi and Sebakwe catchment areas has shown a decrease in precipitation by 15 – 18% and an increase of evaporation by 7.5 – 13%. This was projected to result in a 50% decrease in the runoff by 2075 (UNFCCC, 1998). Runde and Mzingwane catchments, where an average rainfall could decrease by between 12% and 16% by 2050, are anticipated to face the largest decline (Brazier, 2015). Also, the recharge rate of wetland and aquifers is expected to be reduced, impacting water availability for irrigation farming (Brazier, 2015). Also, water demand for domestic purposes, irrigation, livestock, industry and energy generation is expected to grow as population, cities, industries and evaporation are projected to rise gradually (UNFCCC, 1998). Further, land degradation particularly water erosion that led to siltation of surface water bodies is in on the increase (Nyakudya and Stroosnijder, 2014). World Bank (2020) states that climate change will result in a 38% decline in national per capita water availability by 2050 in the best-case scenario, pushing inhabitants of Zimbabwe to depend on groundwater sources.

The surface and groundwater resources are challenged by climate change and variability due to unpredictable seasonal rainfall and losses from evaporation, low runoff and sedimentation in reservoirs (Ngara, 2017, Chitata *et al.*, 2014). Water resources are gradually moving towards the level where current irrigation technology will not be sustainable. Therefore, users of resources responsible for managing the available water resources has a responsibility to formulate water resource utilization policies (FAO, 2016).

2.3.5 Impact of climate change on SISs

2.3.5.1 Water stress

The relationship between climate change and water stress could be the main contributing factor to vulnerability among SISs. Projected reduction in rainfall translates to reduction in runoff and refill of water bodies (Brazier, 2015). Dams, rivers and catchment areas are susceptible to drying, resulting in inadequate water supply for irrigation purposes. Also, groundwater recharge is predicted to be more severe in arid and semi-arid regions due to a decline in runoff (Palombi and Sessa, 2013). Therefore, a rise in temperature and a decrease in rainfall are predicted to worsen water stress among SISs (Magrath *et al.*, 2014, Mosello *et al.*, 2017). Increased warming will increase irrigation water demand by triggering a rise in evapotranspiration (Nhemachena *et al.*, 2020). Moreover, siltation of surface water bodies due to erosion is resulting in loss of surface

water reserves (Nyakudya and Stroosnijder, 2014), straining further available water resources for irrigation use.

Water stress among SISs in Zimbabwe is associated with a combined effect of rising water deficit in catchment areas, increase in population, rapid urbanization, and industrialization (Mutekwa, 2009, Mutambara *et al.*, 2017, Muronzi and Mukarwi, 2019). For example, a fall of the lake's water level in mid-2013 resulted in the diversion of water from the Ruti Irrigation Scheme and allocating it to sugar estates, making the problem of the SIS farmers more acute (Magrath *et al.*, 2014). This was followed by the dam's total drying up in September 2013, resulting in the loss of the entire cropping season (Magrath *et al.*, 2014). Also, Hanusch *et al* (2019) anticipate SIS performance to decline in the face of climate change and variability, coupled with depleted sources of resilience in the country. In Mkoba Irrigation Scheme, only 20% of irrigated land was utilized in 2015 as the dam could not meet irrigation water requirements (Moyo *et al.*, 2017). The absence of an accessible and reliable water source following the destruction of a dam in the Chirume community in 2008 has resulted in crop loss due to water stress during prolonged mid-season droughts (Brown *et al.*, 2012). Low rainfall experienced in Zimbabwe due to climate change leads to poor crop yields resulting in massive economic, environmental and social costs (Nangombe, 2015). The 1991/1992 drought resulted in water stress, reducing Zimbabwe's agriculture production and gross domestic product (GDP) by 45% and 11%, respectively (Bhaga *et al.*, 2020). The increasing trend and severity of similar events resulting from climate change cripples the national economy and livelihoods of rural people (Nangombe, 2015).

Several studies have shown excessive water stress-related yield decline in most SISs in the western parts of the country, particularly Matabeleland South and North (Nangombe, 2015, Muronzi and Mukarwi, 2019, Mutambara *et al.*, 2017). The water stress is projected to particularly affect schemes in AEZ IV and V (Mugandani *et al.*, 2012, Muronzi and Mukarwi, 2019). Climate change is likely to worsen **potential** evaporation in Zimbabwe, especially in the Lowveld, where it is higher (< 2 200mm), while precipitation is a paltry (< 300mm) (FAO, 2016). However, there is challenge of scarcity of data and accurate simulations of the potential effect of climate change on water sources and catchment areas in Zimbabwe (Mapani *et al.*, 2017). The projected rise in irrigation water demand of 7% to 21% by the 2080s due to a surge in evapotranspiration water demand (Palombi and Sessa, 2013) will worsen water stress in SISs. Some studies suggest that increased

temperature and low rainfall are altering water available for irrigation purposes (Nkomozepi and Chung, 2012, Magadza, 1994); therefore, the decline in water availability for irrigation diminishes productivity and livelihoods of scheme farmers.

2.3.5.2 Competing needs

Irrigation water has multiple uses among rural communities where most schemes are located. Water, an essential element in biological, social and economic systems (Meinzen-Dick, 1997), has competing uses that affect water discharge to SISs. Competing water needs vary from one AEZ to another, while it is likely to intensify with climate change. High-level pressure on water resources due to the combined demand of agriculture and other sectors has resulted in water scarcity in Zimbabwe's rivers, impacting water users and the environment (Mutekwa, 2009, Mutambara *et al.*, 2017). In rural Zimbabwe, water is needed for livelihood needs, including domestic uses, gardening, fishing, irrigation, recreation, reeds, dip tanks and livestock watering (Katsi *et al.*, 2007, Senzanje *et al.*, 2008). However, in Mkoba and Silalatshani irrigation schemes in the Midlands and Matabeleland South provinces respectively, water is diverted from irrigation canals to home gardens (Moyo *et al.*, 2017). While in Chakohwa Irrigation Scheme in Manicaland, water from canals was used to irrigate sugarcane and bananas (Samakande *et al.*, 2004). An increase of average irrigation water requirement of 33%, 66% and 99% is expected in the 2020s, 2050s and 2090s time slices, respectively, from a baseline of 67 mm for maize production in Zimbabwe (Nkomozepi and Chung, 2012).

Water, energy, and food are closely linked. Water use for energy generation, representing 15% of global water withdrawal, competes with water demands for food production (HLPE, 2015). Energy is essential for making water available for irrigation, food processing, and wastewater treatment (HLPE, 2015). Electrification is lacking in rural areas in Zimbabwe, with those connected to the grid suffer frequent power cuts (Mutambara *et al.*, 2017), making pumping of water for irrigation purposes challenging. Moreover, there are limited prospects of expanding the national grid to rural areas, as it will be more costly than in dense urban settlements (Mutambara *et al.*, 2017).

Meaningful development opportunities are missed where there is no clear link between water use, energy supply and mainstream agricultural livelihood in Zimbabwe (Pittock *et al.*, 2015). The nexus' effectiveness among SISs in Zimbabwe can be determined by community institutions' strength, ownership and management structure (Pittock *et al.*, 2015). The variable climate and

recurrent droughts in the country make the water supply sporadic, affecting hydropower's potential in Zimbabwe. Competing community needs around water use have been seen in the development and use of SISs and hydropower stations. Sophisticated and organized community structure at a scheme in Chipendeke in Manicaland province has integrated 80 KW hydropower plant and irrigation (Pittock *et al.*, 2015). Electricity from the power plant is used to pump water for irrigation and power cold storage facility to keep their produce fresh for sale (Pittock *et al.*, 2015). However, conflict arises between users of electricity and farmers who need water for irrigation, especially during the dry season when there is a need to ration water for irrigation and power generation, forcing switching water between the two as an incentive to resolve the tension (Pittock *et al.*, 2015). Multiple uses of available water resources can result in conflicts and lead to the possibility of multiple but independent failures in the water supply system in the face of climate change (Magadza, 1994). According to Palombi and Sessa (2013), climate change exacerbates tensions and increases competition for water.

2.3.5.3 Pests

Climate change will lead to new and emerging pests, whose effects vary with AEZs. Crop loss will be increased by a myriad of climate change-related factors that include decrease in host plant resistance, reduction in the efficacy of pesticides and the arrival of alien pest species (Gemmill-Herren *et al.*, 2019, Mafongoya *et al.*, 2019). Changes in both precipitation and temperature will lead to increased infestations of pests like white flies and disease outbreaks, reducing crop and animal productivity and driving up expenditure on pesticides, herbicides and veterinary drugs (Brazier, 2015, Kutywayo *et al.*, 2013). Change in pest distribution is among the most commonly reported biotic response to climate change (Kutywayo *et al.*, 2013, Mafongoya *et al.*, 2019). A study in Mutare District shows that coffee white stem borers respond more to precipitation factors (Kutywayo *et al.*, 2013). Mafongoya *et al.* (2019) postulate that incidences of pests in Zimbabwe respond to changes in seasonality, temperature and rainfall patterns. Projected climate change-related temperature and precipitation changes will likely result in crop losses due to increased biotic stress from weeds, insects, fungi, viruses, nematodes and rodents. Pests cause yield loss at all stages of the production cycle, from planting to postharvest (Gemmill-Herren *et al.*, 2019). It is projected that yield loss of major staple crops due to increased pests alone will expand by 10 to 25% for each degree of global mean surface warming (Brazier, 2015). Temperature enhances

development rates of pests, a shift in pests species composition and increased spread of invasive pests into new zones as their suitable climatic conditions change (Mafongoya *et al.*, 2019).

Zimbabwe's smallholder farmers are projected to face a wave of new pests spreading to Southern Africa, including fall armyworm (*Spodoptera frugiperda*), tomato leaf miner (*Tuta absoluta*), and cotton mealy bug (*Phenacoccus solenopsis*) (World Bank, 2020). Mid-season and prolonged dry spells may promote the occurrence of insect pests, such as armyworms (Mutekwa, 2009). Fall armyworm destroyed 20% of the nation's maize crops during the 2016-2017 farming season, worsening the nation's food status with over 4 million of its population dependents on food aid (World Bank, 2020). New and emerging pests that are suited to change in conditions make farming difficult in Zimbabwe (World Bank, 2020, Mafongoya *et al.*, 2019). However, characteristically poor smallholder farmers have no option to deal with new pests. A countrywide survey by Mafongoya *et al* (2019) in Zimbabwe found out that smallholder farmers perceived an increase in abundance of aphids, whiteflies, stem borers, ball worms, red spider mite, termites and diamondback moths, and the emergence of new pests due to shortening winter, increasing heating and lengthy dry spells.

The population in need of agricultural transformation is the one that is most vulnerable to climate change impact due to water scarcity and increased pests and diseases. Farmers are struggling to cope with the impact of climate change, which is projected to alter the magnitude, timing and distribution of pests resulting in crop loss. Smallholder farming in Zimbabwe has experienced greater vulnerability to climate change hazards due to endemic poverty, restricted access to capital and technology and substandard infrastructure, impacting food and nutrition security. The projected increase in rainfall variability, temperature and extreme events exacerbate the predominantly rainfed farming system's vulnerability affecting its response to national food needs.

2.4 Institutional arrangement and capacity

2.4.1 Socio-economic conditions

There are limited statistics on the contribution of SISs to the national GDP; however, evidence that SISs contribute to food security, nutritional security, income and general well-being than rainfed farmers is overwhelming (Rukuni, 1988, FAO and SAFR., 2000, Hanusch *et al.*, 2019, Dube, 2016). In addition, SISs provide rural people with an alternative source of employment and income (IFAD, 2016). However, gendered plot ownership exists in SISs in Zimbabwe, where males

household heads own approximately 67.9% of plots despite that most scheme labour is provided by women (FAO SAFR, 2000).

Climate change impact on SISs is worsened by non-climatic factors, including population growth, urbanization, global economic growth, rising competition for natural resources, agronomic management, technological innovations, trade and food prices (Palombi and Sessa, 2013). These factors have an immediate impact on water resources, hence need to be understood and incorporated in climate change adaptation discourse in SISs (Palombi and Sessa, 2013). The population of Zimbabwe of 16.6 million people, rising at the rate of 2.3% per annum and is projected to reach 22.2 and 33.2 million by 2030 and 2050, respectively (Nyoni and Bonga, 2017, FAO, 2016). Per capita water availability will decline by 38% from 2.45ml per capita per year in 2012 to 1.52ml per capita per year by 2050 in Zimbabwe (Davis and Hirji, 2014).

Zimbabwe has experienced a deteriorating socio-economic environment following the Economic Structural Adjustment Program (ESAP) of the 1980s and the downwards macroeconomic trends in the 2000s, which impact the supply of basic agricultural inputs (fertilizers, seeds, crop chemicals, and electricity) (IFAD, 2016, Chirisa, 2019, Mosello *et al.*, 2017). In the 2000s, a decline in the country's GDP was noted (IFAD, 2016). The economic downturn perpetuated widespread poverty and loss of livelihood opportunities, particularly in rural areas, mostly in semi-arid and arid regions where 76% of people live below the national poverty datum line (Scoones *et al.*, 2019, Manzungu, E., 2004a). The turn of events has deteriorated the schemes' ability to cope and transform to match temporal and permanent changes in climatic conditions.

Also, Zimbabwe has endured HIV/AIDS, which remains higher above 15%, decimating the labour force and diverting income from scheme farming (Muzari *et al.*, 2016). The current outbreak of Corona Virus pandemic / epidemic (2020 into 2021) and its associated control measures like lockdowns negatively affects small and medium enterprises in Zimbabwe, which are mainly agro-based (Nyanga and Zirima, 2020).

Conflict and insecurity, inequitable land distribution, low education, poor infrastructure, gender inequality, dependence on natural resources and low health status perpetuate vulnerability at the household level in Zimbabwe (Muzari *et al.*, 2016). Zimbabwe's drought and food insecurity situation were projected to result in 1.5 million people (16%) being food insecure by 2050 (World Bank, 2020).

2.4.2 Water management

Zimbabwe has limited conceptual and practical analysis of the management of SISs, as much of the recent studies focused on the quantitative performance of SISs. According to Manzungu (1999) SISs in Zimbabwe are threatened by management problems. Water management in SISs in Zimbabwe is characterised by inefficient and inflexible scheduling, making it challenging to maximize yield and profit (Moyo *et al.*, 2020, Manzungu, E., 2004b). Poor water management, low input use, relatively small irrigated plots, and complex group dynamics have been implicated for low crop yields in SISs in Zimbabwe (GoZ, 2021a). However, the recent development of Accelerated Irrigation Rehabilitation and Development Plan 2021 – 2025 has ended the challenges of adopting other policies to address SISs challenges. In addition, SISs in Zimbabwe's primary focus on food security at the expense of economic growth has resulted in farmers' failure to meet the schemes' maintenance and development demands (Mosello *et al.*, 2017).

Water pricing is among tools used to manage water scarcities and competing demands to protect the resource and its quality (HLPE, 2015). Therefore, water pricing policies can incentivize water conservation, construction, operation and maintenance of the systems (Mudhara and Senzanje, 2020). However, use of water pricing impacts availability of water for agricultural uses especially for marginalized populations (HLPE, 2015). A case study in irrigation projects in Nyanyadzi, Zimbabwe, noted that communities view irrigation as a development expenditure for the government and donors in their pursuit to ensure food security among rural communities (Chifamba *et al.*, 2013). This, in turn, diminishes the proportion of cost recovery, threatening the viability and sustainability of SISs (Chifamba *et al.*, 2013).

Given that the country's agricultural system is heavily subsidized, cost recovery of water delivery is arduous and complicated (Chifamba *et al.*, 2013). Fundamental planning, designing and maintaining the water delivery system is constrained by stakeholders' inability to address the budget deficit challenge in SISs (Chifamba *et al.*, 2013). Mutambara *et al* (2017) suggest that low productivity, dependency syndrome, poor services and political interference in water governance in SISs in Zimbabwe affect farmers' contribution towards water bills. Failure to pay water bills directly affects water access, water resource planning and infrastructure maintenance, hampering the system's ability to adapt and mitigate the souring climate change impact (Mudhara and Senzanje, 2020, Mutambara *et al.*, 2017).

SISs in Zimbabwe can exploit short- and long-term adaptation and management practices. Conservation agriculture, crop rotation and mulching are common adaptation practices implemented in Zimbabwe (Milne *et al.*, 2019, Brazier, 2015). However, the usefulness of the policies is limited by a lack of appropriate mechanization, making it labour-intensive (Milne *et al.*, 2019). Conservation agriculture is mostly implemented among rain-fed farmers and its consideration for **SISs** farming is minimal (Milne *et al.*, 2019).

2.5 Gaps, limitations and areas for future research

2.5.1 Gaps and limitations of vulnerability studies

The literature remains unclear about the future patterns and impact of climate change on water availability for **SISs** farming in Zimbabwe. All models might not point to the same scenario, as there are large variations in the assessment of runoff and recharge. Several studies projected a general decline in rainfall and rise in temperature across the country (Brazier, 2015, Benitez *et al.*, 2018, IPCC, 2014, Mazvimavi, 2010), while others suggest a redistribution of the AEZs (Mugandani *et al.*, 2012). Some studies suggest shrinkage of more productive regions, while others suggest a shift in AEZs, making existing zones obsolete and misleading (Chanza and Gundu-Jakarasi, 2020). There is a dearth of literature on combined insights from quantitative predictive models with quantitative explanatory models, especially for rural areas where data availability is limited. The inclusion of climate change in SISs in Zimbabwe in the existing literature is negligible, although its impact on schemes **is** overwhelming. A multidimensional risk analysis is needed to assess climate change impact on water availability for SIS farming. However, the bottom-up approach gives opportunities to build resilience and develop vulnerable communities.

2.5.2 Area of future research

The SISs provide employment, fight hunger and ‘hidden hunger’ in rural communities (IFAD, 2016, FAO SAFR, 2000), which account for 66% of Zimbabwe’s population (Nyoni and Bonga, 2017). However, literature has shown the collapse and underperformance of **SISs** due to climate change to be more severe, particularly in semi-arid and arid regions of the country (GoZ, 2018, Masasi and Ng’ombe, 2019, Brown *et al.*, 2012). However, the assessment of the vulnerability of SISs to climate change is limited. To better understand vulnerability to climate change in SISs for future adaptation policy formulation, development and funding, there is a need to assess their vulnerability. This will enable stakeholders to be advised on how to develop local strategies to

adapt to climate change. Investigating vulnerability in SISs is important for more vulnerable schemes to be identified and provide a database for the nature of support needed in each area. Also, investigating the institutions and governance aspects that affect smallholder irrigation adaptation to climate change is key in addressing climate change vulnerability in SISs.

2.6 Conclusion

This article has reviewed the impact of climate change in Zimbabwe's SISs and identified associated adaptation options implemented based on available literature. In Zimbabwe, climate change has resulted in a rise in temperature and a decrease in rainfall. Studies show the sensitivity of SISs to climate change as recharge of surface and underground water bodies deteriorate, impacting water access among schemes. The crop growing area was reported to shift as climatic conditions become harsher in primary production zones. Therefore, climate change results in a decline in the productivity of schemes and increases production costs beyond the reach of scheme farmers. Literature has shown that existing adaptation strategies fail to catch up with climate change effects as more schemes are reported as having collapsed, especially in drier regions. However, local institutional actors play a key role in the adaptation of SISs to climate change. They formulate policies and offer critical support by maintaining existing schemes, providing subsidies and establishing new schemes. For a successful adaptation of SISs to climate change, there is a need to assess vulnerability further and advise stakeholders based on policy and investment options needed at local and national levels. Engaging with scheme farmers and stakeholders at local level is required to understand vulnerability based on their lived experience, yet this issue is not documented in Zimbabwe.

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CHAPTER 3

ASSESSING VULNERABILITY TO CLIMATE CHANGE IN SMALLHOLDER IRRIGATION SCHEMES OF ZIMBABWE²

Abstract

Globally, climate change poses enormous threats to the livelihoods of rural communities in arid and semi-arid regions. Assessing the extent of vulnerability is critical to identify climate hot spots and develop appropriate adaptation policies and strategies. This paper uses the Livelihood Vulnerability Index (LVI) and the Livelihood Vulnerability Index—Intergovernmental Panel on Climate Change (LVI-IPCC) to compare vulnerability to climate change in the Exchange, Insukamini, and Ruchanyu smallholder irrigation schemes (SISs) in the Midlands Province of Zimbabwe. A questionnaire was used to collect data from a sample of 317 randomly selected households. Results show higher exposure and sensitivity to climate change in the Insukamini irrigation scheme despite the higher adaptive capacity. Both LVI and LVI-IPCC show that households in Insukamini irrigation scheme are more vulnerable to climate change than in Exchange and Ruchanyu irrigation schemes, attributed to water insecurity, poor social networks, and natural disasters and climate variability. The study recommends that development and investment in Insukamini and Ruchanyu should prioritize improving social networks while Exchange should primarily focus on improving livelihood strategies. Using the LVI-IPCC framework is a key methodology for understanding the vulnerability of communities in SISs and identifying areas that need prime development and investment. These results have implications on implementing investments and livelihood policies in SISs of Zimbabwe.

Keywords: exposure; adaptive capacity; sensitivity; livelihood vulnerability index; adaptation

3.1. Introduction

Climate change poses a significant threat to smallholder agricultural systems in arid and semi-arid regions (Mavhura *et al.*, 2015), in which a greater proportion of the population depends on the agricultural sector for food and income security (Mukwada and Manatsa, 2018). The risk posed by

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climate change is now greater in developing countries, given high exposure and sensitivity coupled with a low adaptive capacity (Leal Filho *et al.*, 2019). Understanding localised vulnerability of livelihood systems of poverty-stricken communities is highly prioritised given the need to develop National Adaptation Plans (NAPs). Currently, many countries in southern Africa, including Zimbabwe, are developing NAPS for improved adaptation to climate change as stipulated in the United Nations Framework Convention on Climate Change (UNFCCC) (Chagutah, 2010). Available evidence suggests that Africa's climate is changing, and the negative implications are direct in communities deriving livelihoods from climate-sensitive sectors (Kotir, 2011, Perez *et al.*, 2015). In southern Africa, there has been an increase in both the frequency and severity of extreme events, particularly droughts (Davis and Vincent, 2017), with negative consequences on the livelihoods of communities dependent on climate-sensitive sectors such as agriculture and natural resources (Davis and Vincent, 2017, Kula *et al.*, 2013). In the absence of adaptation strategies, climate change poses a significant threat to the achievement of sustainable development.

Zimbabwe is one of the countries in southern Africa regarded as a climate hot spot. Over the past century, daily maximum and daily minimum temperatures in the country, have increased by 2.6 °C and 2.0 °C, respectively (Bhatasara, 2017, Simba *et al.*, 2012), while rainfall has dropped by approximately 10% over the same period (Bhatasara, 2017, Simba *et al.*, 2012). Meanwhile, cyclones and droughts have become more severe in the past decade (Bhatasara, 2017). Empirical evidence suggests that climate change is expected to result in increased temperature and a more variable precipitation pattern, including high frequency and intensity of extreme weather events (IPCC, 2014) with severe implications for human welfare (Mpambela and Mabvurira, 2017, Brown *et al.*, 2012, Manyeruke *et al.*, 2013). The minimum temperature in Zimbabwe is projected to rise by 0.99 °C to 1.18 °C and by 1.55 °C to 1.98 °C in the 2030s and 2050s, respectively (World Bank, 2020). Similarly, the maximum temperature is expected to increase by 1.08 °C to 1.31 °C and by 1.8 °C to 2.27 °C in the 2030s and 2050s, respectively (World Bank, 2020). Meanwhile, projections for rainfall indicate that it will change its pattern, frequency, and intensity (IPCC, 2014). As a result, there is increased expectation that warm spell durations and heatwaves will escalate (IPCC, 2014), with droughts and cyclones following suit. The droughts are projected to increase by 21% and 47% in the 2050s and 2080–2090s, respectively (World Bank, 2020), while days of the subsequent dry spell are projected to increase by thirteen and twenty-five days per annum in the 2050s and 2090s, respectively (World Bank, 2020). Thus, a decline in precipitation

pattern, a warming trend and an increase in the severity of weather extremes are expected to be the new norm for southern Africa, where Zimbabwe is located. However, the evaporation rate of 5.1 mm at maximum temperature of 24.9 °C reported in Zimbabwe will increase as climate change impacts worsen (Simba *et al.*, 2013).

Zimbabwe, with 13.1 million people (ZIMSTAT, 2016), is an agro-based economy (Green, 2020, Chanza and Gundu-Jakarasi, 2020). It provides 60% of inputs to manufacturing industries (Simba *et al.*, 2013), it is a market to 40% of industrial outputs (ZIMSTAT, 2016, Chanza and Gundu-Jakarasi, 2020), contributes 30% of export earnings (Chanza and Gundu-Jakarasi, 2020), employs 60–70% of the national labour force, contributing up to 19% of the national GDP, and provides livelihoods for 70% of the national population (Chanza and Gundu-Jakarasi, 2020). In addition, it is a source of food and income security for over 67% of the population (World Bank, 2019). Despite the role of agriculture in socio-economic development, the sector, which is mainly rain-fed, is highly vulnerable to climate change and extreme weather events, particularly droughts (World Bank, 2019, Brown *et al.*, 2012). For example, the severe drought of 1991/1992 resulted in a decline of the nation's agricultural production by 45% and its GDP by 11%, respectively (Bhaga *et al.*, 2020). These extremes have severe implications for poverty. Empirical evidence suggests that over the past three decades, extreme poverty rose from 29% (4.7 million people) in 2018 to 34% (5.7 million people) in 2019 due to sub-normal rainfall (Green, 2020). Poverty will worsen land and forest degradation, further reducing the capacity of communities to absorb climate shocks (Thomalla *et al.*, 2006). In the absence of policies and strategies, smallholder farmers will have difficulties in sustainably increasing agricultural yields given high climate variability (Adu *et al.*, 2018). Therefore, to develop appropriate policies and adaptation strategies, it is critical to carry out vulnerability assessments in light of the significant investments the country has made in smallholder irrigation schemes. In total, 216,000 ha of irrigation land were developed in Zimbabwe by 2020, of which 26,000 ha are under smallholder irrigation farming (GoZ, 2020), yet currently, only 175 000 ha are functional and predominantly under overhead irrigation (77%) (GoZ, 2020). Thus, assessing vulnerability of the SISs using credible methods and tools is a priority research area given the risk posed by climate change.

The most useful method of assessing vulnerability, which is recently in use at the society level, is the Livelihood Vulnerability Index (LVI) adapted to the IPCC framework (LVI-IPCC) (Hahn *et*

al., 2009). LIV-IPCC indices, developed by Hahn *et al.* (2009), were widely used to quantify vulnerability to climate change and variability (Hahn *et al.*, 2009, Sarker *et al.*, 2019, Sujakhu *et al.*, 2019, Abeje *et al.*, 2019, Amuzu *et al.*, 2018). LVI-IPCC maps LVI components into exposure, adaptive capacity, and vulnerability (Simane *et al.*, 2016). The LVI-IPCC indices can synthesize complex situations where a broad range of factors contribute to individuals' and societies' vulnerability (Botero and Salinas, 2013). It recognizes diversity in natural hazards, climatic conditions, and the socio-economic setup of communities (Simane *et al.*, 2016). LVI-IPCC can also be used to compare the vulnerability of systems by comparing factors that worsen vulnerability within the community (Simane *et al.*, 2016). Different scholars have analysed the vulnerability of Zimbabwean communities to climate change and variability and tried to develop adaptation strategies to climate hazards (Brown *et al.*, 2012, Jiri *et al.*, 2017, Jiri and Mafongoya, 2018, Chanza, 2018, Utete *et al.*, 2019). Since Hahn *et al.* (2009) conducted research using LVI-IPCC in 2009, no research was conducted using LVI-IPCC in Zimbabwe. The present research is the first of its kind to assess vulnerability using LVI-IPCC in Zimbabwe. The results of most of these studies are general and aggregate, and they do not focus on the vulnerability of smallholder farming communities in the nation. Although agriculture was identified among the extremely vulnerable sectors to climate change and variability in Zimbabwe (Chanza, 2018), most studies focus on rain-fed agriculture, leaving the smallholder irrigation farming, something that has the potential to plunge the country into disaster, unnoticed. A handful of studies on vulnerability were conducted in Gokwe District (Gwimbi, 2009), Muzarabani District (Mavhura *et al.*, 2017), Epworth (Harare) (Tawodzera, 2011), and Kariba resort town (Dube and Nhamo, 2020). However, to the best of our knowledge, the vulnerability assessment studies conducted in the country do not capture the vulnerability of smallholder irrigation farmers in the country, nor do they use the LVI-IPCC approach. In order to close this lacuna, a study was undertaken in the Midlands province, which, despite having the presence of several SISs (Utete *et al.*, 2019), is among the highly vulnerable provinces to climate change and variability in Zimbabwe (Moyo *et al.*, 2017). Thus, it was essential to understand the sources of the vulnerability to climate change in the SISs in the province for informed decisions in adaptation planning.

3.2. Materials and methods

3.2.1. Study area

To address the objectives of this study, we assessed three SISs in the Midlands province of Zimbabwe (Figure 3.1). The Midlands province is among the top three provinces with the highest number of SISs in Zimbabwe (IFAD, 2016). Moreover, of the SISs in the province, only slightly above half (about 53%) are reportedly functional (IFAD, 2016). In addition, irrigation schemes in the province are presumably vulnerable to climate change (Mhembwe *et al.*, 2019). Therefore, this study will be of significant reference to the vulnerability of SISs in Zimbabwe and across the region to climate change.

This study looked at three SISs. First, the Exchange irrigation scheme in Zhombe communal land, Silobela in Kwekwe District is around 60 km North-West of Kwekwe town and 80 km North-West of the provincial town of Gweru (Nyamayevu *et al.*, 2015). It has a total irrigable area of about 168.8 ha irrigated arable land, occupied by 982 scheme farmers. It is in agroecological Zone 4, which is characterised by semi-arid climatic conditions, with average rainfall ranging from 450–650 mm and an average temperature of 26 °C (Chanza *et al.*, 2019, Chivandi *et al.*, 2012). The soils are mainly clay loam with high fertility (Nyamayevu *et al.*, 2015). The Exchange irrigation scheme was developed in two phases; 56 ha were developed from 1973 and 111.8 from 1985 (Chancellor and Hide, 1997). The scheme draws its water from the Exchange dam which is temporarily stored in a night storage reservoir. Concrete-lined channels are used to deliver water to the plots. The Ex-change irrigation scheme uses a surface irrigation system to deliver water at an application rate of 90 mm per ha per 6 days cycle (0.9 mega litres per ha). Maize and sugar beans have a gross irrigation water requirement of 450 to 600 mm per ha (4.5–6 mega litres) (SEEDCO, 2020). The main crops grown are maize and sugar beans. The scheme has an average yield of 7 tonnes for maize, 1 tonne for winter sugar beans, and 1.2 tonnes for summer sugar beans (Chancellor and Hide, 1997). However, the market does not favour high-value crops due to the extended distance from the nearest towns and poor road network (Hettige, 2006).

Second is the Insukamini irrigation scheme in the Lower Gweru district is approximately 46 km North-West of the provincial town of Gweru. The scheme has a total irrigable area of about 41 ha, occupied by 125 scheme farmers. It is in agroecological Zone 4 and receives annual precipitation between 600–800 mm and an average temperature of 16 °C (Mark, 2012). Its soils are

characterised as sandy loam and clay loam. Farmers in the scheme grow a wide range of crops, including wheat, maize, peas, rape, sugar beans, onions, cabbages, tomatoes, and garlic (Matsa, 2012). The scheme was established in 1988 by the government of Zimbabwe through its funded national resettlement programme following the construction of the Insukamini dam by Danish International Development Agency (DANIDA) in 1986 (Matsa, 2012). It draws its water from the Insukamini dam, which is delivered gravitationally via a 1.6 km long open concrete canal. The Insukamini irrigation scheme uses a surface irrigation system to deliver water at an application rate of 90 mm per 6 days cycle (0.9 mega litres per ha). Maize, wheat, and sugar beans have a gross irrigation water requirement of 450 to 600 mm per ha (4.5–6 mega litres) (Matandare, 2015). The scheme farmers attain an average yield of maize of 4.4 tonnes per hectare and yields of 1.9 tonnes for sugar beans (Matandare, 2015). Farmers in the Insukamini irrigation schemes market their crops mainly to Gweru and Bulawayo towns. They use various market channels, including hawkers, farmgate sales, Grain Marketing Board (GMB), shops, and urban deliveries (Matsa, 2012).

The third is the Ruchanyu irrigation scheme in Shurugwi District nearly 29 km South-West of Shurugwi town. It has a total irrigable area of 27 ha operated by 85 scheme farmers. The scheme uses sprinkler irrigation technique. The scheme is in agroecological Zone 3 and it receives an average annual rainfall between 650–850 mm and an average temperature of 16 °C (Mhembwe *et al.*, 2019). It was established in the early 1980s. The scheme uses engines to pump water from the Mutevekwi River, but its pumping is challenged by vandalism of irrigation equipment (water pumps) and regular power cuts (Mhembwe *et al.*, 2019). Soils are fertile sandy loam soils. Farmers market their product on the farm gate and in Shurugwi town. The Ruchanyu irrigation scheme uses a sprinkler irrigation system to deliver water at an application rate of 90 mm per 6 days cycle (0.6 mega litres per ha). Maize, the major crop grown in the scheme, has a gross irrigation water requirement of 450 to 600 mm per ha (4.5–6 mega litres per ha). However, the yields are low (less than 2 tonnes per hectare) due to the challenges of pumping water.

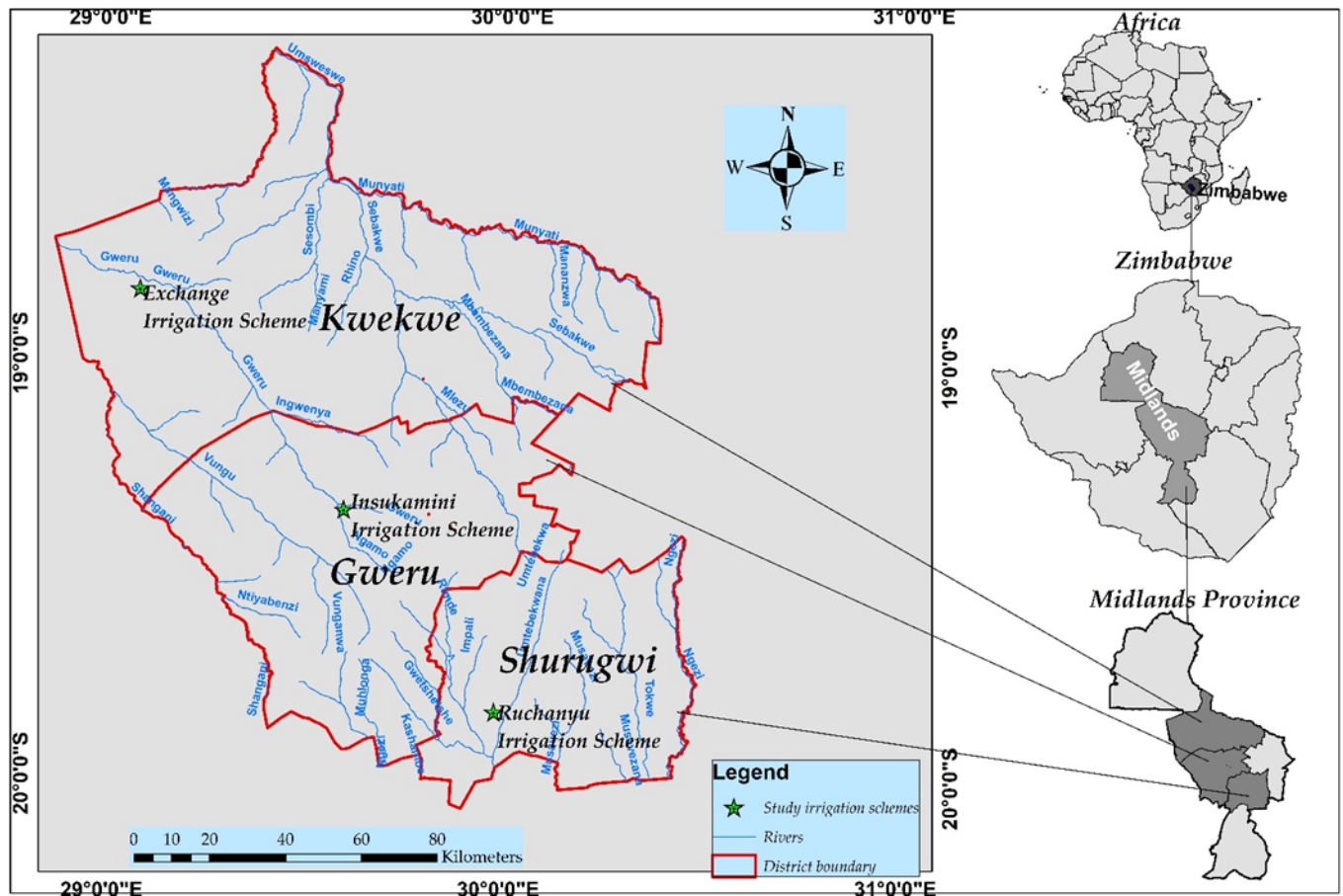


Figure 3. 1: Map of the study area.

3.2.2. Data collection

The study used questionnaire surveys, Focus Group Discussions (FGDs), and Key Informant Interviews (KIIs) to collect data. We collected data on demographic, livelihood strategies, food, water, health, social networks, and natural disaster profiles for estimating LVI. The questions that were asked under each profile were based on existing literature on vulnerability analysis. Nonetheless, we conducted a pilot study to determine the suitability of the questionnaire for the study. Random sampling was used to select households to be interviewed based on the homogeneity of the households in each scheme. A statistically significant sample of 317 households (192 from Exchange irrigation scheme, 88 from Insukamini irrigation scheme, and 37 from Ruchanyu irrigation scheme) was selected for the study ($p \leq 5\%$). The sample size stated above was considered for this study because it is moderately small and thus, yields stronger estimates (Sadiq *et al.*, 2019, Dechartres *et al.*, 2013). We used the power test to determine the chances of a null hypothesis being rejected because it is false (Sadiq *et al.*, 2019). We used

stratified random sampling to obtain a reasonable sample from each scheme. To attain the desired power of estimates, we considered a margin error of 5%, a confidence level of 95%, and the assumption of a response rate of 50%. We randomly selected 10–15 household heads for the FGDs to help understand vulnerability to climate change in SISs. Key informant interviews provide expert information about the challenges of climate change in SISs. Data on rainfall, minimum, and maximum temperatures were obtained from the Department of Metrological Services of Zimbabwe.

3.2.3. Data analysis

The LVI-IPCC framework by Hahn *et al.* (2009) is the approach used for data analysis in this study. It was used to measure the vulnerability of each SIS to climate change and to compare the vulnerability of the schemes. It identifies the factors that contribute to the vulnerability of each scheme to climate change. The LVI score, which ranges from 0 (least vulnerable) to 1 (most vulnerable), was used. In this work, we adopted the vulnerability classes used by Thuy and Anh (2021), where LVI scores are classified into four categories: low (0–0.25), moderate (0.25–0.5), high (0.5–0.75), and very high (0.75–1). Similarly, we classified LVI-IPCC scores into the following categories: low (–1––0.5), moderate (–0.5–0), high (0–0.5), and very high (0.5–1). Following previous work by UNDP (2007), Equation 1, which is used when calculating life expectancy, was applied to standardize the different variables that were measured using different scales.

$$Index_{sd} = \frac{S_v - S_{min}}{S_{max} - S_{min}} \quad (1)$$

where S_v is the original subcomponent value of area v and S_{min} and S_{max} are the minimum and maximum value of the subcomponent, respectively. Equation (2) was used to produce the value of major components.

$$M_{dj} = \frac{\sum_{i=1}^n Index_{sdi}}{n} \quad (2)$$

where M_{dj} is the value of major component d in area j , $Index_{sdi}$ is the indexed value of subcomponent i , and n is the number of subcomponents in major component M_{dj} .

The values of the seven major components—Socio-Demographic Profile (SDP), Livelihood Profile (LP), Social Network (SN), Health (H), Food (F), Water (W), or Natural Disasters and Climate Variability (NDCV)—were used to calculate LVI using Equations (3) and (4).

$$LVI_j = \frac{\sum_{i=1}^7 W_{Md} M_{dj}}{\sum_{i=1}^7 W_{Md}} \quad (3)$$

Equation (3) can be expanded to Equation (4)

$$LVI_j = \frac{W_{SDP}SDP_j + W_{LP}LP_j + W_{SN}SN_j + W_H H_j + W_F F_j + W_W W_j + W_{NDCV}NDCV_j}{W_{SDP} + W_{LP} + W_{SN} + W_H + W_F + W_W + W_{NDCV}} \quad (4)$$

where LVI_j is the livelihood vulnerability index of area j ; W_{Md} is the weight of component d ; and W_{SDP} , W_{LP} , W_{SN} , W_H , W_F , W_W , W_{NDCV} are the weighed values of SDP , LP , SN , H , F , W , and $NDCV$ profiles, respectively.

3.2.4. IPCC framework of calculating LVI

Calculating LVI using Hahn *et al.*'s (2009) IPCC framework approach starts by combining seven major components of LVI into three contributing factors to LVI: exposure (E), sensitivity (S), and adaptive capacity (AC), as in Equation (5). Adaptive capacity is composed of Socio-Demographic Profile, Livelihood Strategies, and Social Networks; Sensitivity is quantified by Health, Food, and Water profiles; while exposure is made up of Natural Disasters and Climate Variability.

$$LVI - IPCC_j = (E_j - S_j) \times AC_j \quad (5)$$

where $LVI - IPCC_j$ —LVI for area j expressed using IPCC vulnerability framework approach; E_j —calculated exposure score for area j ; S_j —calculated sensitivity score for area j ; and AC_j —calculated adaptive capacity score for area j .

3.3. Results

The results of our analysis are presented in two sections. The first section makes a comparative and contrasting analysis of the livelihood vulnerability index of the three irrigation schemes using the seven major components and sub-components. The second section deals with LVI contributing factors and LVI-IPCC.

Comparing LVI among schemes

Figure 3.2 illustrates the LVI indices of the seven major components for the Exchange, Insukamini, and Ruchanyu irrigation schemes. Subsequently, Table 3.1 displays the indices of the sub-components of the LVI for each scheme. The results indicate that the dependency ratio was high among the three schemes as the number of orphans and aging household members are high. The female-headed households have a moderate vulnerability score in all schemes. The households headed by individuals without formal education have low vulnerability scores in all schemes. The majority of the household heads have attained at least a year of formal education.

Additionally, the households looking after orphans have a high vulnerability score in Ruchanyu, a moderate vulnerability score in Insukamini, and a low vulnerability score in Exchange. Insukamini has a high vulnerability score in relation to the age of household heads, whereas in Ruchanyu and Exchange, the vulnerability scores are moderate. Overall, the three schemes yielded a moderate vulnerability score on the socio-demographic profile index.

The households with members working in other communities have high vulnerability scores across the three schemes as youths in rural communities move to urban areas and neighbouring countries to seek employment. Furthermore, the households solely dependent on agriculture for their livelihoods have very high vulnerability scores in all three schemes. However, a low vulnerability score was attained in the three schemes for the livelihood diversification index. Most of the scheme farmers have various livelihood options: crafting, fishing, artisanal mining and gathering, trading wild fruits and wild insects. Ruchanyu has a high vulnerability score for livelihood strategies, while Exchange and Insukamini attained moderate vulnerability scores.

The receive-give ratio yielded very high vulnerability scores in all three schemes. However, all of them had moderate scores for the borrow-lend ratio. In addition, the households that have not received any assistance from the government and NGOs have a moderate vulnerability score in Insukamini but low scores in low Exchange and Ruchanyu.

The households dependent on the family farm for food have scored very high vulnerability scores for the three schemes, as scheme farmers primarily rely on the family farm for food. Generally, households in rural areas rely on the family farm for food. Households in the three schemes have low vulnerability scores for the number of months households struggle to find enough food for their families during the year. They rely on irrigation farming for food and have a culture to save food for the future season. Households in Exchange and Ruchanyu have high vulnerability scores

in relation to crop diversification index compared to Insukamini, which recorded a low vulnerability score for this sub-component. Farmers in Exchange are limited to the production of maize and sugar beans for household consumptions. In addition, farmers in Ruchanyu face challenges accessing water due to pump breakdown, inability to pay electricity bills, and regular power cuts.

Moreover, the households that do not save harvested crops for consumption during the greater part of the year have low vulnerability scores in the three schemes. The households that do not save seeds have a moderate vulnerability score in Exchange but low scores in Insukamini and Ruchanyu. Generally, vulnerability scores of food component were moderate in Exchange and Ruchanyu but low in Insukamini.

Water conflicts have moderate vulnerability scores across all schemes in the study. The vulnerability score in relation to the average time to clean water source was high in Insukamini, moderate in Exchange, and low in Ruchanyu. A moderate vulnerability score of lack of access to a constant clean water supply was observed among the households in Insukamini compared to the other two schemes, which scored low vulnerability scores. The Insukamini dam regularly dries up during the summer season of the year. In relation to the water-related subcomponents, the vulnerability scores of water were moderate in Insukamini and Exchange but low in Ruchanyu. Ruchanyu has high water sensitivity in relation to irrigation infrastructure maintenance compared to Insukamini with a moderate score and Exchange with a low score. The vulnerability score of households not satisfied with water distribution in the scheme was moderate for the three schemes. Similarly, poor conflict resolution in schemes attained a moderate vulnerability score for the three schemes. However, the three schemes reported high vulnerability scores on the decline in irrigation water supply. Households not participating in water scheduling yielded higher vulnerability scores in Exchange and Insukamini and low scores in Ruchanyu. Insukamini has a higher vulnerability score for households not participating in water-related training, while Exchange and Ruchanyu attained moderate scores.

Vulnerability in relation to time to the nearest health facility has low vulnerability scores in the three schemes. A moderate vulnerability score was obtained in Ruchanyu for the percentage of households with chronically ill members, while Exchange and Insukamini have low scores. However, Insukamini and Ruchanyu have both reported moderate vulnerability scores for the percentage of people who were so sick two weeks prior to the survey, while Exchange reported a

low score. Based on health-related sub-component, the three schemes recorded low vulnerability scores.

Table 3. 1: Sub-components, components, and LVI of Exchange, Insukamini, and Ruchanyu irrigation schemes.

	Exchange	Insukamini	Ruchanyu	Test Statistic (<i>p</i> - Value)
Socio-Demographic profile	0.372	0.404	0.430	F = 2.776
Dependency ratio	0.802	0.689	0.804	$p \leq 0.10$
Female household heads	0.365	0.409	0.297	
Household head did not attend school	0.005	0.012	0.000	
Households with orphans	0.193	0.364	0.568	
Average age of household heads	0.496	0.544	0.482	
Livelihood Strategies	0.551	0.480	0.496	F = 5.081
Households with members working outside	0.661	0.529	0.608	$p \leq 0.01$
Households depending solely on agriculture	0.922	0.830	0.811	
Livelihood diversification Index	0.070	0.080	0.070	
Food	0.329	0.224	0.296	F = 0.298
Households' dependent on family farm for food	0.870	0.727	0.946	$p \geq 0.10$
Number of months without food	0.062	0.118	0.101	
Crop diversification index	0.37	0.08	0.300	
HHs that do not save food	0.042	0.068	0.081	
HHs that do not save seed	0.302	0.136	0.054	
Water	0.379	0.570	0.352	F =24.856
Water conflicts	0.265	0.364	0.378	$p \leq 0.01$
Time to water source	0.409	0.584	0.122	
Households without constant water supply	0.068	0.352	0.081	
Households not satisfied with irrigation infrastructure maintenance	0.196	0.452	0.616	

Household not satisfied with water distribution in scheme	0.309	0.484	0.487	
Households reporting poor conflict resolution in scheme	0.377	0.459	0.481	
Household reporting a decline in irrigation water supply	0.823	0.859	0.687	
Households not participating in water scheduling	0.698	0.722	0.189	
Households not participating in water related trainings	0.268	0.853	0.311	
Health	0.116	0.195	0.235	F = 3.955
Hours to health facility	0.201	0.188	0.112	$p \leq 0.05$
Households with chronically ill members	0.068	0.068	0.297	
Households with sick members in the last 2 weeks	0.078	0.330	0.297	
Social Networks	0.335	0.616	0.509	F = 9.762
Receive: Give ratio	0.954	0.840	0.846	$p \leq 0.01$
Borrow: Lend ratio	0.302	0.409	0.405	
Households without assistance from government and NGOs	0.005	0.386	0.243	
Households without members in cooperatives	0.078	0.830	0.541	
Natural Disasters and Climate variability	0.444	0.503	0.442	F = 2.257
Household that does not receive warning about pending natural hazard	0.193	0.330	0.162	$p \geq 0.10$
Number of floods, droughts events in the past 10 years	0.317	0.550	0.400	
Households with members lost or injured due to floods or drought in the past 10 years	0.531	0.614	0.514	
Households that lost livestock due to floods or drought in the past 10 years	0.026	0.034	0.108	

Households who report a rise in drought incidences	0.943	0.955	0.811	
Mean, standard deviation of monthly rainfall	0.609	0.609	0.609	
Mean, standard deviation of monthly average maximum daily temperature	0.536	0.536	0.536	
Mean, average of monthly average minimum daily temperature	0.393	0.393	0.393	
LVI	0.444	0.503	0.442	F = 4.462 $p \leq 0.05$

Insukamini has a very high vulnerability score for cooperative membership, while Ruchanyu has a high score and Exchange has a low score. The overall vulnerability scores of the social network component were high in Insukamini and Ruchanyu, while low in Exchange.

The percentage of households that did not receive warnings of pending natural hazards indicated a moderate vulnerability score in Insukamini and low scores in Ruchanyu and Exchange. The vulnerability score in relation to incidences of natural hazards (droughts and floods events) was high in Insukamini and moderate in Exchange and Ruchanyu. The percentage of livestock fatalities due to floods and droughts produced high vulnerability scores in the three schemes. The households that reported death or in-jury due to natural hazards reported low vulnerability scores in all schemes. The house-hold members that reported a rise in drought incidences have very high vulnerability scores among the three schemes. The mean standard deviation of monthly rainfall was high among all schemes. In addition, the mean standard deviation of monthly average maximum daily temperature showed high vulnerability scores in all the schemes. Overall, Insukamini has a high vulnerability score of natural disasters and climate variability index, whereas Ruchanyu and Exchange recorded moderate scores.

All three schemes have moderate vulnerability scores for LVI. The results of major components are illustrated using a graphical diagram, with a scale that ranges from 0 (less vulnerable) to 1 (more vulnerable) (Figure 3.2). Figure 3.2 shows that Insukamini is more vulnerable in terms of social networks, water, and natural disasters and climate variability, while Exchange is more vulnerable in terms of livelihood strategies and food. Ruchanyu has a comparatively higher vulnerability in terms of socio-demographic profile and health.

Figure 3.3 below shows LVI contributing factors for Exchange, Insukamini, and Ruchanyu irrigation schemes.

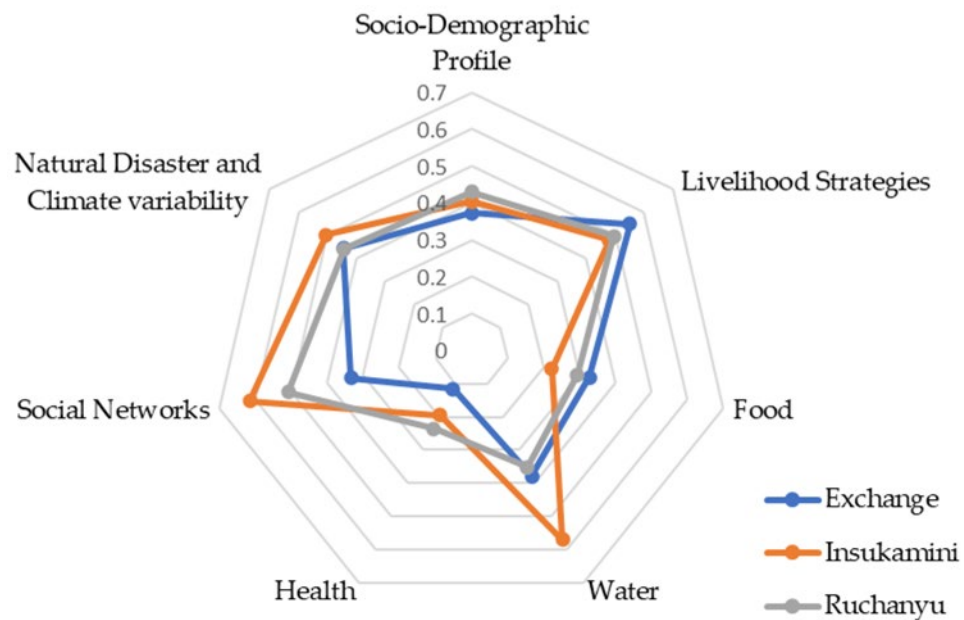


Figure 3. 2: Spider diagram of major components of the livelihood vulnerability of Exchange, Insukamini, and Ruchanyu irrigation schemes.

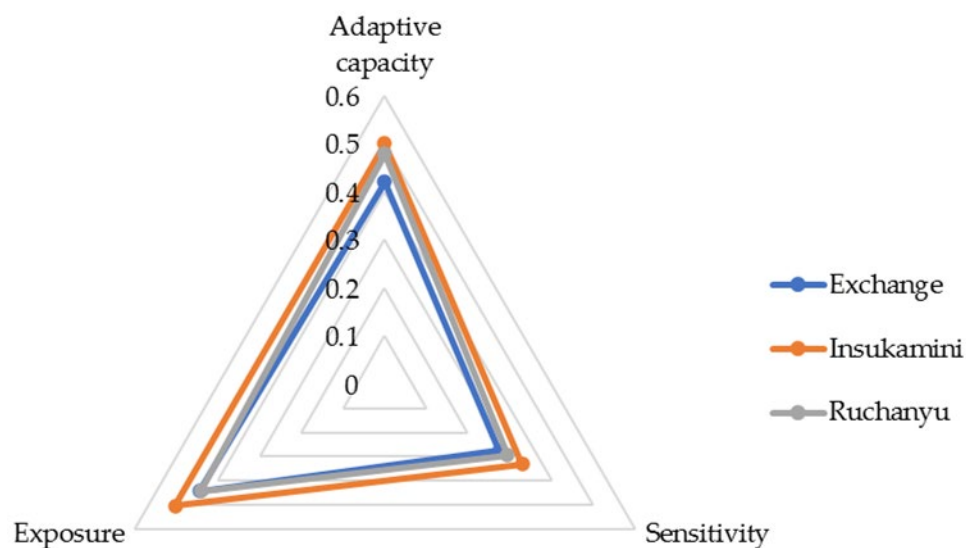


Figure 3. 3: Triangle diagram for contributing factors of LVI-IPCC.

3.4. Discussion

The use of indexed vulnerability analysis shows significant differences in the levels of vulnerability among the households in the three schemes ($p \leq 0.05$). Recently, indexed

vulnerability analysis has similarly found differences in vulnerability of communities in Bangladesh (Mudasser *et al.*, 2020), Ghana (Williams *et al.*, 2020), and Indonesia (Yulisa *et al.*, 2021). To better understand the sources of differences in vulnerabilities of the three schemes, the three contributing factors to vulnerability: exposure, sensitivity, and adaptive capacity were compared. Our results indicate that there were no significant differences in exposure among the three schemes ($p \geq 0.10$). This revelation that shows that communities with the same exposure can have differences in vulnerabilities is consistent with literature that much of the vulnerability does not emerge from the sky (Ribot, 2013). The majority of the households in the schemes were affected by natural hazards such as droughts, cyclones, and floods.

Nevertheless, most of the farmers in the three schemes reported an increasing trend of droughts. It has been previously noted that schemes in Zimbabwe are facing increased water stress as drought worsens (Moyo *et al.*, 2017, Magrath *et al.*, 2014). Droughts are among the disasters that have been reported to be on the rise in Zimbabwe due to climate change (Matsa, 2012, Chigavazira and Zandamela, 2021). Vulnerability indices in Table 3.1 show that a high percentage of households in the three schemes lost their live-stock due to droughts. Previous studies have reported a loss of livestock during the drought periods of 1992 (Matope *et al.*, 2020, Belle *et al.*, 2017). Although the differences in exposure to climate change are high, households in Insukamini indicated limited access to natural disaster warnings. Early warnings of projected natural disasters and future weather patterns help households prepare, reduce, or prevent the impact of the climatic event (Amuzu *et al.*, 2018), enabling scheme farmers to develop and adopt water use strategies during such seasons to meet their crop water needs. Consequently, there is no significant variation in natural disasters and climate among the households in the three schemes.

Nonetheless, there was cognisance of the existence of memory illusions when data are collected through toad science. Memory illusions refer to a situation where participants may exaggerate climate trends due to recent climate extremes experienced in an area (Labarrere *et al.*, 2011). The recent occurrence of climate extremes may mask the perception of people who tend to remember the recent extremes (Nhemachena and Warikandwa, 2019). To overcome the problem of memory illusion, standardising findings using the existing recorded trends is necessary. Most households in Insukamini recorded the highest number of members injured or died due to natural disasters. Most of the participants in Insukamini reported a rise in incidences of droughts over the years.

Climate data from Thornhill Airbase in Gweru were used as a standard for the three study sites since it was the only one containing rainfall and temperature data that have acceptable gaps. In Zimbabwe, meteorological trend analysis is hampered by inadequate weather network coverage. For example, at least two-thirds of the 64 synoptic stations in Zimbabwe are situated in the central watersheds, while there remains inadequate network coverage in arid and semi-arid regions of the country, where rainfall is highly erratic (GoZ, 2016). The limited coverage of rural communities makes tracking the impact of climate change in rural areas notoriously challenging and biased.

The sensitivity of the three schemes of the study significantly varies ($p \leq 0.05$) due to the schemes' variation of water and health components. However, the water challenges in Insukamini influence the scheme's overall sensitivity, given that Ruchanyu, with significantly high vulnerability, has a lower sensitivity index than Insukamini. Water is an essential source of livelihood in SISs in Zimbabwe; nevertheless, water conflicts are prevalent in smallholder irrigation farming across the country due to the systems' common pool resource nature and imbalance of demand and supply of freshwater (Duker *et al.*, 2020). A moderate vulnerability score of water conflicts resolution in the three schemes reflects limited water access. Nonetheless, households in Insukamini are relatively more vulnerable regarding water ($p \leq 0.01$) due to higher distances to clean water sources and scarcity of water during dry seasons of the year. A majority of the farmers in Insukamini and Exchange travel long distances to the nearest water source during the dry season. On average, households in Exchange and Insukamini travel at least double the distance households in Ruchanyu travel to the water source. However, distance to water sources signifies water insecurity, diminishes available labour force, contributes to poor health, and worsens women's burden, given their primary responsibility of collecting water (Irianti and Prasetyoputra, 2019). Water becomes scarcer during the year's dry season, compromising Insukamini households' access to water for day-to-day use and irrigation purposes.

Similarly, the involvement of most households in the Insukamini irrigation scheme in commercial market gardening of vegetables that demand a constant water supply makes water supply challenges more visible than in other schemes (Dube, 2016). Improving water security is likely to improve the livelihoods of households in schemes since it is closely associated with food security, health security, and other livelihood options (Cook and Bakker, 2012). However, water scarcity is

projected to be more severe with climate change, worsening water stress and water shortages (Cook and Bakker, 2012).

Households in Ruchanyu reported poor participation in irrigation infrastructure maintenance. This study confirms the findings by Mutambara and Munodawafa (2014) that scheme farmers using sprinkler irrigation systems have limited participation in operation and maintenance. Limited knowledge of basic operation and maintenance of pumps and sprinkler systems have been cited as the basic limitation to scheme infra-structure maintenance. Challenges in conflict resolution might be related to satisfaction with water distribution since they both have a moderate vulnerability index in the three schemes. Conflicts affect the development of the scheme (Mutambara and Munodawafa, 2014). The high vulnerability score for the decrease in irrigation water supply reported in the three schemes is related to climate change and increased demand for water from other sectors. In Exchange and Insukamini, the scheme committees are responsible for the watering schedule.

Although households in the Exchange irrigation scheme reported a longer average time to the nearest clinic, households in Ruchanyu are more vulnerable regarding the health index ($p \leq 0.05$). The study shows that it takes almost twice as much time to reach the nearest healthcare centre in Exchange compared to Insukamini and Ruchanyu. This reflects lack of access to health services. Ruchanyu has reported relatively more households with chronically ill members and more households with members who have been sick in the past two weeks. The higher prevalence of chronic illness and ill members in the past two weeks relates to the higher proportion of the working-age population involved in artisanal mining (Mutambara *et al.*, 2021, Makore and Zane, 2012). The dominance of artisanal mining leads to increased prevalence of infectious diseases such as the HIV/AIDS pandemic in Shurugwi following increased moral decay as prostitutes and drug abusers invade the area (Mutambara *et al.*, 2021). Mutambara and Munodawafa (2014) postulate that diseases including HIV/AIDS makes smallholder irrigation farming more vulnerable to shocks such as climate change. HIV/AIDS hit the rural population hard in the late 1990s, making households more vulnerable (Mushongah and Scoones, 2012). However, basing vulnerability analysis on current illness incidences undermines the harm caused by previous health incidences in current and future vulnerability to climate change.

The households in the three schemes have moderate vulnerability scores for food component with minimal differences ($p \geq 0.10$). The majority of households in the three schemes of the study depend on the family farm for food. Households that primarily depend on the family farm for food have lesser scope to diversify their livelihood (Mukherjee and Siddique, 2020). However, the number of months without food was low as the majority of the households save food. The study reveals that the majority of the households in the schemes save seed. Our findings support findings by Moyo *et al.* (2017) that most scheme farmers depend on retained seed that is poor yielding and disease-prone, making them more vulnerable to climate change. Households in the three schemes practice diversified farming since vulnerability based on crop diversification is low. High diversification index could be a strategy to adapt to climate change (Mushongah and Scoones, 2012).

Variation in adaptive capacity among the three schemes was attributed to their significant differences in socio-demographic profiles, livelihood strategies, and social network components. Households in the three schemes have a high dependency ratio, and this translates to a lower active working population than minors and aging household members compared to Insukamini and Exchange. Our findings concur with other findings in rural areas in Zimbabwe, where the dependency ratio was found to be high (Frischen *et al.*, 2020, Musemwa and Musara, 2020). The higher dependency ratio in Ruchanyu was attributed to higher numbers of orphans compared to the other two schemes. This implies that a smaller sized labour force will actively engage in minimum livelihood activities. This is worsened by the need to divert their labour for the dependent household members (Frischen *et al.*, 2020). Households with a larger labour force have a higher affinity for engaging in multiple livelihood activities (Makate *et al.*, 2019). High dependency ratio may likely contribute to households' financial exclusion in the Ruchanyu irrigation scheme, affecting their ability to participate in economic activities fully and challenging their adaptation to climate change (Agyemang-Badu *et al.*, 2018). Such findings suggest that a high dependency ratio diminishes household income. However, a high dependency ratio and large numbers of households with orphans in Ruchanyu are attributed to a significantly higher vulnerability index of socio-demographic profile ($p \leq 0.10$).

Nonetheless, minors and aging people in rural areas of Zimbabwe are frequently involved in household working, contributing to household income and food access (Irianti and Prasetyoputra,

2019). A high dependency ratio worsens the multi-faceted responsibilities of women who primarily provide labour in schemes (Matandare, 2015). There were moderate female-headed households among the three schemes of the study. This study supports the results that female household heads who own plots in SISs actively participate in scheme farming (Matsa, 2012). Gender influences farming decisions as women have limited influence and resources to make crucial decisions in response to the impacts of climate change (Makate *et al.*, 2019). The gender of the household head also has implications for the inequality of land allocation (Makate *et al.*, 2019). Vulnerability to climate change and variability is gendered and socially constructed (Matandare, 2015). Women in rural areas face more challenges than their male counterparts because of their roles in societies that are more sensitive to climate change (Dube, 2016). Child-rearing activities and household duties limit female household heads from exploring potential livelihood opportunities (Mazuru, 2019). However, the majority of female household heads are not married. Makate *et al.* (2019) postulate that marital status signifies the family system's strength, affecting decision-making, adoption of technology, productivity, and land use. In all the schemes, the majority of household heads have attained formal education with an average of 8.9 years; hence, integrating technology to adapt to climate change is likely to face minimum challenges. Formal education better positions them to access information, make better decisions, use effective land, embrace technologies and techniques, access support from more comprehensive sources and more livelihood strategies, and adapt to climate change (Abeje *et al.*, 2019, Makate *et al.*, 2019). However, the vulnerability index of the socio-demographic index is significantly higher in Ruchanyu due to the high dependency ratio and the high number of households with orphans.

Households in the three schemes have a high percentage of households with members working outside the scheme community. Members outside the irrigation communities improve the food security of their households through the provision of remittances (Nhundu *et al.*, 2010). Previous studies noted that the majority (76.7%) of Zimbabwean youth migrate from rural areas to foreign countries and they send remittances to their place of origin to reduce potential vulnerability (Sithole and Dinbabo, 2016). The households in the three schemes solely depend on agriculture for their livelihood since they all attained a very high vulnerability score for dependency on agriculture. The results from this study support previous research findings that majority of the households in rural areas of Zimbabwe directly depend on agriculture for their livelihoods (Chanza and Gundu-Jakarasi, 2020). Primary dependency on agriculture implies that scheme farmers are

more prone to climate change-induced disasters. Despite the three sub-components of livelihood strategies within the same vulnerability scores, Exchange was significantly more vulnerable in terms of livelihood strategies ($p \leq 0.01$).

Limited horizontal and vertical linkages among the communities in Insukamini have resulted in significantly high vulnerability in relation to social networks ($p \leq 0.01$). Reliable horizontal and vertical linkages strengthen the structural and functional relationships in an institution and beyond, improve institutional resilience, bond and bridge social capital, and create a space of exchange (Tompkins, 2005). The engagement of farmers in Insukamini with government and NGO programs was found to be very low compared to the other two schemes. Findings from this study support the findings by Mutambara and Munodawafa (2014) that government and NGO participation is dominant to other groups of farmers, disadvantaging others. Government and NGOs were emulated for providing support to farmers in rural areas. Many households in Exchange reported the ongoing participation of the Smallholder Irrigation Revitalization Programme (SIRP) in the maintenance of scheme infrastructure. Their limited engagement with government and NGOs may relate to commercial-oriented production, hence, limited reliance on handouts. Similarly, their participation within the community through resource sharing and engagement in cooperatives is still at its infant level.

Figure 3.4 shows the major components contributing to livelihood vulnerability of communities in the Exchange, Insukamini, and Ruchanyu irrigation schemes. Figure 3.4 reflects that communities in the Exchange irrigation scheme are more vulnerable to livelihood strategies, natural disasters and climate variability, socio-demographic profile, social networks, and food. In contrast, in Insukamini, they are more vulnerable to social networks, natural disasters and climate variability, livelihood strategies, social demo-graphic profile, and water. Furthermore, communities in Ruchanyu are more vulnerable to social networks, livelihood strategies, socio-demographic profiles, natural disasters, and climate variability.

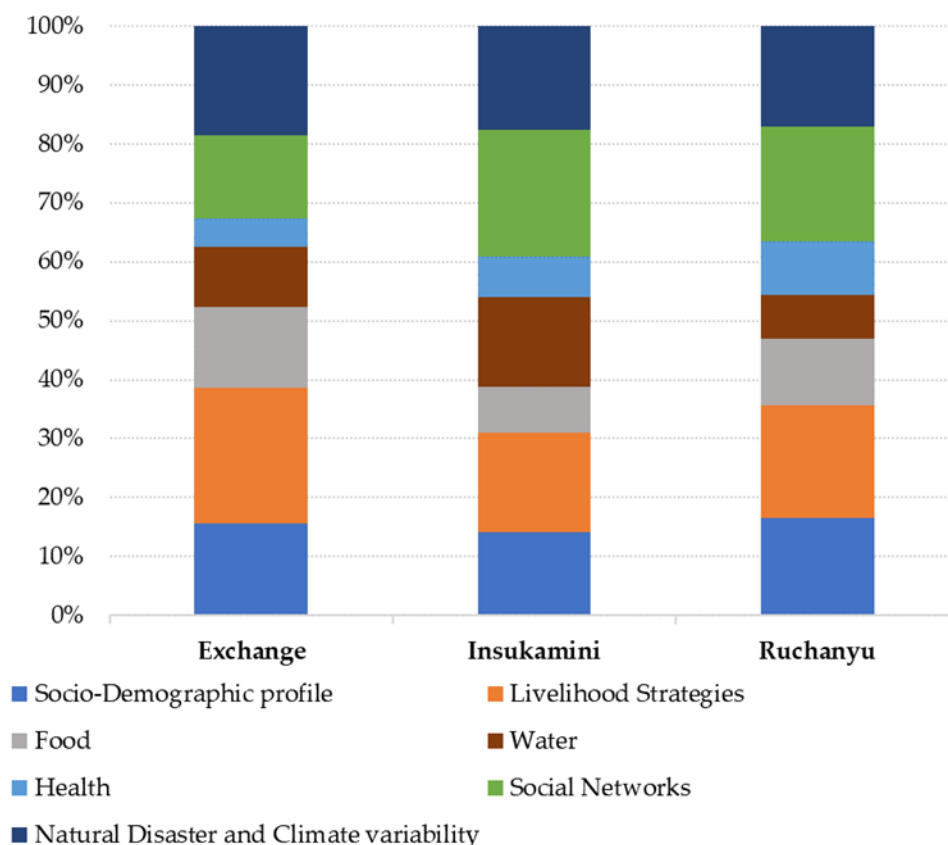


Figure 3. 4: Major components contributing to vulnerability of communities in Exchange, Insukamini, and Ruchanyu irrigation schemes.

Given that SISs grow different crops does not mean that growing crops from the least vulnerable scheme will solve the situation of the most vulnerable scheme. As illustrated in Figure 3.4, the main influencing factors to vulnerability in Insukamini and Ruchanyu are social networks, while in Exchange are livelihood strategies. Social networks should be prioritized in Insukamini and Ruchanyu irrigation schemes due to their higher severity compared to other components. Livelihood strategies should be prioritized in Exchange due to its higher severity compared to other components. The focus area for development varies from one scheme to another. Focusing development and innovation on the key profile in each scheme will likely be an effective way of improving other profiles, given a close interconnection of the profiles and their subcomponents.

IPCC framework of calculating LVI

Households in Insukamini have significantly high indices of adaptive capacity and sensitivity (Appendix 3.3). However, the LVI-IPCC score for Insukamini was significantly higher than that of households in Ruchanyu and Exchange. This implies that the Insukamini irrigation scheme is

overall more vulnerable to climate change and variability than the Ruchanyu and Exchange irrigation schemes. Considering that exposure was not significantly different, sensitivity and adaptive capacity significantly contribute to the variation in vulnerability to climate change among the three schemes. The possibility of reducing vulnerability to climate change should be through improving adaptive capacity and consequently addressing the sensitivity of the scheme communities. The dependency of the scheme households on the farm as a primary source of food is a significant setback in the face of increased water stress in irrigated agriculture due to climate change (Frischen *et al.*, 2020). Livelihood diversifying with both agricultural and non-agricultural activities will improve households' adaptation to the impacts of climate change.

Given that most household heads have attained formal education, their potential to adapt to innovations and livelihood options is very high. However, most of the farmers in the schemes are aged; hence, their likelihood to venture into new livelihood options is likely to be limited by their advanced age, which challenges coping with the rapidly changing technologies whenever needed. In addition, a generally high dependency ratio robs the farmers of potential investment income given that most of them also have an additional responsibility of caring for orphans.

3.5. Conclusions

This paper uses the LVI-IPCC to understand the vulnerability to climate change of households in SISs. This assessment is critical to understand the vulnerability to climate change of SISs in Zimbabwe and to develop a tailor-made intervention to make households in SIS more sustainable in the face of climate change. Our results indicate that households in the Insukamini irrigation scheme are more vulnerable to climate change and variability. Natural disasters and climate variability, social networks, and water security contribute to high vulnerability in Insukamini irrigation scheme. The LVI-IPCC shows that households in the Insukamini irrigation scheme have a higher vulnerability to climate change than those in Exchange and Ruchanyu. Interventions to address vulnerability to climate change in Insukamini should prioritize strengthening social networks, improving water security, and raising awareness of pending natural hazards and future weather trends. There is a need to ensure that disseminating early warning information of natural disasters is carried out timeously, particularly in the Insukamini irrigation scheme. Broadcasting climate information using SMSs, radio, and TVs is wide-ranging and thus, unlikely to address the needs of a specific area. The role of extension workers of disseminating natural disaster and

weather information must be strengthened as farmers tend to be more reliant on them for a wide range of information.

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CHAPTER 4

SOCIO-DEMOGRAPHIC, INSTITUTIONAL AND GOVERNANCE FACTORS INFLUENCING ADAPTIVE CAPACITY OF SMALLHOLDER IRRIGATION SCHEMES IN ZIMBABWE.³

Abstract

The provision of resilience and adaptation to climate change in smallholder irrigation communities is a critical component in implementing common pool resource management. Institutions in many smallholder irrigation schemes in developing countries are diverse and they contribute to adaptation to climate change and improving livelihoods of scheme communities. Human behaviour, institutional capacity and culture play important roles in shaping vulnerability of communities to climate change. However, how these contribute to vulnerability of smallholder irrigation schemes to climate change **need to be understood**. In order to close this lacuna, this study seeks to explore how socio-demographic, governance and institutional factors influence adaptive capacity in Exchange, Insukamini and Ruchanyu irrigation schemes. Questionnaire-based interviews, group discussions and key informant interviews were used for data collection. Adaptive capacity calculated using the livelihood vulnerability model was used as the dependent variable for this study. Ordinary least square regression was used to assess socio-demographic, institutional and governance factors influencing adaptive capacity in the smallholder irrigation scheme. The hypothesis that stronger institutions positively influence the adaptive capacity of smallholder irrigation systems was accepted. The study reveals that adaptive capacity is significantly ($P \leq 5\%$) influenced by a margin of 0.026 for age squared, 0.073 for gender, 0.087 for education, 0.137 for household size, -0.248 for satisfaction with irrigation committee, 0.356 for participation in irrigation water scheduling, and -0.235 for participation formulation of rules. Assessing factors influencing adaptive capacity help to improve the livelihoods of scheme farmers in the face of climate change.

Keywords: Climate change; livelihoods; vulnerability; scheme management; common-pool resource

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4.1 Introduction

Climate change, characterised by changes in precipitation patterns, increased frequency and severity of droughts, threatens the viability of smallholder farming systems in arid and semi-arid regions (Kalele *et al.*, 2021) in the developing world. Thus, smallholder irrigation schemes (SISs) are promoted to increase the adaptive capacity of these marginal environments. These SISs are common-pool resources (CPRs); their success is dependent on the robustness of self-governing institutions and capacity to sustainably manage the productive resources as conditions change (Ma'Mun *et al.*, 2020, Villamayor-Tomas and García-López, 2017). The strength of the institutions governing socio-ecological systems like irrigation schemes is important to most smallholder farmers' livelihoods and food security (Thapa and Scott, 2019). However, socio-ecological systems have numerous complex variables that interact and affect how they operate at multiple levels (Cox *et al.*, 2010, Ostrom, 2011).

Previous studies have shown that the institutions in the SISs should be effective in collective decision-making, allocation of limited water resources, infrastructure maintenance, and conflict resolution (Villamayor-Tomas and García-López, 2017, Wang *et al.*, 2021). Institutions thrive on building and sustaining cooperation in the CPR system through satisfying both short-term self-interests and long-term group goals (Raub *et al.*, 2013) in an evolving ecological, socio-economic and political environment shaping its emergence, evolving and operation (Wang *et al.*, 2021). SISs are run by Irrigation Management Committees (IMCs), which are mainly governed by customary laws and water use rights that authorise scheme farmers to collectively manage water use (Villamayor-Tomas and García-López, 2017). Nevertheless, environmental change and increased water scarcity have added an extra burden on these functional socio-ecological systems that have shown mixed performances (Ma'Mun *et al.*, 2020). The relationship between CPRs management and adaptation calls for integrating climate and socio-ecological system management policies (Villamayor-Tomas *et al.*, 2020, Villamayor-Tomas and García-López, 2017) in SISs. Institutions can constrain or enable adaptation (Bisaro and Hinkel, 2016); hence, institutional analysis is essential in adapting socio-ecological systems to climatic change.

Climate change adaptation involves a change of human practices in anticipation of climate change (Villamayor-Tomas *et al.*, 2020). IPCC (2001) defines adaptation as changes in processes and practices to moderate potential damages or benefit from climate change opportunities. Adaptive

capacity is an individual or a system's predicted ability to prepare and adapt to future changes (Engle, 2011). Adaptation, which is the manifestation of adaptive capacity, is important to resilience and adaptive management, which are intertwined with institutional analysis (Villamayor-Tomas and García-López, 2017). Thus, institutional elements such as regulations, property rights, and rules change with climate adaptation (Villamayor-Tomas *et al.*, 2020).

Analysis of the role of institutional and adaptation in irrigation systems was inspired by Ostrom (2011) through her institutional analysis framework developed to understand and overcome uncertainties and complex social dilemmas. Reflections across different CPR systems show the success and failure of Ostrom principles (Wang *et al.*, 2021, Anderies *et al.*, 2016). This is not surprising given the myriad and complex relationship between institutions and adaptation in SISs. Globally, the findings from publications on the roles of institutions on adaptation in SISs have produced contrasting results under different settings (Wang *et al.*, 2021). This shows that previous successful institutional actions may not be effective in a different context, creating a knowledge gap on patterns and dynamics of institutional changes in diverse socio-ecological and political contexts (Wang *et al.*, 2021). Therefore, given the heterogeneity of the farming systems worldwide, especially in southern Africa, more evidence-based studies are required to explore the role of institutions in adaptation in SISs. This scientific inquiry is critical given that in the absence of unambiguous local knowledge, the role of institutions in adaptation in SISs would largely remain a conjecture. The CPRs nature of SISs highlights the need to understand the relation between institutions and adaptation to climate change. SISs in southern Africa and especially in Zimbabwe may differ from similar CPRs worldwide based on their biophysical, cultural and political context, challenging understanding of the performance of their institutions on adaptation based on existing studies.

In agriculture, a sensible conjecture is climate-proofing crop yields in smallholder farming systems given their vulnerability to climate change. By developing the targeted 350 000 ha for irrigation under the Zimbabwe National Development Strategy 1 (2021 – 2025), the country aims to increase agricultural output, particularly in smallholder farmers (GoZ, 2020). The IMCs running SISs are key to climate-proofing crop yields. Thus, policy strategies are required to strengthen institutions for reducing sensitivity while building resilience to climate change.

Based on the literature on the role of institutions on adaptation in the **SISs** (Villamayor-Tomas, 2018, Villamayor-Tomas *et al.*, 2020, Meinzen-Dick *et al.*, 2002, Lam, 2006, Cifdaloz *et al.*, 2010, Cox and Ross, 2011, Ma'Mun *et al.*, 2020), the following conjectures were made: a) Institution influence the adaptive capacity of **SISs**; b) Institutional elements such as scheme rules, governmental and private organization support, water sharing and scheme maintenance and, c) IMCs and participation of scheme member influence adaptive capacity.

Zimbabwean context is suitable for studying the relationship between institutions and adaptation in SISs due to multiple reasons. First; Irrigation schemes in the country have a linear relationship with higher food security and income that is compromised by drought-related challenges and limited investment in infrastructure maintenance (van Rooyen *et al.*, 2020). Secondly, the government of Zimbabwe and partners in irrigation development, including the International Fund for Agricultural Development (IFAD) and Smallholder Irrigation Revitalization Programme (SIRP), continue to invest in new SISs and rehabilitate existing ones. Lastly, through the recently availed Irrigation Policy, the Government of Zimbabwe intends to improve water use efficiency, improve access to finance, inputs, markets, overcome governance challenges, and improve policy and regulation environment in irrigation schemes. Thus, strong institutions in SISs are required to achieve these objectives. Therefore, this study seeks to assess the impact of institutional and governance factors on the adaptive capacity of **SISs** in Zimbabwe.

4.2 Methodology

4.2.1 Study area

This study was conducted in Midlands Province of Zimbabwe. It progressed from the identification of three research sites (Exchange, Insukamini and Ruchanyu Irrigation schemes). The selection of the study sites was based on the diversity of their characteristics, as shown in Table 4.1.

Table 4. 1: Characteristics of Exchange, Insukamini and Ruchanyu Irrigation schemes

Variable	Scheme		
	Exchange	Insukamini	Ruchanyu
Year constructed	From 1973 and from 1985 ³	1988	1980s
Location	Zhombe communal area ⁴	Lower Gweru	Shurugwi
Geo-coordinates	- 18°50'51: 29°4'36	- 19°21'31: 29°35'25	- 19°50'39: 29°58'45
Land area	168.8 ha ^{4,5}	41 ha	27 ha ⁵
Distance from nearest town	60km from Kwekwe 80km from Gweru	41 km from Gweru	29 km from Shurugwi
Agroecological zone	4 ⁵	4 ³	3
Number of households	982	125	85
Source of water	Exchange dam	Insukamini dam	River
Water delivery	Concrete canals	Concrete canals	Sprinkler
Management system	Consultative and democratic	Consultative and democratic ¹	Consultative and democratic
Rainfall	450 – 650 mm	600 – 800 mm ²	650 – 850 mm ⁵
Temperature		16°C ²	16°C ⁵
Soils	Clay loam ⁵	Sand loam and clay loam ²	Sandy loam ⁵
Main crops and average yields	Maize (7 t/ha) Beans (1 t/ha in winter and 1.2 t/ha in summer)	Maize (4.4 t/ha) Beans (1.9 t/ha) Onions, cabbages, tomatoes, wheat, peas, garlic and rape	Maize

Data in the table was sourced from (¹ Matsa, 2012, ²Chanza *et al.*, 2019, ³Chancellor and Hide, 1997, ⁴Nyamayevu and Chinopfukutwa, 2018, ⁵Mhembwe *et al.*, 2019)

4.2.2 Data collection

Questionnaire-based interviews, Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) were undertaken to collect data in Exchange, Insukamini and Ruchanyu irrigation schemes. A pilot study was done to test the suitability of the questionnaire for this study. The scheme was fragmented into the head, middle and tail sections for the purpose of data collection.

This study used random sampling to identify respondents of this study. Random sampling is a probabilistic sampling method brought to the fore by Bowley (Bellhouse, 1988). A statistically significant sample of 317 households (192 from Exchange irrigation scheme, 88 from Insukamini irrigation scheme and 37 from Ruchanyu irrigation scheme based on proportional representation) was selected for the study ($P \leq 5\%$) as shown in Table 4.2. The formula below was used to determine the sample size of this study:

$$n = \frac{N}{Ne^2} \quad (1)$$

Where n – sample size, N – population and e – confidence interval

Six focus group discussions each composed of 10 -15 representatives, were also done to discuss rules, policies, strategies and governance issues in schemes. Key informant interviews were done with eleven officials that included extension workers, district and provincial Agricultural Technical and Extension Services (AGRITEX) officers, and Department of Irrigation (DIRR) staff to get their perspectives on climate change in irrigated agriculture.

Gender, marital status, age, years in formal education, number of years in irrigation farming and number of years in farming are the socio-demographic factors captured for this study. Institutional factors which were studied includes traditional leaders, cooperatives, academic institutions, irrigation management committees, NGOs and private organizations. Governance factors studied includes water scheduling, electing committee members and formulating of scheme rules.

Table 4. 2: Sampling design

Irrigation Scheme	Population Size	Sample Size
Exchange	982	192
Insukamini	125	88
Ruchanyu	85	37
Total	1 192	317

4.2.3 Data analysis

Firstly, adaptive capacity was computed from raw data set using weighted-balance and integrated approach. Weighted balance and integrated approach adapted after (Hahn *et al.*, 2009) was used to calculate adaptive capacity. Major components of adaptive capacity (socio-demographic factors, livelihood strategies and social networks) consist of subcomponents, each contributing equally to the index and given equal weighting. The weighted balance and integrated approach are mainly used in calculating Livelihood Vulnerability Index (LVI) and Climate Vulnerability Index (Sarker *et al.*, 2019). The use of weighted balance and integrated approach is recently increasing due to the increased need to analyse vulnerability climate-related disasters (Sarker *et al.*, 2019). Ordinary least-square (OLS), one of the familiar statistical techniques in the social sciences used to predict the values of continuous response variables in multivariate analysis (Hutcheson, 2011), was applied. The Breusch-Pagan/Cook-Weisberg test for heteroskedasticity was applied to identify the existence of any linear form of heteroskedasticity of OLS. OLS satisfies the need of this study due to its ability to provide the best estimates with continuous and coded categorical variables (Hutcheson, 2011). Recently, OLS was used to assess the effects of climate change adaptation on livelihood vulnerability in Ghana (Azumah *et al.*, 2021). Linearity of regression coefficients, absence of serial correlation, predictors being uncorrelated with coefficients, absence of multicollinearity and normality of residuals are the limitations met to have the best OLS estimates from this study.

Equation (2) was used to standardize specific components.

$$Index_{sv} = \frac{S_v - S_{min}}{S_{max} - S_{min}} \quad (2)$$

Where S_v – original subcomponent value; S_{min} and S_{mux} – minimum and maximum value of the subcomponent, respectively.

An average of each subcomponent was calculated using Equation (3)

$$M_{vj} = \frac{\sum_{i=1}^n Index_{svi}}{n} \quad (3)$$

Where M_{vj} – value of major component j for area v ; $Index_{svi}$ – subcomponent value indexed by i of major component M_j ; n – number of subcomponents in major component M_j .

$$IndexAdaCap = \frac{W_{SDF}SDF + W_{LS}LS + W_{SN}SN}{W_{SDF} + W_{LS} + W_{SN}} \quad (4)$$

Where $IndexAdaCap$ – adaptation capacity index; W_{SDF} , W_{LS} , W_{SN} – weight for socio-demographic factors (SDF, livelihood strategies (LS and social network (SN), respectively.

An OLS regression analysis was performed on vulnerability indices of Adaptive Capacity to assess governance and institutional factors influencing the adaptive capacity of scheme communities. OLS regression was performed with Adaptive Capacity as a dependent variable, while socio-demographic factors, governance and institutional variables.

$$Y_i = a + b_1X_1 + b_2X_2 + \dots + b_mb_m + c \quad (5)$$

Where Y_i – the dependent variable (**Adaptive capacity**); $X_1, X_2, \dots, X_m$ – the independent variables; a – constant; $b_1, b_2, \dots, b_m$ – multiple regression coefficients.

4.3 Results

4.3.1 Socio-demographic characteristics

Table 4.3 shows socio-demographic characteristics of households in Exchange, Insukamini and Ruchanyu Irrigation Scheme. Based on this study, Ruchanyu Irrigation Scheme has the most male respondents and Insukamini have the least ($P \leq 0.05$). Among the three schemes, most of the respondents in Ruchanyu were significantly married than respondents in Ruchanyu and Exchange, given that over nine-tenth of the respondents were married ($P \leq 0.05$). Although marital status was generally high in the schemes, the majority of the female household heads (53.8%) were not married, as shown in Table 3. It was observed that Exchange is dominated by aging farmers (average age of 56 years) compared to Ruchanyu and Insukamini Irrigation schemes. Data from the questionnaire survey revealed that respondents from Insukamini Irrigation scheme acquired the highest level of formal education (10 years). In comparison, those in Exchange irrigation scheme attain the least educational level (8.5 years).

In respect of household size, respondents in Ruchanyu Irrigation Scheme have the largest household size (average of 7.42 members) while the respondents in Exchange Irrigation Scheme had the least (average of 4.52) as shown in Table 3. Respondents in Exchange Irrigation Scheme are more experienced farmers (average years in the farming of 31.24 years), while those in Ruchanyu had the least experience in farming (average years of farming of 20.15 years). Respondents in Exchange Irrigation Scheme are more experienced in irrigation farming (average of 23.59 years), while those in Ruchanyu Irrigation Scheme are last experienced (average of 9.36 years) (Table 4.3).

Table 4. 3: Socio-demographic variables of scheme farmers

Variable	Frequency	Mean	Percentage	Significant level	Standard deviation
Gander (Male)					
Exchange	122		63.5	*	
Insukamini	52		59.1		
Ruchanyu	70.3		70.3		
Marital Status (Married)					
Exchange	135		70.3	*	
Insukamini	63		71.6		
Ruchanyu	35		94.6		
Marital status by gender of household heads (Married)					
Male			89.5	*	
Female			46.2		
Age					
Exchange		56.24			12.78
Insukamini		52.30			
Ruchanyu		53.14			
Years of formal education					
Exchange		8.53			3.14
Insukamini		10.02			
Ruchanyu		8.90			

Size of household		
Exchange	4.52	2.22
Insukamini	5.85	
Ruchanyu	7.42	
Number of years in farming		
Exchange	31.24	14.38
Insukamini	20.45	
Ruchanyu	20.15	
Years in irrigation farming		
Exchange	23.59	12.74
Insukamini	11.23	
Ruchanyu	9.36	

Note: * indicates significance level at 5%.

4.2 Governance and institutional factors

Across the three irrigation schemes in this study, there is a significant difference in satisfaction of participation of local institutional actors in the schemes ($P \leq 0.01$) as shown in Table 4.4.

Table 4. 4: Ranking of effectiveness of institutional factors by Exchange, Insukamini and Ruchanyu Irrigation Schemes Farmers

Scheme	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Significance level (X^2)
Effectiveness of traditional leaders in irrigation farming						
Exchange	1.6	5.7	30.2	53.6	8.9	*
Insukamini	6.8	6.8	72.7	13.6	0	
Ruchanyu	5.6	11.1	44.4	22.2	16.7	
Effectiveness of cooperatives						
Exchange	19.3	11.5	34.9	31.3	3.1	*
Insukamini	50.9	23.6	21.8	3.6	0	
Ruchanyu	0	25.0	18.8	12.5	43.8	
Effectiveness of NGO and PVT Organizations						
Exchange	0.5	0	0	28.1	71.4	*

Insukamini	0	6	57.8	36.1	0	
Ruchanyu	13.3	40	10	16.7	20	
Effectiveness of Academic Institution						
Exchange	0	0.5	7.3	57.3	34.9	*
Insukamini	1.6	18.8	65.6	12.5	1.6	
Ruchanyu	0	11.1	14.8	66.7	7.4	
Effectiveness of Irrigation Committee						
Exchange	3.1	1.6	10.4	43.2	41.7	*
Insukamini	1.1	2.3	2.3	62.5	31.8	
Ruchanyu	3.4	10.3	6.9	55.2	24.1	
Effectiveness of Community/Fellow Farmers						
Exchange	0.5	0	1.6	40.6	57.3	*
Insukamini	0	14.7	5.9	63.2	16.2	
Ruchanyu	3.3	10	16.7	30.0	40.0	
Effectiveness of Government Agencies (Extension Workers)						
Exchange	0	0	2.1	21.6	76.30	*
Insukamini	0	0	2.4	48.2	49.4	
Ruchanyu	0	3.7	7.4	44.4	44.4	

Note: * indicates significance level at 5%.

For the three schemes in this study, there is a significant difference in the participation of scheme farmers in irrigation water scheduling, electing/removing members, and water scheduling ($P \leq 0.01$) (Table 4.5).

Table 4. 5: Ranking of participation in Governance factors by Exchange, Insukamini and Ruchanyu Irrigation scheme farmers

	Never	Sometimes	Always	Significance Level
Participate in irrigation water scheduling				
Exchange	8.9	42.7	48.4	*
Insukamini	24.1	5.7	70.1	
Ruchanyu	3.1	9.4	84.4	

Participate in electing / Removing committee members				
Exchange	11.5	39.6	49.0	*
Insukamini	1.1	13.6	85.2	
Ruchanyu	0	21.2	78.8	
Participation in formulating scheme rules				
Exchange	19.8	55.7	24.5	*
Insukamini	18.2	12.5	69.3	
Ruchanyu	0.0	15.2	84.8	

Note: * indicates significance level at 5%.

4.3 Factors affecting adaptive capacity

The results in Table 4.6 show that socio-economic, governance and institutional factors significantly influence scheme farmers' adaptive capacity. Adaptive capacity is significantly impacted by the following socio-economic factors: age squared ($P < 0.05$), gender ($P < 0.05$), education ($P < 0.05$), household size ($P < 0.01$), farming experience ($P < 0.05$) and livestock unit ($P < 0.05$). Institutional and governance factors influencing adaptive capacity are participation of cooperatives ($P < 0.05$), irrigation committee ($P < 0.01$) and governance agencies ($P < 0.05$). Participation of farmers in electing/removing committee members ($P < 0.05$), formulating rules ($P < 0.05$) and irrigation water scheduling ($P < 0.05$) are governance factors affecting adaptive capacity. The effect of age squared, gender, education, household size, years in farming, government agencies, and irrigation water scheduling on adaptive capacity are positive. Livestock unit, satisfaction with irrigation committee, electing/removing committee members and formulating rules negatively affect adaptive capacity.

Table 4. 6: Effects of socio-demographic factors, governance and institutional factors on adaptive capacity

	B	Std. Error	dy/dx
Age Squared	0.026*	0.006	0.0004
Age	-0.002	0.003	-0.003
Gender	0.073*	0.011	0.074
Education	0.087*	0.020	0.125

Household size	0.137*	0.026	0.145
Farming experience	0.011*	.006	0.007
Traditional Leaders	0.046	0.067	0.073
Cooperatives	0.104*	0.047	0.135
Private Organization and NGOs	-0.005	0.073	-0.013
Academic Institutions	0.077	0.074	0.132
Irrigation Management Committee	-0.248*	0.061	-0.261
Government agencies (Extension Officer)	0.212*	0.116	0.093
government initiatives and policies	0.009	0.134	0.075
Electing/removing committee members	-0.165*	0.100	-0.052
Formulating rules	-0.235*	0.098	-0.323
Irrigation Water scheduling	0.356*	0.112	0.357

Note: * indicate significance level at 5%.

4.4 Discussion

The positive coefficient of age squared confirms the converse relationship between age and adaptive capacity (Haykir and Çelik, 2018). The convex relationship suggests that when the age of farmers reaches a certain age, the relationship between age and adaptive capacity changes and becomes positive. This means that as households head gets older, they become more adaptive to climate change. Mudombi-Rusinamhodzi *et al.* (2012) find similar results that aging farmers in Zimbabwe are more adaptive to climate change.

Similarly, the positive coefficient of gender means that males are more adaptive, while female farmers have a limited probability of obtaining higher adaptive capacity (Table 4.5). Climate change is gendered in nature; hence, most of the responsibilities of women are climate-sensitive, making them suffer more because of climate variability than men (Mazuru, 2019). Female **farmers'** lower adaptive capacity is attributed to limited access to production inputs (Azumah *et al.*, 2021). Women characteristically have limited access to productive resources (assets, inputs and services) compared to men (Patil and Babus, 2018, Raney *et al.*, 2011, Doss *et al.*, 2018), militating their

adaptation to climate change and variability. Mosello *et al.* (2017) find out that female-headed households in Zimbabwe are particularly vulnerable since they hold less land, produce lower yields, own fewer heads of livestock and are excluded from accessing services like extension and credit. Results obtained from the study further revealed that 53.8% of the female household heads were not married, while a majority of male household heads were married (89.5%). Women's marital status is a factor in determining their access to adaptive strategies compared to the case of men (Van Aelst and Holvoet, 2016). Findings by Van Aelst and Holvoet (2016) show that divorced and widowed women are disadvantaged in agricultural water management although they can pursue more income-earning activities outside the farming sector. A study in Mozambique suggests that female-headed households have a lower adaptive capacity (Panda *et al.*, 2013).

The positive coefficient of education implies that education is key for reducing uncertainties and ensure sustainable agricultural practices, hence increasing the adaptive capacity of smallholder farmers in SISs. Education is one of the generic capacities usually associated with development policies (Villamayor-Tomas and García-López, 2017). Oates *et al.* (2017) find that low educational levels and lack of skills and weak leadership undermine farmers' ability to manage their schemes effectively. More educated and experienced farmers have improved access to infrastructure and market, greater capacity to manage and analyse information and use it more efficiently (Sheng Tey *et al.*, 2018, Choden *et al.*, 2020). Educated farmers have a higher opportunity to improve their production, access information, and understand commercial farming concepts that are critical in adapting to climate change (Moyo *et al.*, 2017, Mutambara and Munodawafa, 2014). Education may potentially positively influence the ability of the household to take advantage of risk management mechanisms, hence, improving the household's overall adaptive capacity. These results are consistent with others who suggest that education improves the adaptive capacity of households (Sheng Tey *et al.*, 2018, Choden *et al.*, 2020, Thathsarani and Gunaratne, 2018, Lemos *et al.*, 2013). In a study in Ghana (Asante *et al.*, 2012) revealed that education positively impacts households with low adaptive capacity.

In terms of household size, the results show that the average household **members within the productive age group** ranged between 4 to 8 persons in adult equivalent among the three schemes. The extensive and semi-extensive nature of irrigation farming in smallholder irrigation schemes in Zimbabwe demands more labour from the households. This work further demonstrates that

household size significantly increases adaptive capacity by a margin of 0.137 ($p = 0.05$) (Table 4.6). The effects of household size suggest that larger household sizes will have enough labour to venture into multiple livelihood options. Similarly, labour availability for agricultural tasks is determined by household size. Household size increases action flexibility, adaptive capacity and spreads the risk across diverse income sources (Li *et al.*, 2017). A study in China finds that household size complements non-agricultural income for apple farmers, and they acquire adaptive capital using non-agricultural income (Li *et al.*, 2017). These results concur with the finding that household size positively affects adaptation options due to a higher propensity to engage in multiple adaptation options (Panda *et al.*, 2013).

The study show that farming experience positively influences the adaptive capacity of scheme farmers. A year increase in farming experience leads to a 0.011 increase in adaptive capacity at a 5% significance level (Table 4.6). The results from this study imply that scheme farmers who have been into farming for an extended period are more likely to be better adaptive to climate change. These findings are consistent with a household survey from Zimbabwe, in which households with more farming experience are better adaptive to climate variability (Mudombi-Rusinamhodzi *et al.*, 2012). In Cameroon, farming experience is among the factors determining the adaptation decision of farmers (Yong, 2017).

The positive relationship between adaptive capacity and satisfaction with cooperatives in the scheme illustrates the importance of collective action on adaptation. These findings imply that farmers' access to support services that include credit, training and information from cooperatives is more likely to make them more adaptive to climate change. Farmers satisfied with cooperatives can potentially be members of cooperatives. Participating in cooperatives is potentially instrumental in shaping farmers' motivation and facilitating the decision to adapt to climate change through cooperatives (Frank *et al.*, 2011). Cooperative plays a pivotal role by enabling technological adaptation by promoting certain technologies in Zimbabwe (Mugabe *et al.*, 2010). Cooperatives promote effective exchange and co-production of local and scientific information and provide new arenas for social interaction (Frank *et al.*, 2011). Members of cooperatives potentially use the best practices approach as they are likely to receive climate change training and better access to financial assistance (Canevari-Luzardo *et al.*, 2020). The ability of individual actors to retain bonding enables members to gain the benefits of cooperatives.

The IMCs in SISs are responsible for conflict resolution, acquiring and managing funds, and maintaining and improving scheme infrastructure. The results from the study show that participants who were satisfied by the IMCs were less adaptive to climate change. A unit change in satisfaction results in reduced adaptive capacity by a margin of 0.25 at a 5% significant level (Table 4.6). The study shows that 86.2% of the participants were satisfied with the IMC. The study's findings support observations in the Makwe irrigation scheme in Zimbabwe, where 85% of the farmers were satisfied with the IMC (Ndlovu *et al.*, 2015). The positive relationship between satisfaction with IMCs and adaptive capacity implies that IMCs consider adaptation to climate change in their activities in water-related issues. The IMCs mobilize government support, donor funding, financial management, organise participation of members in scheme maintenance, ensure equitable distribution of water and information sharing, and facilitate the development of collective adaptation that is context-specific to the risk the scheme faces. Villamayor-Tomas and García-López (2017) postulate that IMCs can provide area-specific **adaption** to cope with water-related climate disturbances.

The results in Table 6 show that satisfaction with government agents including agriculture extension (AGRITEX) officers, ZESA, EMA and ZINWA significantly affects the adaptive capacity of scheme farmers. Although farmers were satisfied with government agencies, FGDs in Ruchanyu Irrigation scheme show that farmers were not satisfied with ZESA's regular load shading, high electricity fares and disconnection of electricity for non-payment. Further, in Exchange Irrigation Scheme, farmers were not satisfied with water allocation by ZINWA, particularly for household use. The positive effect of satisfaction with extension officers on adaptive capacity suggests that scheme farmers who are satisfied by extension officers have a higher probability of adapting to climate change. This is consistent with previous findings in Zimbabwe, in which households' adaptive capacity in rural communities is enhanced through extension information (Nyikahadzoi *et al.*, 2017, Makate and Makate, 2019). There is a significant variation of satisfaction with extension officers among schemes (Table 4.5). This implies that farmers in different schemes have a different adaptive capacity level in relation to their satisfaction with extension workers. Extension workers provide climate knowledge that could help farmers be more innovative in light of the negative impacts of climate change (Mutekwa, 2009).

Similarly, extension officers have access to information regarding output prices, road networks in the area, transport costs, and market intelligence (Makate *et al.*, 2016, van Rooyen *et al.*, 2020). Production information from extension officers gives farmers the necessary production knowledge to supply quality products to meet market demand (van Rooyen *et al.*, 2020). Extension services in Zimbabwe can provide production knowledge if provided appropriate capacity and resources (Mosello *et al.*, 2017). Analysis by Mosello *et al.* (2017) reveals that extension in Zimbabwe is inadequate to respond to numerous challenges faced by scheme farmers, which may likely affect their capacity to influence the adaptive capacity of scheme farmers. However, improving existing knowledge, models, and models' ability to predict climate change in Zimbabwe may help improve extension workers' provision of knowledge to farmers (Mutekwa, 2009).

The results from the study show that the participation of scheme farmers in electing committee members negatively affects adaptive capacity. This implies that participation in electing committee members would likely create a negative psychological capital endowment among scheme farmers. Psychological capital is individual mindset and attitude affecting motivation to take initiatives (Phakathi and Wale, 2018). A study by Phakathi and Wale (2018) found that psychological capital impacts the value of water in SISs in KwaZulu-Natal, South Africa. Of the respondents, fewer scheme farmers did not participate in electing committee members compared to 62.4% who regularly attend meetings at a 1% significance level. A similar trend was observed among schemes in KwaZulu-Natal, South Africa, where 65% regularly attend meetings (Mudhara and Senzanje, 2020). However, there is a need to explore why participation in electing irrigation committee contribute to negative psychological capital.

The negative relationship between participation in the formulation of scheme rules and adaptive capacity is worrying. These findings may imply the ineffectiveness of scheme rules in response to climate change. According to van Rooyen *et al.* (2020), the potential impact of changing rules is very powerful. Moreover, these findings contribute to the understanding that scheme farmers fail to develop regulations to implement generic and specific adaptation institutions to their context. Increasing monitoring and enforcement of rules is essential to improve the effectiveness of rules to improve adaptive capacity. Monitoring and sanctioning rules ensure compliance, improving institutional performance (Meinzen-Dick, 2007), creating trust among scheme members and facilitating collaborative planning. Meinzen-Dick *et al.* (2002) suggests that identifying factors

that create incentives for user participation is critical for developing better policies and effective implementation of any policy. Villamayor-Tomas and García-López (2017) assert that changing policies and political economy conditions are amongst socio-economic disturbances faced by the rural populations in developing countries.

Among the governance factors, participation in irrigation water scheduling positively contributes to adaptive capacity; this implies that farmers who participate more in water scheduling were more adaptive to climate change. Irrigation scheduling practices were emulated for improving water use efficiency on the farm as it dictates the frequency of irrigation and volume of water applied (Mudhara and Senzanje, 2020). Irrigation water scheduling is essential for the optimization of water allocation (Li *et al.*, 2018).

4.5 Conclusion

Climate change is disproportionately affecting food systems across developing countries, particularly smallholder farming systems in Sub-Saharan Africa. The adaptive capacity of farmers enables them to cope with the unprecedented impacts of climate change. This study illustrates how socio-demographic, institutional and governance factors influence the adaptive capacity of smallholder irrigation farmers in Zimbabwe. The hypothesis that stronger institutions influence adaptive capacity in smallholder irrigation systems was accepted. The adaptive capacity of scheme farmers was significantly influenced by socio-demographic, institutional and governance factors. For socio-demographic factors, adaptive capacity **was higher for older** farmers, male farmers, more educated farmers, larger households, and farmers more experienced **farmers**. The study identifies the positive impact of satisfaction by cooperatives and extension officers and the negative impact of satisfaction by the irrigation committee on farmers' adaptive capacity. This study also noted the negative effect of participation of scheme farmers on electing/removing committee members and formulating rules on their adaptive capacity and the positive effect of participation in irrigation water management on adaptive capacity. Admittedly, it is not clear why adaptive capacity is negatively affected by participation in electing committee members, and **why** formulating rules **has** a negative impact on adaptive capacity. However, our augment in this study is an eye-opener to explore the root cause of this relationship. Since higher adaptive capacity decreases livelihood vulnerability to climate change, understanding and addressing these factors will help scheme farmers cope with proposed extreme climate change and vulnerability cases. Therefore, it is

necessary to explore this relationship to reveal alternative ways of addressing livelihood vulnerability in SISs. Subsequently, considering low adaptive capacity and its role in addressing vulnerability, farmers are to engage with extension workers, participate in cooperatives and be involved in irrigation water scheduling. In order to improve adaptive capacity, scheme management should support the participation of youth in farming **through facilitating their training** and support the needs of female farmers. This article recommends further studies to explore the appropriate combination of factors that might improve the adaptive capacity of farmers in the schemes.

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CHAPTER 5

GENDERED PERCEPTIONS OF PEST PREVALENCE AND MANAGEMENT IN ZIMBABWE SMALLHOLDER IRRIGATION SCHEMES⁴

Abstract

A better understanding of gendered perception on the prevalence and management of pests in irrigated agriculture in the context of a changing climate can help recommend more gender-sensitive policies, particularly in smallholder farming systems. Limited studies have been conducted to assess gender differences in perception of the prevalence and management of pests among smallholder irrigation schemes. This study seeks to understand gendered perceptions on the prevalence and management of pests in Exchange, Insukamini and Ruchanyu irrigation schemes in Zimbabwe. Semi-structured questionnaires were administered using face-to-face interviews with participants. Data from Focus Group Discussions and Key Informant Interviews were used for validating data from questionnaire interviews. Mann-Whitney U test was employed to assess perception on the prevalence of pests between male and female farmers. Findings from this study depict that females perceived a higher prevalence of cutworms ($P \leq 0.01$), red spider mites ($P \leq 0.01$), maize grain weevils ($P \leq 0.01$), and termites ($P \leq 0.01$) than males, while males perceive a higher prevalence of fall armyworms ($P \leq 0.01$), bollworms ($P \leq 0.01$) and whiteflies ($P \leq 0.1$) than females. Perception of the prevalence of pests is based on farmers' experience and shapes how they manage pests. Understanding the gendered context and factors shaping the perception of the prevalence of pests is necessary to consider gender-sensitive approaches for improving pest management practices.

Keywords: pest control, female farmers, Mann Whitney U test, food security, pesticides, pest management capacity

5.1. Introduction

Crop production is threatened by climate change, particularly in arid and semi-arid regions of the world (Nhemachena *et al.*, 2020). Increase in temperature accelerates pests reproduction,

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development and movement, which can affect population dynamics by influencing fecundity, survival, generation time, population size, and geographic range (Skendžić et al 2021). Irrigation offers a credible entry point to adapt to the negative impacts of climate change in these regions. However, despite their enormous benefits in reducing moisture stress, irrigation might encourage the proliferation of new and emerging pests (Gullino *et al.*, 2021). Irrigation results in humid conditions that contribute to the build-up of pests, reaching an outbreak (Sithanantham *et al.*, 2002). In order to take advantage of the role played by irrigation in climate change adaptation, pest management is key to reducing pest-related losses and improving agricultural productivity. Therefore, understanding pest management from the lens of the farmer is important for the successful control of pests under irrigated agriculture, more so given that climate change has significant implications for pests in agriculture (Shrestha, 2019). Thus, perception of the prevalence of pests is increasingly becoming important in pest management in view of the economic damage caused by pests.

Globally, an average yield loss of 21.5% for wheat (*Triticum*), 30.0% for rice (*Oryza sativa*), 22.5% for maize (*Zea mays*), 17.2% for sweet potatoes (*Ipomoea batatas*), and 21.4% for soya bean (*Glycine max*) can be attributed to pests alone (Savary *et al.*, 2019, Gullino *et al.*, 2021). Pests are more economically relevant in Africa, where crop losses equivalent to approximately USD 4.4 billion were attributed to pests from 1980 to 1990 (Biber-Freudenberger *et al.*, 2016). Available evidence shows that climate change contributes to the increased risk of pests affecting crops across the agricultural systems of Africa (Dhanush *et al.*, 2015, Karuppaiah and Sujayanad, 2012, Bjorkman and Niemela, 2015). In sub-Saharan Africa (SSA), crop pests alone result in the loss of one-sixth of agricultural productivity (Dhanush *et al.*, 2015). More specifically, in 2018, an estimated yield loss of 11.6% was attributed to the fall armyworm (FAW) (*Spodoptera frugiperda*) in Zimbabwe, albeit from two districts only (Baudron *et al.*, 2019).

Irrigation development may exacerbate the agricultural losses attributed to pests. Empirical evidence shows that some pests, such as FAW, which cannot survive in cold conditions, favour warm moist conditions (Nagoshi *et al.*, 2012). However, for infection, fungi prefer high relative humidity or wet leaf surfaces (Cairns *et al.*, 2012). Thus, these might have implications for infection rates in irrigated agriculture. Numerous studies have evaluated the effects of climate change on pests distribution, occurrence, abundance, and severity of their risks in managed

systems (Gullino *et al.*, 2021). A global study concluded that the potential distribution of FAW will increase with increased rainfall (Zacarias, 2020). In another study in KwaZulu-Natal, the outbreak of pests was common in SISs (Matthews, 2017).

A study in Namibia acknowledges that irrigated areas are an environment where pest outbreaks are rampant (Charamba *et al.*, 2018). These studies show that irrigation has its own share of challenges as far as pests are concerned. The impacts of pests will be felt more by smallholder farmers, who have limited economic means to cope with the impact of climate change (Biber-Freudenberger *et al.*, 2016). For instance, a majority of farmers in Africa have limited capacity to purchase insecticides (Sisay *et al.*, 2019). Over the years, SSA has embarked on massive investment in irrigation systems (Xie *et al.*, 2014), including smallholder irrigation schemes. In Zimbabwe, 450 smallholder irrigation schemes on an area of 26 000 ha had been developed by 2020 in rural areas (GoZ, 2020).

In developing countries such as Zimbabwe, both men and women are involved in agriculture, but women provide 70% of the total labour force (FAO, 2017, Huyer and Nyasimi, 2017). Meanwhile, the level of participation of women in irrigated agriculture is high in Zimbabwe (FAO, 2017). Nonetheless, women have limited access to extension services, education, credit, agricultural inputs (Makate *et al.*, 2019), and capacity building due to structural barriers that create gender gaps and inequalities (Chibaya *et al.*, 2009). These gender inequalities, if not recognized, have severe repercussions on agricultural transformation and development (FAO, 2010). This is particularly relevant for a majority of countries in SSA, including Zimbabwe. In the majority of the region, women provide 50% of the labour force (Raney *et al.*, 2011).

Meanwhile, in Zimbabwe, women constitute 86% of the agricultural labour force (FAO, 2017). Paradoxically, female farmers in Africa “are excluded from conversations that determine agricultural policies, while discriminatory laws and practices deprive them of their land, their rights, and their livelihoods” (GFFW, 2015). Zimbabwe has embraced the concept of gender equality and policies to promote gender-sensitive agricultural training (FAO, 2017). Thus, it is crucial to understand the gendered dimension of the implications of climate change on pest prevalence in Zimbabwe to formulate policies that address the gendered aspect of pest management, including the effective allocation of human and financial resources.

Perception is a cognitive contact with the surrounding environment, based on an individual's primary awareness, learning, memory, expectation, and attention (Bernstein, 2018). Perception of the threat of environmental problems influences environmental attitude and ecological behaviour, hence determining the practices individuals engage in (Milfont *et al.*, 2010). Perception of the prevalence of pests translates into decisions on pest management practices in response to changing occurrence of pests (Awudzi *et al.*, 2021).

The gendered evaluation of pests specifically focusing on irrigation agriculture has received limited research attention. Such studies are particularly relevant in SSA and especially in Zimbabwe, considering the attention given to irrigated agriculture and the role played by women in these farming systems.

Unfortunately, to the best of our knowledge, the gendered perception of pest prevalence research is scarce in Zimbabwe. This is a paradox, given that a majority of women are farm laborers and involved in pest control. This article seeks to use the gendered perception on the prevalence of pests and pest management in the context of irrigated agriculture under climate change in smallholder irrigation schemes of Zimbabwe. It seeks to answer the following question: What is the gendered perception on the prevalence and management of pests in smallholder irrigation schemes given climate variability and change?

5.2 Methodology

5.2.1 Study area

To answer the objectives of this study, we conducted our research in three smallholder irrigation schemes **that were randomly selected** in Midlands Province, Zimbabwe (Figure 5.1). Midlands Province was selected for this study since it is among the top three provinces with the highest number of smallholder irrigation schemes (GoZ, 2020). Therefore, this study will be of significant reference to gendered perception on the prevalence and management of pests in relation to climate change in Zimbabwe and the SSA region.

Three schemes, namely Exchange, Insukamini and Ruchanyu were considered for this study. Exchange irrigation scheme is located in Silobela communal area, Kwekwe District, approximately 60 km North-West of Kwekwe town. It has about 168.8 ha of irrigable land developed partly from 1973 and 1985 (SIRP, 2017, Nyamayevu *et al.*, 2015). A total of 982

households currently occupies Exchange irrigation scheme. The scheme is in an agroecological zone (AEZ) IV with semi-arid climatic conditions, receiving an average rainfall ranging from 450 – 650 mm (Manatsa *et al.*, 2020). The soils are highly fertile clay loams. Irrigation water is drawn from Exchange Dam. Maize (*Zea mays*) and sugar beans (*Phaseolus vulgaris*) are the main crops grown in Exchange irrigation scheme, yielding an average of 15t and 2.1t per ha, respectively (SIRP, 2017). Farmers in the scheme have challenges reaching a more reliable market due to poor road networks (SIRP, 2017).

Insukamini irrigation scheme is located in Lower Gweru communal area, Gweru District, Midlands province, Zimbabwe. It is nearly 45 km North-West of Gweru, the Midlands provincial town. It has a total of 41 ha developed in 1988 and is occupied by 125 households (Matsa, 2012). The scheme is located in AEZ IV, with annual rainfall ranging from 600 – 800 mm (Manatsa *et al.*, 2020). The soils in the scheme range from sandy loam to clay loam. Its water comes from Insukamini dam through a 1.6 km long concrete canal.

Ruchanyu irrigation scheme is located in Shurugwi district, about 62 km South-West of Gweru town. It has about 27 ha of irrigable land developed in the early 1980s (Mhembwe *et al.*, 2019). A total of 85 households currently operates the scheme (Mhembwe *et al.*, 2019). It is in AEZ III with annual rainfall ranging from 650 – 850 mm (Mhembwe *et al.*, 2019). The soils in the scheme are classified as sandy loam (Mhembwe *et al.*, 2019). Water is pumped from Mutevekwu River (Mhembwe *et al.*, 2019). Maize is the main crop grown by farmers in the scheme. The farmers do not have a well-established market for the crop, as the local market cannot purchase all the produce.

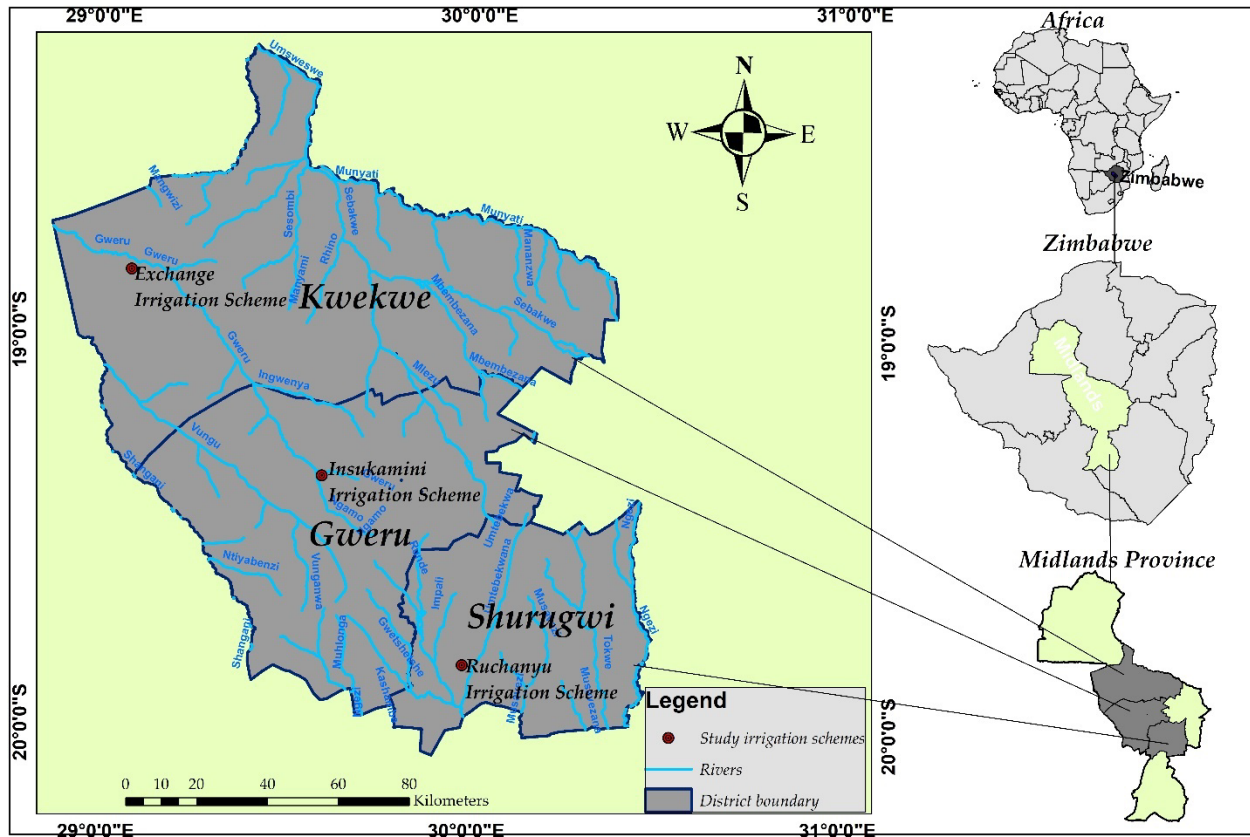


Figure 5. 1: Map of the study area

5.2.2 Data collection

A questionnaire-based survey was used to collect primary data for this study. Data was also collected using focus group discussions (FGDs) and eleven key informant interviews (KIIs) for triangulation of the findings from the questionnaire. Gender, social class, and age were considered when choosing participants from FDGs and KIIs for equal representation. A pilot study was done to test the suitability of the data collection tools for the study. Further, a random selection was used to select 317 participants (192 from Exchange irrigation scheme, 88 from Insukamini irrigation scheme and 37 from Ruchanyu irrigation scheme based on proportional representation) for this study. A sample selection formula in equation (1) below was used to calculate the sample size. Six FGDs were done with 10 – 15 randomly selected participants who didn't participate in questionnaire interviews. FGDs help to have a clear understanding of perception on the prevalence of pests in the schemes. KIIs provide expert information about changes in pests, pest control and crops affected by each type of pest.

$$n = \frac{N}{Ne^2} \quad (1)$$

Where: n – sample size, N – population and e – confident interval

For this study, semi-structured questionnaires were administered using face-to-face interviews with the respondents. The participants were asked to show their level of perception about the changes in pests over the given period using the following Likert Scale: Strongly Disagree (1), Disagree (2), Not Sure (3), Agree (4), Strongly Agree (5).

5.2.3 Data analysis

Data for this study was collected using a five Likert scale response. This was due to our interest in participants' perception of the prevalence of pests in response to climate change. For this study, data was collapsed to a binary response. Responses with Strongly Decrease, Decrease and No Change were coded (0), while those with Agree and Strongly Agree were coded (1). To determine the gendered perception of the prevalence of pests, a Mann-Whitney U test was used. Mann-Whitney U test was used to test if there are differences in perception on the prevalence of pests between male and female respondents. The Mann-Whitney U test was used to test the null hypothesis that there is an equal perception of the prevalence of pests between male and female respondents since the respondents are from the same set of schemes. The differences in perception on the prevalence of pests were considered significant at $p = 0.05$.

5.3. Results

The socio-economic characteristics of respondents of this study are shown in Table 5.1. Results show that male farmers were significantly married than female farmers ($P \leq 0.05$). On average, both male and female participants in the schemes were literate. The schemes consist of aging scheme farmers averaging 55 years for males and 54 years for females.

There were statistically significant differences ($P \leq 0.05$) between male and female farmers on knapsack sprayer ownership, where more males (64.1%) owned knapsack sprayers compared to their female (50%) counterparts. **From a cultural perspective, property is owned under the name of the husband who is the head of the family. In addition, it is generally accepted that spraying for pests is a male job, similar to ox ploughing.** Further, there were statistically significant differences ($P \leq 0.05$) between male and female farmers on spraying frequency, where more males (53%) sprayed more than their female (42.1%) counterparts. In addition, there were statistically

significant differences ($P \leq 0.05$) between male and female farmers on management, where more females (57.3%) poorly manage pests compared to their male (46.5%) counterparts.

Table 5. 1: Socio-demographic factors

Variable	Male	Female	Significant level	Standard deviation
Marital status (Married)	89.5	46.2	*	
Education (years)	9	8		3.14
Average Age	55.33	53.84		12.78
Fulltime farmer (%)	86.0	92.3	N/A	
Own Knapsack sprayers (%)	64.1	50	*	
Full time farmers	86.4	92.3		
Household Size	5	5	N/A	
Number of years in farming	27	27	N/A	
Raise livestock	94	93.5		

Note: Statistically significant at 5% level indicated by (*).

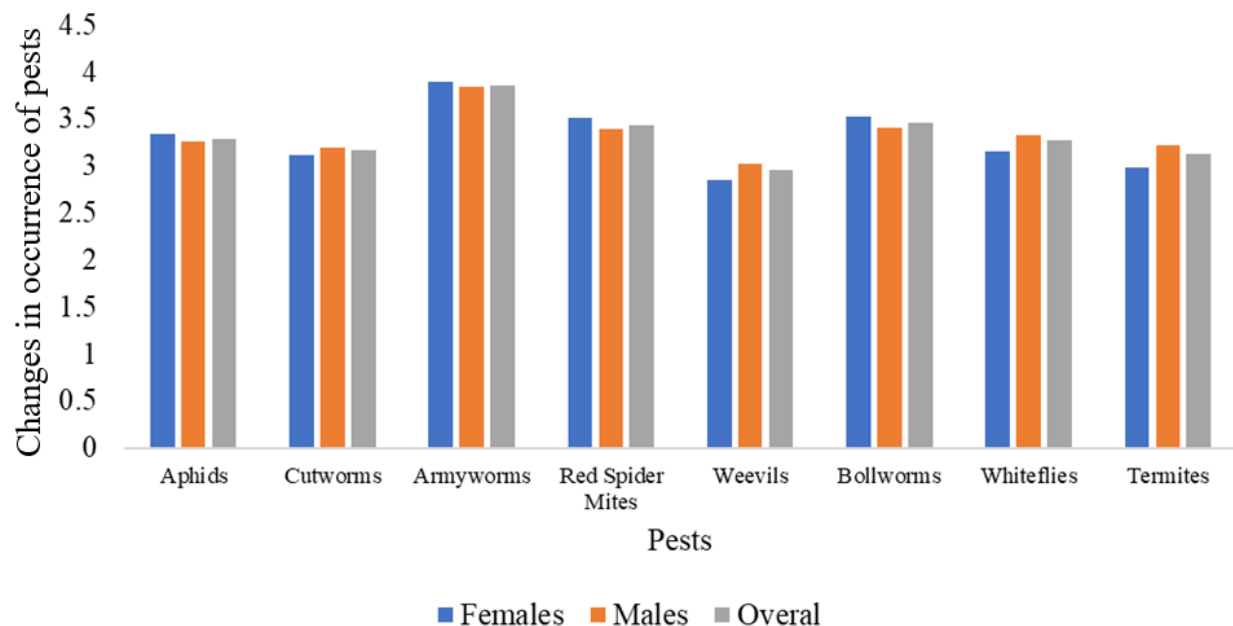
Table 5.2 below shows crops grown in the schemes by gender.

Table 5. 2: Crops grown by gender

Crop	Male		Female	
	Frequency	Percentage	Frequency	Percentage
Maize	121	66.5	61	33.5
Sugar Beans	18	72	7	28
Wheat	18	86	3	14
Cabbage	19	61	12	39
Tomatoes	7	50	7	50
Onion	8	62	5	38
Cucumber	0	0	3	100
Squash	6	100	0	00

5.3.1 Perception of change on pest prevalence in irrigation schemes under climate change

In general, Figure 5.2 illustrates that scheme farmers perceive a rising prevalence of pests under climate change. Both male and female farmers perceive an increase in incidences of pests between 2010 and 2020.



Note: 1 – Strongly Decrease; 2 – Decrease; 3 – No Change; 4 – Increase; 5 – Strongly Increase

Figure 5. 2: Perceived changes in occurrence of pests during the period 2010 to 2020 in Exchange, Insukamini and Ruchanyu Irrigation Schemes in the Midlands Province, Zimbabwe

5.3.2 Gendered perception on the prevalence of pests in SISs under climate change

The results for assessing the gendered perception of pest prevalence are shown in Table 5.3 and Table 5.4. The results reveal a gendered perception of pest prevalence in the three schemes considered for this study. The perception of pest prevalence shows that female farmers perceive a higher increase in the prevalence for most pests than males, who perceive a higher increase in the prevalence for only three types of pests (Table 5.3). Male and female farmers have a similar perception of the prevalence of aphids. Thus, in relation to male participants, female participants have a better perception of the prevalence of cutworms ($U = 2100.50$, $p \leq 0.05$).

In contrast, male farmers perceive a higher increase in FAW prevalence than their female counterparts ($U = 6362.00$, $p \leq 0.05$). On the other hand, female participants significantly perceive a higher increase in the prevalence of red spider mites than male participants ($U = 5232.00$, $p \leq 0.05$). Similarly, female participants perceive a substantially rising prevalence of maize grain

weevils than male participants ($U = 6596.50$, $p \leq 0.05$). Nonetheless, males have a significant perception of a higher increase in the prevalence of bollworms than females ($U = 4425.00$, $p \leq 0.05$). Males have a considerable perception of a higher increase in whiteflies incidences than females ($U = 7171.50$, $p \leq 0.05$). However, female farmers perceive a higher increase in the prevalence of termites than male farmers ($U = 3018.50$, $p \leq 0.05$) (Table 5.3 and Table 5.4).

Table 5. 3: Ranks of gendered perception on pest prevalence

	Gender	N	Mean Rank	Sum of Ranks
Aphids	Female	192	145.13	27865.00
	Male	88	130.40	11475.00
	Total	280		
Cutworms	Female	192	154.91	29743.50
	Male	88	109.05	9596.50
	Total	280		
Fall	Female	192	129.64	24890.00
Armyworms	Male	87	162.87	14170.00
	Total	279		
Red spider mite	Female	192	155.25	29808.00
	Male	86	104.34	8973.00
	Total	278		
Maize grain weevils	Female	191	148.46	28356.50
	Male	87	119.82	10424.50
	Total	278		
Bollworms	Female	192	119.55	22953.00
	Male	87	185.14	16107.00
	Total	279		
Whiteflies	Female	192	133.85	25699.50
	Male	85	150.63	12803.50
	Total	277		
Termites	Female	192	165.78	31829.50

Male	85	78.51	6673.50
Total	277		

Table 5. 4: Mann-Whitney U test for perception on pest prevalence

	Aphids	Cutworms	Fall Armyworms	Red spider mite	Maize grain weevils	Bollworms	Whiteflies	Termites
Mann-Whitney U	7559.00	2100.50	6362.00	5232.00	6596.50	4425.00	7171.50	3018.50
Wilcoxon W	11475.00	3375.50	24890.00	8973.00	10424.50	22953.00	25699.50	6673.50
Z	-1.46	-4.79	-3.32	-5.06	-2.94	-6.55	-1.68	-8.59
Asymp. Sig. (2-tailed)	0.146	0.000	0.001	0.000	0.003	0.000	0.094	0.000
Exact Sig. (2-tailed)	0.146	0.000	0.001	0.000	0.003	0.000	0.094	0.000
Exact Sig. (1-tailed)	0.073	0.000	0.000	0.000	0.002	0.000	0.047	0.000
Point Probability	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 5.5 illustrates major pests, perception of pest prevalence and strategies used to control pests considered for this study. Several existing methods of control of pests are categorized under **pesticides**, cultural and integrated pest management. Although there was a generally high rate of pesticide use, farmers who did not perceive an increase in the prevalence of pests significantly use pesticides to control pests than those who perceive an increase in the prevalence of pests ($p < 0.05$). In contrast, farmers who perceive an increase in the prevalence of pests were more likely to use integrated pest management strategies than those who did not perceive an increase in the prevalence of pests. Some measures of pest control include field management, use of **drought** resistant varieties and crop rotation. However, pest management strategies were similar for two groups of farmers for maize grain weevils.

Table 5. 5: Major pests, perception of pest prevalence and strategies used to control pest

Pests	Perception of pest prevalence	Pest management strategies (%)			Significant level
		Pecticides	Cultural	Integrated pest management	
Aphids	0	93.20	3.40	2.30	***
	1	61.00	0.70	37.70	
Cutworms	0	85.10	2.00	10.90	***
	1	68.50	1.80	29.70	
Fall	0	91.20	0.00	8.80	***
Armyworms	1	69.30	1.00	28.20	
Red spider mites	0	90.10	0.00	7.00	***
	1	73.30	0.70	43.00	
Maize grain weevils	0	81.30	0.90	15.90	NS
	1	71.80	1.30	25.60	
Bollworms	0	86.20	10.30	10.30	***
	1	66.70	30.70	30.70	
Whiteflies	0	84.60	1.30	14.10	***
	1	67.90	0.70	30.60	
Termites	0	80.20	0.0	19.80	NS
	1	67.80	2.50	28.10	

Note: 0 – no increase in the prevalence of pests; 1 – an increase in the prevalence of pests. Statistically significant at 5% level indicated by (***). NS – not statistically significant.

Figure 5.6 illustrates spraying frequencies to control different types of pests. As shown in Table 5.6, farmers who did not perceive an increase in the prevalence of pests use chemical pesticides more frequently compared to farmers who perceive an increase in the prevalence of pests. However, for maize grain weevils, the relationship is not significantly different for the two groups of farmers.

Table 5. 6: Frequency of spraying chemical pesticides by scheme farmers

Pests	Frequency of spraying chemical pesticides
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	Perception of pest prevalence	Once a week	Twice a week	Once a month	Twice a month	Once visible	Significant level
Aphids	0	19.30	49.70	10.20	17.00	3.40	***
	1	19.20	33.60	38.40	6.80	1.40	
Cutworms	0	25.70	45.50	10.90	14.90	1.00	***
	1	21.60	36.00	33.30	5.40	1.80	
Fall	0	15.80	70.20	8.80	5.30	0.00	***
Armyworms	1	21.30	30.70	32.20	10.90	2.50	
Red spider	0	21.10	45.10	9.90	16.90	4.20	***
mites	1	21.30	37.30	32.00	5.30	2.00	
Maize grain	0	17.80	46.70	17.80	13.10	1.90	NS
weevils	1	23.10	38.50	24.40	7.70	5.10	
Bollworms	0	19.00	65.50	12.10	0.00	0.00	***
	1	21.30	33.30	26.70	14.00	2.70	
Whiteflies	0	24.40	53.80	11.50	5.10	2.60	***
	1	16.40	36.60	32.10	12.70	1.50	
Termites	0	16.00	46.20	20.80	15.10	0.00	***
	1	22.30	35.50	35.50	3.30	1.70	

Note: 0 – no increase in the prevalence of pests; 1 – an increase in the prevalence of pests. Statistically significant at 5% level indicated by (***). NS – not statistically significant.

5.4. Discussion

A changing trend of pests due to climate change is evident in Zimbabwe (Kutywayo *et al.*, 2013, Ch, 2013, Mafongoya *et al.*, 2019). The outbreak of pests is a constraint to agriculture production in Zimbabwe and climate change results in rising pest pressure (Mafongoya *et al.*, 2019). Female farmers are increasingly involved in controlling pests, which contributes to their awareness of the prevalence of pests. Earlier studies on pest prevalence have been based on simulations, laboratory and field experiments to determine the prevalence of pests (Kutywayo *et al.*, 2013, Gullino *et al.*, 2021), which may be of limited implications for pest management in the smallholder farming sector. This study will help policymakers to improve policies through understanding the differences in perception on the prevalence of pests between males and female farmers in

Zimbabwe. Results from this study found gender differences in perception on the prevalence of pests.

Generally, the respondents have perceived a rising prevalence of pests. The results are consistent with findings by Gullino *et al.* (2021), who found that the majority of studies in cereals like maize and horticultural crops indicate a spike in pest risks in subtropical agricultural systems under climate change. Increased pests result in rising plant health problems in agricultural systems (Gullino *et al.*, 2021). Studies like Juroszek *et al.* (2020) and Bjorkman and Niemela (2015) indicate that pest risks will increase in agricultural ecosystems under climate change, and impacts vary with the system's potential and natural ecosystem. Invasive expansion of pests results in economic and social damage by decimating crops (Juroszek *et al.*, 2020). According to Edmonds (2013), prevention, mitigation and adaptation are needed to reduce projected pest risks in agriculture.

The mean ranks in Figure 5.2 show that pests like aphids, cutworms, bollworms, red spider mites, whiteflies, and FAW are becoming more severe. This study supports the finding by Katsaruware-Chapoto *et al.* (2017) in Zimbabwe that aphids, cutworms and whiteflies have increased. Several studies acknowledge a changing trend of pests as temperature rises and rainfall decreases due to climate change (Mafongoya *et al.*, 2019, Battisti and Larsson, 2015, Scherm, 2004, Andrew and Hill, 2017, Katsaruware-Chapoto *et al.*, 2017, Halsch *et al.*, 2021). A general increase in incidences of pests and the emergence of new pest species is projected for Southern Africa (Mafongoya *et al.*, 2019). Kocmánková *et al.* (2009) eluded that behaviour, distribution, development, survival, and reproduction increase as temperature rises. According to Shaw and Osborne (2011), climate-driven crop management adaptations like irrigation have permitted year-round cultivation of maize, increasing pests and vector prevalence. The increase of crop pests reduces the availability and access to appropriate quality of food. Further, a rise in the prevalence of pests increases pesticide use, making food unhealthy for humans and livestock (Van der Fels-Klerx *et al.*, 2016, FAO, 2008). There is also a danger of direct food losses and reduction of income in the absence of adequate control measures (FAO, 2008). However, perception of pest prevalence is essential to predict potential outbreak, their impacts on crop yields (Scherm, 2004, Andrew and Hill, 2017, Katsaruware-Chapoto *et al.*, 2017). Thus, these perception studies on pest outbreaks in a changing climate can help inform pest management practices in SISs.

This study showed that the perception of the prevalence of pests significantly differs between male and female participants, creating winners and losers in the face of climate change. The food system in Zimbabwe lacks disaggregation of data by gender. FAO (2017) reported a high literacy rate for both males (98%) and females (97%) in Zimbabwe, which might imply that both male and female participants are equal observers of the prevalence of pests. Perception of the prevalence of pests is based on farmers' experience and shapes the way they manage the pests. The results showed that female farmers have a significant perception of the higher increase in the prevalence of cutworms, red spider mites, maize grain weevils, and termites. In contrast, male farmers perceive a higher prevalence of FAW, bollworms, and whiteflies (Table 5.2 and 5.3). **This relates to women participation in production of crops like maize, tomatoes, and post-harvest processing of maize.** The perception of the prevalence of most pests relates to their expected trends with climate change. Our findings suggest that the prevalence of pests is increasing due to climate change was also echoed by KIIs and FDGs. Relating to these findings, female farmers are equally aware of trends of pests as their male counterparts.

These findings imply that the gender of the person does not limit their perception of pest prevalence; hence views from both males and females on pest trends and climate change should be valued equally. Consequently, female farmers are equally observers of climate change and pest incidences as their male counterparts (Atreya, 2007, Whyte, 2014). Their context of observations should be well understood and considered during policy formulation and decision-making.

Our observation of the gendered perception of pest prevalence may relate to variation in gender roles, asset endowments, crop choices, pest management, asset endowments, and resource ownership (Sharaunga and Mudhara, 2021, Whyte, 2014, Atreya, 2007). In Zimbabwe, men have greater access, ownership and control of resources and services than women (FAO, 2017). Given that the majority of female household heads were single (Table 5.1), they own land and experience control over production decisions and expenditure (Badstue *et al.*, 2020). Single women in this study actively participate in all farming activities that are more aligned to males and make choices on crops grown. Hence, they are actively instrumental in monitoring and controlling pests as their male counterparts. However, considering that their education and involvement in full-time farming are similar to that of male farmers (Table 5.1), their perception of the occurrence of pests is of significant importance.

The significant relationship between gender and perception of the prevalence of maize grain weevils ($p \leq 0.01$), where women have a perception of a higher increase in the prevalence of maize grain weevils than men, might relate to the role of women in the household. In Zimbabwe, women are the overseers for grain and ensure that the grain does not have pests (FAO, 2017). Women are responsible for preparing food for the household, giving them better access to post-harvest storage facilities than men. Women in Zimbabwe are usually more confined in homes (FAO, 2017) and are responsible for preparing household meals (Savari *et al.*, 2020, McLaughlin *et al.*, 2003, Mazuru, 2019). Nevertheless, this study shows that males significantly perceived the rising prevalence of aphids, FAW, bollworms, and whiteflies compared to females ($P \leq 0.01$).

Despite female farmers' perception of rising trends of pests, they have reported that they are facing challenges in pest management. Technological uptake by women in Zimbabwe depends on its ease to use and friendliness (FAO, 2017). Similarly, the spraying frequency of female farmers is lower than that of their male counterparts, despite their perception of increasing incidences of pests. According to FAO (2017), there is gendered ownership of valuable resources in rural Zimbabwe and access to training and extension services. Gender-sensitive training and extension services are critical in addressing gendered pest management challenges. According to Kwarazuka *et al.* (2020), women's failure to spray is due to limited financial resources, knowledge and access to information (Kwarazuka *et al.*, 2020). Further, females and males were found to adopt different pest control methods (Kwarazuka *et al.*, 2020); hence, there is a need to assess and consider gendered pest control methods. In a study in KwaZulu-Natal, South Africa, poor capital asset endowments, socio-economic factors, livelihood strategies, and transforming structures and processes were blamed for challenging investment opportunities of female farmers in rural communities (Sharaunga and Mudhara, 2021).

From the findings of this study, gender stereotyping through expectations, roles and behaviour in the context of community, society, or field of study (Jule, 2016), which consider women as poor observers of the prevalence of pests, undermine their contribution to pest management. Sex has been considered to cover physiological characteristics and is a social construction of gender stereotyping (UN, 2021). This perpetuates gender-based stereotyping of the differences between men and females, resulting in gender-biased expectations, hence ignoring individual capacity and performance (Jule, 2016). UN (2021) suggests that identities and expressions vary or depart based

on preconceptions and misconceptions of societal objectives such that people adopt roles, forms of expression, and behaviour considered entitlements. Further, women must not embrace stereotyping of femininity, which undermines their perception of the prevalence of pests.

Pest prevalence can be worsened by climate change (Gullino *et al.*, 2021) and the condition of the scheme. Also, scheme farmers differ their crop rotation cycles across seasons, pose a challenge of rotating pests as they can shift from the host plot to the next across seasons given that plots are closer to each other. Further, growing the same crop across the scheme during the same season posed challenges as some farmers were not controlling pests, making pests more invasive and spreading faster. Mobilising farmers to grow the same crop during the same season interrupts market balance where some crops will flood the market while others will be under short supply. For instance, most of the harvested onions in Insukamini were not sold due to an increased supply. Implementing collective decisions on pest control in SISs is difficult due to the myriad of challenges that the scheme farmers face.

The results from the study support findings that farmers in Zimbabwe are reliant on a broad spectrum of insecticides to control the pest (Tibugari *et al.*, 2012). Nevertheless, the perception of an increase in the prevalence of pests makes farmers integrate chemical pesticides with cultural methods of controlling pests (Table 5). While the perception of an increase in the prevalence of pests makes farmers depend mainly on the regular application of chemical insecticides with limited use of integrated pest management. However, high chemical insecticides application rate is highly associated with insecticide resistance (Tibugari *et al.*, 2012). Although pesticides minimise crop loss, they result in contamination of the ecosystem and undesirable health effects (Barzman *et al.*, 2015). Nonetheless, Scott *et al.* (2018) recommend that the use of nanotechnology-produced pesticides may potentially improve the efficacy and safety of pesticides; however, its availability in developing areas is a limiting factor.

The results depict that the perception of the increasing prevalence of pests influences farmers' decision to use integrated pest management. Munkvold and Gullino. (2020) and Thomas *et al.* (2017) recommend integrated pest-management practices, among other strategies, to control pests in face of increasing threats from pests due to climate change. Therefore, farmers were recommended adopt integrated pest management strategies related to the diversity of their farming system, capacity, and agroecosystems' nature.

However, there is much room to improve pest management on farms resulting in cost-benefit improvements. Jactel *et al.* (2020) suggest using an interdisciplinary approach as an important way to manage the new and emerging pest species by considering knowledge gained from different disciplines. Crop insurance is also an attractive alternative to protect farmer's livelihood under climate change. It is evident that climate change is increasing the problem related to pests in managed ecosystems. Surveillance, monitoring and pest risk analysis are vital for evaluating the introduction, spread and economic consequences of pests, essentially identifying potential pest management options to reduce the risk of pests to acceptable levels (Gullino *et al.*, 2021). Climate-smart pest management based on selected existing management methods enhance mitigation and strengthen resilience. Pest management improvements are valuable, with or without climate change scenarios. Dilling *et al.* (2015) assert that there is much potential to improve on-farm and regional pest management systems. Building pest management capacity in farming systems is of paramount importance to maintaining current and future food security and managing financial risks. Adjusting plant-protection protocols to suit current and projected climate change scenarios is crucial to maintaining and preserving current and future food security (Gullino *et al.*, 2021).

Climate and pest monitoring, pest prevention approaches, adopting mechanical, cultural, biological and chemical pest control approaches, farmer networks and organisations, participatory appraisals, enhance accessibility of extension services for farmers, early warning systems, monitoring of existing pests and investment in training programmes, and infrastructure are among possible coping strategies against threat of pests (Heeb *et al.*, 2019). Further, regulation of agro-inputs and agro-input suppliers, establish and enhance financial services, and facilitation of national and international funding mechanisms are key to improve coping against threat of pests (Heeb *et al.*, 2019).

5.4.1 Policy implications of the study

The increasing prevalence of pests due to climate change is transforming food safety policies (Carvalho, 2017), food security policies (Gregory *et al.*, 2009), phytosanitary measures (Eschen *et al.*, 2015), and pest management policies and practices (Heeb *et al.*, 2019). Hence, perception of the prevalence of pests is an integral element of policy formulation in recent years. Several studies encourage the need to understand the impact of pest prevalence on food safety (Carvalho, 2017),

food security (Savary *et al.*, 2019), and pesticide management strategies (Andrew and Hill, 2017) through understanding human perception, which shapes their behaviour and attitude of farmers.

Pests are an integral part of the food system and have negatively impacted crop production via crop yields losses (Gullino *et al.*, 2021). In the context of climate change, pests are believed to be expanding their range, increasing in population and increasing their generations (Gullino *et al.*, 2021, Biber-Freudenberger *et al.*, 2016). Male and female farmers participate in crop production (Akter *et al.*, 2016) and pest management (Wang *et al.*, 2017). Therefore, an improved understanding of the gendered perception of the prevalence of pests may enable policymakers to design policy control measures with respect to female farmers.

Findings from this study might be useful for organisations like Food and Agriculture Organisation (FAO), International Plant Protection Convention (IPPC), Food Safety Authority (FSA), and national governments on designing pest control programs targeted for female farmers. The insights from this study can be extremely valuable for policymakers to facilitate policies to reduce the impacts of pests and address gender differences at the farm, regional and national levels.

5.4. Conclusions

This study sought to assess the gendered perception of the prevalence of pests and existing pest management practices under irrigation schemes. Our study results show that both male and female farmers were aware of trends of pests under climate change. Female participants perceived a higher increase in the prevalence of cutworms, red spider mites, maize grain weevils, and termites. While male participants have a distinct perception of the higher growth in the prevalence of FAW, bollworms and whiteflies. Participants in this study reported a rising number of aphids, cutworms, FAW, red spider mites, bollworms, whiteflies, and termites and a decrease in maize grain weevils. Perception of the prevalence of pests shapes the behaviour of farmers towards changing pest trends and pest management practices of farmers. Policymakers and researchers are recommended to acknowledge the gendered perception of the prevalence of pests in policy formulation. Based on the study findings, perception of the prevalence of pests helps researchers understand the awareness of scheme farmers about the impacts of climate change in Zimbabwe and the region. Further, this study has implications for pest management practices and food security. It recommends surveillance and monitoring of pests, integrated pest management practices,

interdisciplinary approaches to managing pests, crop insurance, and building pest management capacity for farmers must be pursued by extension services and research organizations.

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CHAPTER 6

CROP WATER PRODUCTIVITY AND NUTRIENT DENSITY IN SMALLHOLDER IRRIGATION SCHEMES OF ZIMBABWE⁵

Abstract

The opportunity for addressing food and nutritional security under water stress is very narrow. Scientists need to inform decision-makers on nutrition-dense crops with low water footprints. This is crucial in light of the need to keep within the **planetary freshwater boundary**. There is a massive potential that smallholder irrigation farming can improve food and nutritional security in sub-Saharan Africa, a region projected to experience water stress due to climate change. **This chapter seeks to identify the water footprint and nutrient-density of crops grown in SISs in Zimbabwe.** Here, a water footprint approach is used to assess the water metrics and nutrient-water matrix of food crops grown in Exchange, Insukamini and Ruchanyu irrigation schemes in Midlands Province, Zimbabwe. The average crop yield ranges from 1.04t/ha for sugar beans to 30.60t/ha for cucumber, the water footprint ranges from 278.85m³/t for cucumber to 4762.98m³/t for sugar beans. Maize and wheat are energy and carbohydrates rich crops with lower water footprints. Sugar beans have a higher protein content and water footprint, okra have high zinc content and low water footprint, while wheat has higher iron content and low water footprints. Interventions should focus on improving water footprint and opt for crops with the higher nutrient value of key nutritional elements like zinc and iron to fight hidden hunger.

Keywords: food system; nutritional security; food security; undernourishment

6.1 Introduction

Identifying nutrient-dense crops with a low water footprint is a global problem that requires urgent attention from the international community. Malnutrition, which is linked to rising illness, mortality and huge healthcare costs, is increasingly becoming a world health concern (Vassilakou, 2021). The global pressure of hunger and undernutrition is increasing under the shadow of Covid-19, challenging the attainment of Sustainable Development Goals 1 (No poverty), 2 (Zero Hunger) and 3 (Good health and well-being) by 2030. Worldwide, approximately 768 million people faced

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hunger in 2020 (FAO *et al.*, 2021), compared to about 650 million people in 2019 (FAO *et al.*, 2021). Undernutrition has grave consequences in children, including diminished physical growth and cognitive impairment (Lemoine and Tounian, 2020, Berhe *et al.*, 2019).

In 2020, stunting affected approximately 22% of children below the age of five years, while wasting affected 6.7% and 5.7% were obese (FAO *et al.*, 2021), intensifying the challenge of achieving the 2025 and 2030 global nutrition targets (UNSCN, 2017). **Nutrient is a substance that an organism must obtain from its surroundings for growth and the sustenance of life (Burlingame, 2001).** Approximately two billion people suffer from micronutrients deficiencies (FAO, 2017). The majority of them are in rural communities, relying on rain-fed agriculture for their livelihoods (Chikozho, 2010).

Undernourishment is of particular concern in African and Asian countries, accounting for more than one-third (282 million) and more than 50% (418 **million**) respectively of the global undernourished people in 2020 (FAO *et al.* 2021). Further, these two continents, which account for 90% of stunted children, 90% of children with wasting, and 70% of overweight children, are the ‘world champions’ of children with malnutrition (UNESCO, 2020, FAO *et al.*, 2021). In Africa, sub-Saharan Africa (SSA) is the region with the highest level of malnutrition. Of the global population that experienced undernutrition in 2020, approximately 24% were from SSA (FAO *et al.*, 2021). Furthermore, in 2020, the region accounted for about 37% of the world’s children that suffered from stunting and nearly one-quarter of wasted children (FAO *et al.*, 2021).

In SSA, the uptake of inadequate calories, protein, and micronutrients is highly prevalent among women between 15 and 49 years and children under five years of age (Chawafambira *et al.*, 2021). The World Health Organisation (WHO) emphasizes iron deficiency and iron-deficiency anaemia as public health issues in SSA (Lemoine and Tounian, 2020). The prevalence of anaemia in the paediatric population of SSA exceeds 60% in some countries (Lemoine and Tounian, 2020, Muriuki *et al.*, 2020, Mwangi *et al.*, 2017). This has grave consequences for brain development, behavioural and cognitive performance, morbidity, and mortality (Lemoine and Tounian, 2020). On the other hand, zinc deficiency, which affects 33.5% of the population in developing countries, results in 14.4% diarrheal deaths, 10.4% malaria deaths, and 6.7% pneumonia deaths among children under five years in Africa (Berhe *et al.*, 2019). Micronutrient deficiencies have broader and varied effects depending on the micronutrient of interest. Micronutrient deficiencies have

negative implications on growth and development, disability and poor productivity (Chiromba *et al.*, 2020). Further, micronutrient deficiencies have severe negative impacts.

Climate change, particularly increasing water stress, complicates the challenge of attaining food and nutritional security. Previous studies have shown that food and nutritional insecurity are linked to growing water scarcity (Mustafa *et al.*, 2019). Global water use has grown at approximately 1% per year with rising population, economic development, and shifting consumption patterns (UNESCO, 2020). Concurrently, groundwater depletion has doubled between 1960 and 2000 to 280km³ per year in 2000 (Ligtvoet *et al.*, 2014). Despite a predefined **planetary freshwater boundary** lower than 4000km³ per year, global water withdrawal from some sectors, agriculture included, has already surpassed the 4000km³/year threshold (Leng and Hall, 2021, Sokolow *et al.*, 2019, Gleeson *et al.*, 2020). Climate change will increase water stress in agriculture. The world is anticipated to face a 40% water deficit under a business-as-usual scenario as the global average temperature is projected to surpass pre-industrial levels by over 1.5°C by 2050 (Allen *et al.*, 2018). Global water scarcity poses a significant challenge for climate adaptation, given that water mediates most climate change impacts (UNESCO, 2020).

There will be limited scope to raise the quantity of water used for irrigation, accounting for 70% of global freshwater withdrawals in the face of competing demands (FAO, 2011, Damerau *et al.*, 2019). Irrigation water withdrawals are estimated to rise by 5.5% by 2050 to meet increasing food demands and global dietary change (UNESCO, 2020, FAO, 2011). Irrigated land accounts for 20% of total cultivated land, generating 40% of the world's agricultural output (UNESCO, 2020). The share of the blue water footprint is highest in arid and semi-arid regions (Mekonnen and Hoekstra, 2011). Mekonnen and Hoekstra (2011) highlighted the water footprint variation across crop categories and regions.

Sustainably increasing nutritional security (SDG 2) and sustainable management of freshwater resources (SDG 6) for human health and security are part of the international agenda. Despite the crucial role of an integrated method in analysing nutritional and water insecurity for informing the adaptation planning-related studies and decision making, especially in communal areas (Bacon *et al.*, 2021), these two issues are often **considered in separately** (Brewis *et al.*, 2020). Thus, improved scholarship literature is required to simultaneously address nutritional deficiency and water security (Bacon *et al.*, 2021, Borrás Jr *et al.*, 2020, Venkataramanan *et al.*, 2020, Sokolow *et al.*,

2019) in smallholder farming systems to transform food systems sustainably. This work will make an important contribution to the growing literature on assessing nutritional deficiency and water insecurity in smallholder farming systems (Bacon *et al.*, 2021, Borras Jr *et al.*, 2020, Venkataramanan *et al.*, 2020, Sokolow *et al.*, 2019). This research is more appropriate in Zimbabwe where to the best of our knowledge, little effort has been made to link nutritional security and freshwater resources management. Hence, there is a need to explore the relationship between nutrient density and water footprint to inform policy and practice on **improving its simultaneous contribution to** ecological sustainability, malnutrition and water insecurity.

In the context of Zimbabwe, nutrient-sensitive agriculture is key to reducing micronutrient deficiency (Chiromba *et al.*, 2020). Furthermore, the agricultural sector provides the “last chance salon” to safeguard human nutrition than any other sector. Unfortunately, the sector is threatened by growing water scarcity due to climate change. Thus, GoZ (2020) is making significant investments in the sector to increase food and nutritional security in a highly variable climate. Suppose the investments in smallholder irrigation are to meet the current and future food, water, and nutritional security challenges of the growing world population. In that case, significant progress will be required to identify, document and promote nutrient-dense crops with a low water footprint.

Reflecting on the national nutritional deficit and projected climate change-related decrease in freshwater resources, this study seeks to identify the nutrient density and water footprint of crops grown in Zimbabwe’s smallholder irrigation schemes (SISs). Firstly, a profile of freshwater requirements for the crops grown in the SISs is provided. Secondly, the yields for crops grown in the SISs are assessed. Thirdly, the water footprint and nutrient content for the crops grown in the schemes are evaluated.

6.2 Methodology

6.2.1 Study site

To assess the water footprint, three SISs in Midlands province of Zimbabwe were considered. The Midlands province is among the provinces with the majority of SISs in Zimbabwe (IFAD, 2016). Slightly less than half (47%) of SISs in the province are reportedly unfunctional (IFAD, 2016). Climate change, especially water stress, is increasingly threatening the SISs in the schemes in the

Midlands province (Dube and Nhamo., 2020). Consequently, this study will be an essential reference to improve water footprint in face of climate change among SISs in Zimbabwe and SSA.

This study focus on three SISs. First, Exchange irrigation scheme in Zhombe communal land, Silobela in Kwekwe District is around 60 km North-West of Kwekwe town and 80 km North-West of the provincial town of Gweru (Nyamayevu and Chinopfukutwa, 2018). Exchange irrigation scheme has 168.8 ha irrigable area with 982 farmers engaged in irrigation farming. The scheme is in agro-ecological Zone 4, characterized by semi-arid climatic conditions, with average rainfall ranging from 450 – 650 mm (Chanza *et al.*, 2019). Soils in Exchange are predominantly fertile clay loams (Nyamayevu and Chinopfukutwa, 2018). Irrigation water is drawn from Exchange Dam into its temporary storage. Water is delivered to the plots by concrete-lined channels. Farmers in the scheme mainly grow maize (*Zea mays*) and sugar beans (*Phaseolus vulgaris*). On average, yields of 7t/ha, 1t/ha, and 1.2t/ha are obtained for maize, winter beans, and summer beans, respectively (SIRP, 2017). The market for high-value crops is challenging due to long-distance to nearest towns and compromised road networks.

Insukamini irrigation scheme is the second scheme considered for this study. It is located in Lower Gweru community, which is 46km North-West of Gweru town. Insukamini has 125 farmers on a total irrigable area of 41 ha. Insukamini is in agro-ecological 4, with average annual rainfall ranging from 600 to 800 mm (Matsa, 2012). The predominant soils in Insukamini range from sandy loam to clay loam. Farmers in the scheme grow cereals (wheat and maize), pulses (peas (*Pisum sativum*) and sugar beans), and vegetables (rape (*Brassica napus*), onions (*Allium cepa*), cabbages (*Brassica oleracea var. capitata*), tomatoes (*Solanum lycopersicum*), and garlic (*Allium sativum*)). The scheme was developed in 1988 by the national government after DANIDA finished the construction of Insukamini Dam in 1986 (Matsa, 2012). It draws its water from Insukamini Dam and is delivered gravitationally via a 1.6km long open concrete canal. In Insukamni irrigation scheme, an average yield of 4.4t/ha and 1.9t/ha were attained for maize and sugar beans, respectively (Chanza *et al.*, 2019). Farmers sell their produce to Gweru and Bulawayo (Matsa, 2012).

The third site is Ruchanyu irrigation scheme in Shurugwi district; it is nearly 29km South-West of Shurugwi town. Ruchanyu irrigation scheme had 85 farmers who used sprinkler irrigation technique on total irrigable of 27. Ruchanyu irrigation scheme is in agro-ecological zone 3 with

average annual precipitation ranging 650 from 850mm (Mhembwe *et al.*, 2019). The scheme was developed in the early 1980s. It pumps water from Mutevekwu River (Mhembwe *et al.*, 2019). Soils are mainly fertile sandy loam soils. Farmers sell their crops locally, either on farm-gate and in Shurugwi town. Yields are low due to the challenges of pumping water. Farmers in the scheme mainly grow maize.

6.2.2 Data collection

Questionnaire-based face-to-face interviews were conducted together with **six** Focus Group Discussions (FGDs) and **eleven** Key Informant Interviews (KIIs). Data on crops grown, water application rate, and crop yields, was collected to address the objectives of this study. **Water application rates were obtained from the Department of Irrigation (DIRR). Data from FGDs and KIIs was used for triangulation purposes.** A pilot study was done to validate the questionnaire for the study. Random sampling was used to select households to participate in the survey. A sample size of 317 households was selected from the three schemes at a statistically significant level ($P \leq 5\%$). A total of 192 were selected from Exchange irrigation scheme, 88 from Insukamini irrigation scheme and 37 from Ruchanyu irrigation scheme based on proportional representation. The FGDs were conducted with about 10 – 15 household heads that were randomly selected to help understand water use in SISs. Expert information relating to water use and crop yields was obtained from KIIs. Data on standardized crop water footprint and nutrition density in crops were sourced from the literature.

6.2.3 Data analysis

The computation of blue water footprints of crops production used in this paper was done in line with the calculation framework of Hoekstra *et al.* (2011). Blue water footprint is defined as the volume of water consumed for the production of goods (Mekonnen and Hoekstra, 2011, Sokolow *et al.*, 2019).

$$WF_{blue,cropx} = \frac{CWU_{blue,cropx}}{Y}$$

Where $WF_{blue,cropx}$ – blue water footprint of crop x (m^3/t), $CWU_{blue,cropx}$ – crop water use (m^3/ha) over the growing period and Y – yield (t/ha). For the case of this study, water application rate per crop was used to determine crop water use. The yield was obtained from yield statistics provided during the household survey. Crop water use for crops considered in this study was

obtained from the KIIs. These findings were verified using existing literature on yield and crop water use.

6.3 Results

The results from the analysis show water footprints and nutrient content for the crops considered in this study. Table 6.1 below shows crop yields and their related blue water footprint. Results illustrate that cucumber has the highest yield (30.60t/ha) and the lowest blue water footprint (278.85m³/t), while sugar beans with a lower yield of 1.04t/ha have the highest blue water footprint of 6370.67m³/t.

Table 6. 1: Yield and blue water footprint of crops grown by scheme farmers

Crop	Yield (Std Dev) (t/ha)	Min (t/ha)	Max (t/ha)	Water footprint (Std Dev) (m ³ /t)	Min (t/ha)	Max (t/ha)
Maize	5.58 (3.21)	0.75	9.00	1911.07 (1427.71)	282.33	11293.33
Okra	10.68 (2.93)	6.82	18.53	782.39 (12.83)	571.38	819.84
Cucumber	30.60 (3.12)	27.00	32.40	278.85 (30.19)	261.42	313.70
Squash	2.77 (0.47)			3061.45 (95.76)	1979.36	3592.80
Cabbage	13.40 (6.14)	1	30	1136.15 (1684.29)	282.33	8470.00
Wheat	5.43 (1.50)	2.5	7.50	1683.76 (738.76)	978.26	3388.00
Onions	6.68 (4.62)	1.00	15.00	2511.50 (2630.31)	562.50	8470.00
Sugar beans	1.04 (1.08)	0.00	1.70	6370.67 (3469.08)	3125.00	22586.67

6.3.1 Blue water footprint and nutrition content of crops grown in the schemes

Figures 6.1 to 6.6 demonstrate the relationship between blue water footprint and the nutrient content of each crop. Each figure includes eight crops that were considered for this study.

Figure 6.1 shows the relationship between water footprint and energy content of crops grown in the three SISs in this study.

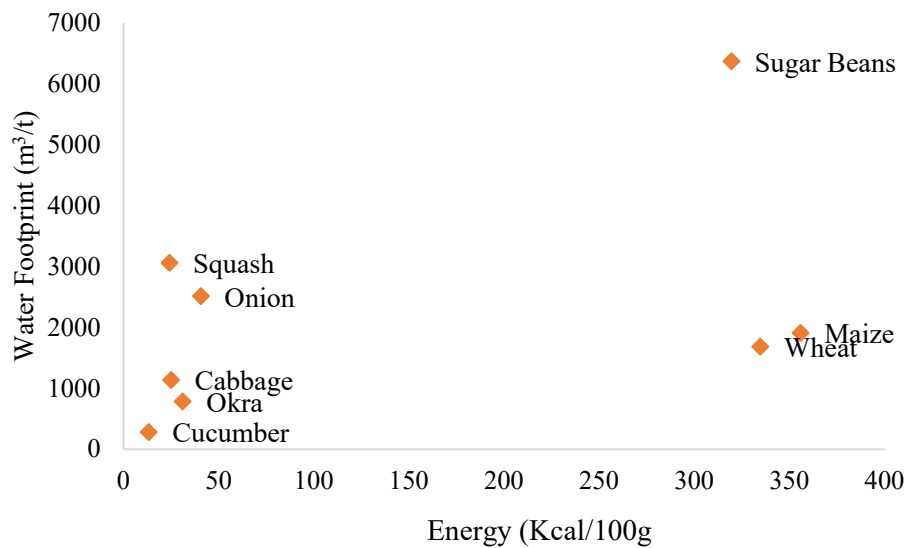


Figure 6. 1: Blue water footprint and energy content of crops grown in schemes

Figure 6.2 shows the relationship between water footprint and iron content of crops grown in SISs.

Figure 6.2 illustrates that wheat has the highest iron content and relatively low water footprint.

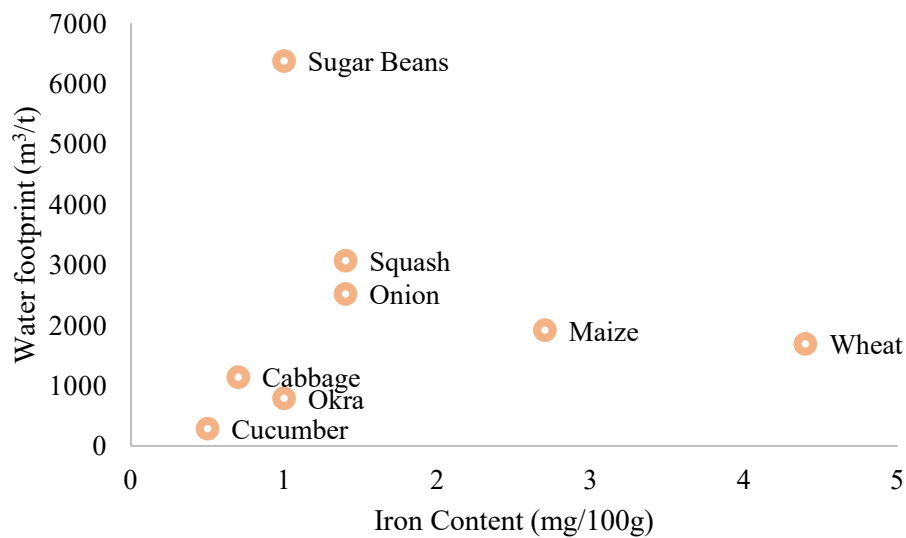


Figure 6. 2: Blue water footprint and iron content

Figure 6.3 illustrates the relationship between the water footprint and zinc content of crops grown in the schemes. Figure 6.3 shows that okra has a lower water footprint and high zinc content. Wheat and maize are alternative sources for zinc, given that they have relatively high levels of zinc and a moderate water footprint.

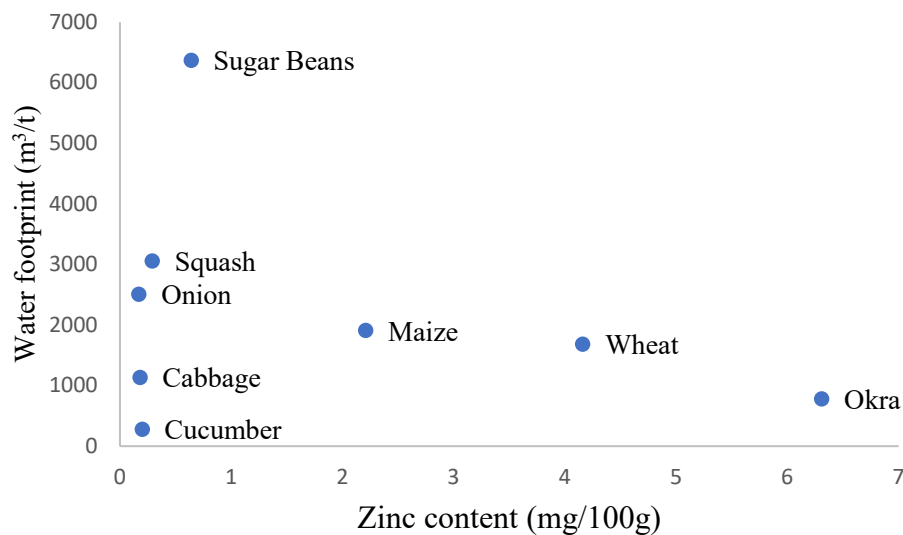


Figure 6. 3: Blue water footprint and zinc content of crops grown in schemes

Figure 6.4 illustrates the average protein-water footprint of crops grown in the SISs. Sugar beans have both higher protein content and a higher water footprint. Figure 6.4 below shows that wheat has a viable amount of protein content and has a relatively low water footprint.

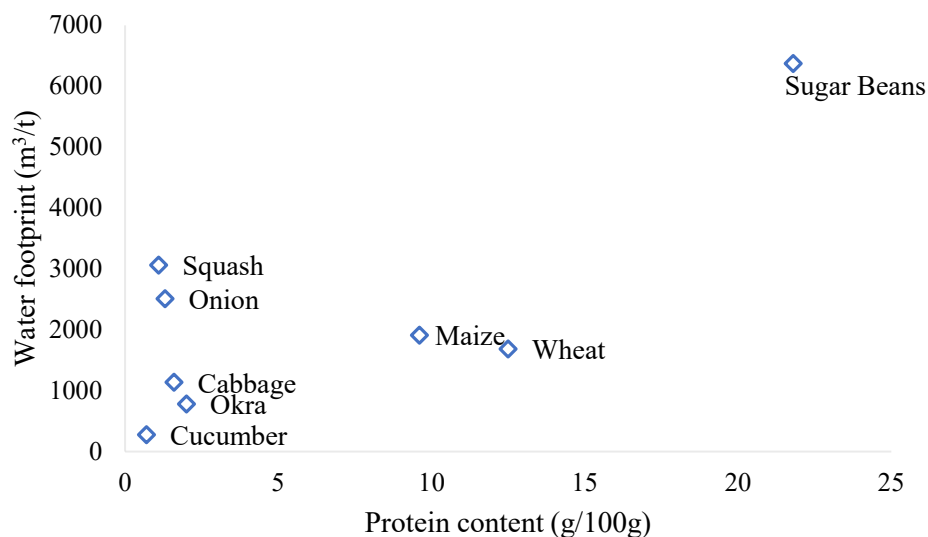


Figure 6. 4: Blue water footprint and protein content in crops grown by scheme farmers

Figure 6.5 shows that squash has both higher vitamin A content and a water footprint of around 3000m³/t. The rest of the crops in the study have extremely lower vitamin A content.

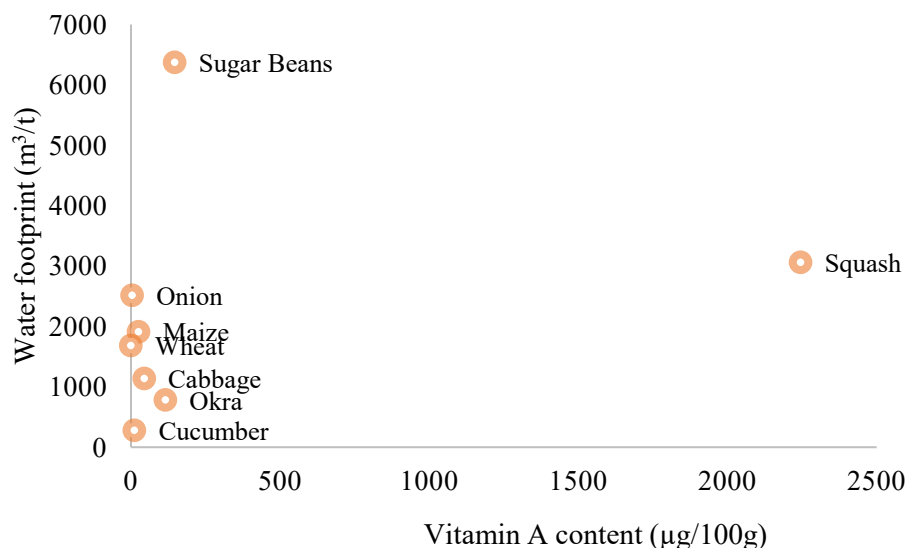


Figure 6. 5: Bluewater footprint and vitamin A content of crops grown by scheme farmers

6.4 Discussion

This paper assesses the relationship between blue water footprint and nutrient content of food crops grown in SISs. **Nutrient content is the level of a nutrient contained in a food (FAO *et al.*, 2021).** The study aims to understand how the two aspects can be combined to improve water efficiency,

food and nutrition security, and sustaining environments in SISs and their communities. Comparing these footprints highlights the effective way to improve nutritional security by maximizing water usage. The relationship between blue water footprint and nutrient content will enable humans to prioritize the production of food crops which produce higher nutrient content scores while using less water. This helps to make responsible use of water in crop production while ensuring that water is available for other competing uses, thereby improving human and environmental health.

6.4.1 Yield and water footprint

Generally, the water footprint of the crops in this study was higher than their standard global water footprint by Mekonnen and Hoekstra (2011) (Table 6.1). Relative to the water footprints of the crops, their average yield was below the average of the region (SEEDCO, 2020) (Table 6.1). Although the global average water footprint by Mekonnen and Hoekstra (2011) was computed based on the statistics of 1996 to 2005 data, the average water footprint for all crops in this study was higher than their average projected water footprints due to relatively lower yield. Therefore, water footprint is highly compromised by crop yields. Results from this study support Nyambo and Wakindiki (2015) findings in South Africa that sugar bean has the highest water footprint. According to Sokolow *et al.* (2019) and Mekonnen and Hoekstra (2011), pulses have a relatively higher water footprint compared to other crops. However, the water footprint of sugar bean in this study was higher than projected by Nyambo and Wakindiki (2015), Mekonnen and Hoekstra (2011) and Sokolow *et al.* (2019). Cucumber has a lower water footprint, although extremely higher than the water footprint projected by Mekonnen and Hoekstra (2011) and Sokolow *et al.* (2019). The low yield attained by smallholder farmers was attributed to a higher water footprint, given that water footprint has an inverse relationship with yield (Nyambo and Wakindiki, 2015, Mekonnen and Hoekstra, 2011). Potential environmental impacts contribute to the water footprint (Sokolow *et al.*, 2019, Nyambo and Wakindiki, 2015). **The amount and timing of precipitation determine irrigation requirements and refill of catchment areas.** According to Clagett-Dame and Knutson (2011), agricultural management practices influence water footprint without impacting evaporation. Agriculture management practices such as mulching and conservational tillage, which can retain or increase soil organic matter, increasing water holding capacity while decreasing evaporation (Sokolow *et al.*, 2019), were limited.

The poor yield reflects on the efficiencies of the irrigation schemes. Based on the findings from the FGDs and KIIs, in Ruchanyu efficiency of the irrigation scheme was challenged by load shading, together with switching off of electricity by ZESA as farmers fail to pay electricity fares. Among the three schemes, participants in FGDs indicate that efficiency of the scheme was attributed by poor state of the scheme infrastructure. However, in Exchange Irrigation Scheme, the state of the infrastructure was expected to improve following its maintenance by Smallholder Irrigation Revitalization Programme (SIRP). Such challenges were reported across other schemes in the country and across the region (Dube and Sigauke, 2015, Hanjra and Williams, 2020, Matsa, 2012, Mhembwe *et al.*, 2019, Nyamayevu and Chinopfukutwa, 2018, SIRP, 2017).

Given that water footprint is loosely linked to yield (Bocchiola *et al.*, 2013, Sokolow *et al.*, 2019), the best way to improve water use efficiency is to develop strategies to improve water productivity. According to Sokolow *et al.* (2019), crop yields can be influenced by factors such as water availability, nutrient supply, crop variety, access to agricultural inputs, pest and diseases prevalence, among several other factors. Sokolow *et al.* (2019) further stressed that water footprint could be influenced by effective nutrient, water, and soil management determined by agricultural management, climatic and soil factors. In SISs considered for this study, there were limited agricultural approaches like mulching, use of manure, conservation tillage, retaining soil organic matter, which can improve water retention and lower evapotranspiration. Further, the dilapidated state of some canals affects water conveyance efficiency. However, the common pool resource nature of SISs makes it notoriously difficult to address these challenges due to participation of multiple users with a wide range of goals (Cox *et al.*, 2010). Climate variability and change could have added an extra burden to the functionality of these socio-ecological systems, which already have mixed performance, making it impossible to address such factors.

6.4.2 Water footprint and nutrient content

The relationship between water footprint and nutrient content could be an effective way to select crops that should be grown to improve the nutritional security of the community without exceeding the planetary freshwater boundary. Given that nutrient-water footprint is influenced by several factors like yield, NCS, crop varieties, pests, and input usage by farmers, further analysis might be necessary to improve the productivity of the crop. Although yields of irrigated crops are expected

to be higher than rainfed farming, this does not determine the efficiency of the irrigated farming systems, especially under smallholder irrigation farming.

The energy and carbohydrate contents were higher for maize and wheat among crops grown in the scheme (Figures 6.2 and 6.3). Wheat and maize are cereals; hence, they have a high NCS of carbohydrates (Chitsiku, 1989). Although energy and carbohydrates contents were higher for maize and wheat, they were compromised by low yield levels compared to the projection of the same regions (SEEDCO, 2020). Healthy diets need to have sufficient carbohydrates to provide adequate dietary energy to maintain body growth, development, and good health (UNESCO, 2020). Innovations to improve yields will improve the water footprint for maize and wheat, reducing food insecurity in households.

Iron content was higher in wheat, followed by maize. Wheat is the best crop for improving access to iron among schemes households given its comparative water footprint and high iron content. Production of crops with low water footprint and iron content increases subsequent production of iron, its availability, and access in diets. Improving water footprint and producing crops rich in iron is more effective when combined with promotion and education interventions. The problem with the production of iron-rich food crops in SISs in Zimbabwe is the lack of implementation and promotion of the efficient production of iron-rich crops. According to UNESCO (2020), iron fortification and biofortification of wheat and maize are cost-effective methods of increasing iron availability and reducing iron deficiency in rural communities. Iron biofortification with crops like maize and wheat consumed daily and in large quantities meets the daily dietary need. Zimbabwe was emulated for its adaption of iron-biofortified crop varieties (UNESCO, 2020); however, the adaptation of the technology in SISs is not well documented. Food of animal origin is a good source of iron, but they are often unaffordable for rural households in developing countries (Lokeshwar *et al.*, 2011); hence growing crops rich in iron is the best alternative to ensure reduction of iron deficiency. Iron deficiency continues to be a major health problem in Zimbabwe and has far-reaching consequences on the health of children between 6 months and five years and women between 15 and 49 years, with over 72% and over 60% of them suffering from iron deficiency (FNC, 2018). Iron is essential for production of red blood cells, which is essential for transferring oxygen from the lungs to the tissues, a critical feature in human survival (Abbaspour *et al.*, 2014).

Okra has a low water footprint and high zinc content compared to the rest of the crops grown in the schemes. Okra has a relatively higher zinc content of more than 3.83mg/100g compared to other crops grown in the scheme (Gemede *et al.*, 2016). Okra is recommended to be grown in SISs to meet zinc requirements in rural communities in a water-saving way. Improving water footprint and the production of crops rich in zinc is more effective if well promoted. The problem with the production of zinc-rich food crops in SISs in Zimbabwe is the limited implementation and promotion of efficient production of zinc-rich food crops. Zinc fortification and biofortification of widely consumed food, including wheat (Wang *et al.*, 2020), sugar beans (Philipo *et al.*, 2021), and maize (Moretti *et al.*, 2014), is a cost-effective way of increasing zinc production and reducing zinc deficiency in rural communities. The Zimbabwe National Food Fortification Strategy, in line with the Food and Nutrition Security Policy, targets zinc fortification in wheat and maize (Chiromba *et al.*, 2020, MoHCC, 2014). According to (Manzeke *et al.*, 2020), most plant-based diets in Africa are often zinc deficient. Manzeke-Kangara *et al.* (2021) postulate that smallholder farmers in Zimbabwe can improve zinc concentration in maize and legumes through improving fertility management and agronomic biofortification. Growing crops rich in zinc is an important intervention to reduce zinc deficiency in rural communities.

Although sugar bean has a high protein content, its water footprint was extremely high compared to all other crops grown in the scheme. In general, sugar beans have a higher protein content than other crops grown in SISs (Chitsiku, 1989). Given that protein is required in extremely large quantities, it will not be sustainable to base its supply on crops with low protein content, although they have a relatively low protein-water footprint compared to beans. Although crops like wheat and maize have a lower protein content, their production and consumption will positively contribute to reducing protein deficiency in rural communities (Setimela *et al.*, 2017). According to Setimela *et al.* (2017), the limited adoption of high-yielding of quality protein maize varieties results in high levels of stunting and kwashiorkor in SSA.

Farmers in the SISs are recommended to grow squash given its high vitamin A content, despite its relatively higher water footprint than other crops. Generally, squash is an excellent source of vitamins compared to other crops (Alam *et al.*, 2020, Salehi, 2021, Lee *et al.*, 2018). Squash production ensures improved access to vitamin A to Zimbabwe's rural communities. Lowering the water footprint of squash by improving yield will immensely contribute to improving access to

vitamin A in a water-saving way. Onion can reach 54.5 t/ha under irrigation (Hussain *et al.*, 2018), while squash can yield 33.9t/ha with irrigation (Wetzel and Stone, 2019). Squash and carrots, which are orange or dark yellow-fleshed, are rich in Vitamin A (Sokolow *et al.*, 2019); introducing crops like carrots may improve vitamin-water footprint and access to essential micronutrients like vitamin A among rural communities. Vitamin A supports cell growth (Clagett-Dame and Knutson, 2011), immune function (Ross, 2012), foetal and reproduction development (Clagett-Dame and Knutson, 2011), and eye health (Zhong *et al.*, 2012). Based on these findings, there is potential for improving the yield of cucumber, onion, and squash, hence lowering the water footprint of these crops as well as the vitamin-water footprint. Given that maize is an important staple food crop in Zimbabwe, extensively consumed across the nation (Gracia-Romero *et al.*, 2018), its biofortification with vitamin A will improve vitamin content in maize. UN (2016) reported that 48% of the children aged 6 – 59 months in SSA have high vitamin A deficiency. Further, the potential of biofortification of maize with iron (UNESCO, 2020), zinc (Chiromba *et al.*, 2020, MoHCC, 2014), protein (Hossain *et al.*, 2019), and provitamin A (Hossain *et al.*, 2019, UN, 2016), is an entry point to reduce overall water footprint. Biofortification will ensure food and nutritional security (Hossain *et al.*, 2019), improving diets in rural areas. However, there is a need to explore whether the penetration of such technology can strengthen income generation and empower indigenous communities.

In **order** to solve food, water and nutritional challenges in rural communities, identifying and growing crops with low water footprints and high nutrient content for two or more nutrients like wheat is essential to improve human health while conserving the environment. This will help to fight hunger, especially hidden hunger, while conserving the environment. Production of nutrient-rich food crops with a low water footprint will improve water use efficiency and ensure food and nutritional security (Damerau *et al.*, 2019). Production of crops with lower water footprints contributes to SISs' ability to compartment current and future food and nutrition insecurities, which can be worsened in the coming decades as climate change is expected to result in water scarcity (Damerau *et al.*, 2019).

Farmers in the schemes produce crops to meet the market demand other than ensuring food and nutritional needs of the local community, hence attractive markets as far as Gweru town and Bulawayo were their preference. However, there was no criteria used to select the crops grown.

Further, this study does not explore the level of acceptability economically. Therefore, there is need to explore the level of economically and culturally acceptability of crops grown in the scheme. Sokolow *et al.* (2019) noted that supply chain influences land-use changes resulting in trade-offs between environmental, social, and economic factors. Although authors agree that schemes were developed to ensure food and nutritional security among the rural community (Dube and Sigauke, 2015, Hanjra and Williams, 2020), their contribution to household income is irrefutable. Hence, farmers opt for crops that meet market demands. There is a need to explore the dynamics of crop utilization by scheme households and sales of crops produced in the schemes.

Further, there is a need to explore the contribution of income from crop sales towards the scheme household nutritional security. Adjusting fertilizer application can be considered based on the costs and benefits of the scheme farmers (Sokolow *et al.*, 2019). Lowering the water footprint and enhancing water productivity in SISs requires collaborative efforts of various stakeholders (breeders, agronomists, policymakers, and donors) (Sokolow *et al.*, 2019).

This study sought to provide context-specific information on the ground circumstances of water footprint and nutrition content among SISs. The findings from this study are essential to address malnutrition and food security without compromising the global freshwater boundary. Based on this study's findings, there is a need for the nation to implement the national-based dietary guidelines, suggesting the production of food crops with limited use of freshwater while providing adequate essential nutrients. Sokolow *et al.* (2019) postulate water footprint analysis as a starting point to understand complex food systems. Thus, exploring policies related to nutritional security and water use efficiency and their implementation in irrigation schemes is necessary. The matrix of water footprint and nutrient content offers a sustainable way of addressing multiple Sustainable Development Goals (SDGs) related to health and wellbeing, food and nutritional security, and environmental sustainability. The finding from this study contributes to an interdisciplinary approach of the food system to addressing food and nutritional insecurity, given high-level water requirements for irrigation farming.

6.5 Conclusion

This study assessed the water footprint and nutrient content of crops grown in three SISs (Exchange, Insukamini, and Ruchanyu) in Midlands province of Zimbabwe. The study sought to find water-efficient alternatives for ensuring an adequate supply of essential nutrients to rural

communities. Smallholder irrigation farmers produce a wide range of crops. Poor yield contributes to the higher water footprint of most crops, given that yield was below the standard of the region. This study concluded that cucumber, okra, and cabbages have low water footprints, while sugar beans **has** a high-water footprint. For crops grown in the scheme, sugar beans have high protein content; wheat has high iron content, squash has high vitamin A content, while okra has high zinc content. The matrix of water footprint and nutrient content differs among the crops grown in the scheme; hence, it is environmentally sustainable to produce crops with lower nutrient-water footprints. Prioritizing the production of food crops with a lower nutrient-water footprint will ensure SDGs relating to health and wellbeing, food and nutrition, and environmental sustainability are met.

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CHAPTER 7

CONCLUSIONS, RECOMMENDATIONS AND FUTURE RESEARCH

7.1 Conclusions

This thesis assesses the a) vulnerability of farmers in SISs to climate change, b) gender perception on pest management, c) crop and nutrient water footprint, and d) socio-demographic, governance and institutional factors influencing adaptive capacity in SISs, namely Exchange, Insukamini and Ruchanyu located in the Midlands Province, Zimbabwe. These are essential topics that require significant research attention given the poor performance of SISs in majority of countries in SSA, including Zimbabwe.

Results of the institutional and governance factors influencing adaptive capacity in Chapter 4 illustrate how socio-demographic, institutional and governance factors influence the adaptive capacity of smallholder irrigation farmers in Zimbabwe. The hypothesis that stronger institutions influence adaptive capacity in smallholder irrigation systems was accepted. Institutional elements influence adaptive capacity. This study shapes the adaptation of institutions in SISs by identifying areas where improvements are needed. Further, strengthening institutions in SISs will improve adaptation to climate change. This can be achieved by understanding factors that affect adaptation to climate change at the local level. Findings from this study reveal that adaptive capacity of scheme farmers was significantly influenced by socio-demographic, institutional and governance factors. Nevertheless, there is need to explore the root cause of this relationship. Understanding and addressing such factors will help scheme farmers to cope with the projected weather extreme which decrease their adaptation to climate change. Subsequently, farmers can engage with extension workers, participate in cooperatives and irrigation water scheduling to increase adaptive capacity.

Results for gendered perceptions of pest prevalence and management in Chapter 5 shows awareness of both male and female farmers on the outbreaks under climate change trends. Female participants perceived a higher increase in the prevalence of cutworms, red spider mites, maize grain weevils, and termites. Nevertheless, male participants perceive a higher prevalence of FAW, bollworms and whiteflies. A rising number of aphids, cutworms, FAW, red spider mites, bollworms, whiteflies, and termites and a decrease in maize grain weevils was perceived. These

perception on the prevalence of pests shapes the behavior of farmers towards changing pest management practices. Furthermore, policymakers should consider gender views on the prevalence of pests in policy formulation. Perception on the prevalence of pests will likely improve our understanding of the possible impacts of climate change on pest and diseases in SISs of Zimbabwe and the SSA region in general.

Unique agro-ecological factors need to be considered in designing tailored recommendations for improving water and nutrient-water footprints at local, national, and regional scales. Variation of climatic conditions, soil characteristics, catchments area, and water management attribute differences in the water footprints of the same crops. Further, water footprint is constrained by factors such as pests, disease, and weeds. Moreover, some farmers have well-established and hard-to-change dietary patterns, making it difficult for them to adopt crops with lower water and nutrient-water footprints to address food and nutritional insecurities by incorporating sustainable diets.

The last result chapter concludes that cucumber, okra, and cabbages have low water footprints, while sugar bean has a high water footprint. However, sugar bean has a high protein content; wheat has high iron content, squash has high vitamin A content, while okra has high zinc content. The study shows that crops such as wheat, squash, and okra have high nutrient content as well as low water footprint; such crops can be recommended for growing in schemes. The water footprint and nutrient content varies across the crops grown in the scheme; hence it is environmentally sustainable to produce crops with lower nutrient-water footprints. The research also proved that some crops have a low nutrient water footprint for two or more nutrients. This study shows that water-nutrient matrix is essential for recommending nutrient-rich crops that are water saving.

Our study is without some limitations. For instance, the approach could have extended a little bit more into the social-economic dimensions including the amount of rainfall received in the areas and the possible impacts irrigation of irrigation on stabilising crop yields, the suitability of soils for the selected crops and economic viability and acceptability of the crops. Further, taking a few on-site measurements such as yield, and water application could have been used to validate responses from interviews and questionnaires. Thus, future studies should consider these as crucial areas of further scientific inquiry.

This study find out that scheme communities are vulnerable to climate change and variability. However, vulnerability varies from schemes to the other, particularly due to variation in natural disasters, social networks and water security. Adaptation to climate change in SISs in influenced by socio-demographic, governance and institutional factors. Further, the findings from this study shows that there is a gendered perception on pest prevelance among the schemes in Zimbabwe. Results show that some nutrient rich crops have low water footprint for example maize, okra and squash.

7.2 Recommendations

- There is a need to ensure that disseminating early warning information of natural disasters is carried out timeously.
- The role of extension workers in disseminating natural disaster and weather information must be strengthened as farmers tend to be more reliant on them for a wide range of information.
- In order to improve adaptive capacity, scheme management should support the participation of youth in farming and support the needs of female farmers.
- There is a need for surveillance and monitoring of pests, integrated pest management practices, interdisciplinary approaches to managing pests, crop insurance, and building pest management capacity for farmers must be pursued by extension services and research organizations.

There is a need to prioritize the production of food crops with a lower nutrient-water footprint to ensure SDGs relating to health and well-being, food and nutrition, and environmental sustainability, are met.

7.3 Implications

- This study has implications on interventions to address vulnerability to climate change in schemes, strengthen social networks, improve water security, and raise awareness of pending natural hazards and future weather trends.
- Further, this study has implications for pest management practices and food security.
- The study also has implications on water use, environmental protection and access to essential nutrients.

7.4 Areas of future research

1. The researchers should explore the appropriate combination of factors that might improve the adaptive capacity of farmers in the scheme.
2. Future research has to look into the participation of women in pest control contributes to pest management.
3. There is a need to explore the dynamics of crop utilization by households and crops sales in SISs.
4. It is essential for scientists to identify technologies that can be adapted to improve nutritional securities in a water-saving way in SISs.
5. Researchers need to examine national-based dietary guidelines suggesting the production of crops with low water footprint and high essential nutrients and their possible implementation.

Appendix 3. 1. Variable selection for LVI-IPCC.

Sub-Components	Explanation	Survey Question	Relationship with vulnerability
Adaptive capacity			
Dependence ratio	Ratio of HH members less than 15 years and elderly 65 and above to working population (15 – 64)	How many HH members are below 15 years and 65 and above?	(+) Vulnerability increases with increase in dependence ratio
Female HH	HH being headed by female. Either single or husband mostly work in other communities.	What is the gender of HH?	(+) Females are more vulnerable than males
HH did not attend school	Number of years of formal education have the HH attained	How many years of formal education have the HH attained?	(+) Illiterate HH are more vulnerable
HH with orphans	HH members under 15 years with deceased parents	How many HH member under 15 years with deceased parents	(+) HH with orphans are more vulnerable
Average age of HH	Age of HH	How old is HH?	(-/+) Vulnerability increases with age
Livelihood Strategies			
Family members working outside the community	HH with family members gainfully working in other community	Do any HH member work in other community for wage?	(-) HH with members working in other communities are less vulnerable
Depending solely on agriculture	HH primarily obtain their income from agriculture	What is the main source of HH income?	(+) HH solely depend on agriculture are more vulnerable
Livelihood diversification Index	$1/(\text{Total livelihood activities} + 1)$	What livelihood activities is your HH perform?	(-) Higher LDI, improve adaptive capacity and reduce vulnerability
Food			
HH dependent on family farm for food	HH that get most of their food from family farm	What is the main source of HH food?	(+) HH that solely depend on family farm for food are more vulnerable
Crop Diversification Index	$1/(\text{crops grown} + 1)$	State crops you have grown in the past year	(-) High CDI, better adaptive capacity and reduced vulnerability
HH that save crops for food	HH that save the crops they harvest for future consumption	Does your HH save crops?	(-) Saving more food reduce vulnerability
HH that save seed	HH that save seed for future farming season	Does your HH save seed?	(-) Saving more seed reduce vulnerability
Water			
Water conflicts	Conflicts which HH experience in accessing water	Does your HH experience conflicts when accessing water?	(+) More water conflicts, more vulnerability.

Time to water source	Time that a HH take to access water.	What time do your HH take to get to water source?	(+) Higher distance to water source increase vulnerability
HH not have constant water supply	HH face challenge to access water	Does your HH have constant water supply?	(+) Limited access to water increases vulnerability
Health			
Time to health facility	Time HH members take to reach the nearest health facility	How much time do you take to reach to the nearest health facility	(+) More distance to health facility led to more vulnerability
HH with chronically ill members	HH with members who are chronically ill	Is anyone in your family chronically ill	(+) HH with chronically ill members are more vulnerable
HH with members who have been sick in the last 2 weeks	HH with members who have been sick last month that they had missed work or school.	Has anyone in your HH been so sick in the past 2 weeks that they missed work or school?	(+) HH with sick members are more vulnerable
Households not satisfied with irrigation infrastructure maintenance	Households not satisfied with irrigation infrastructure maintenance	Are you satisfied with irrigation infrastructure maintenance?	(+) HH not satisfied with irrigation infrastructure are more vulnerable
Household not satisfied with water distribution in scheme	Household not satisfied with water distribution in scheme	Are you satisfied with water distribution in scheme?	(+) HH not satisfied with water distribution are more vulnerable
Households reporting poor conflict resolution in scheme	Households reporting poor conflict resolution in scheme	Are satisfied with conflict resolution in scheme?	(+) HH reporting poor conflicts resolution in scheme are more vulnerable
Household reporting a decline in irrigation water supply	Household reporting a decline in irrigation water supply	Has water supply to your plot decline over the past 10 years?	(+) HH reporting decline in irrigation water supply are more vulnerable
Households not participating in water scheduling	Households not participating in water scheduling	Do you participate in water scheduling?	(+) HH not participating in water scheduling are more vulnerable
Households not participating in water related trainings	Households not participating in water related trainings	Have you participated in water related training?	(+) HH not participating in water related trainings are more vulnerable
Social Networks			
Receive : Give ratio	Ratio of number of HH who receive to number of HH who give in the past year	Did your HH receive help relative or friends in the past year? Did your HH help relatives and friends in the past year?	(-) Higher receive : give ratio reduces vulnerability

Borrow : Lend ratio	Ratio of number of HH who borrow to number of HH who lend in the past year	Did your HH borrow in the past year? Did your HH lend in the past year?	(-) High receive : give ratio reduces vulnerability
HH that have not get assistance from government or NGOs	HH that did not receive assistance from the government or NGOs in the past years	Have your HH get assistance from government or NGOs in the past year?	(+) Not receiving assistance from NGOs and government increases vulnerability
HH with members not in cooperatives	HH with members in cooperatives	Is any of your HH member part of the cooperative	(+) Not participating in cooperatives will increase vulnerability
Natural Disaster and Climate Variability			
HH that do not receive warning about pending natural hazard	HH that do not receive warning about pending natural hazard.	Did you receive early warning about natural hazards before they occur?	(+) HH that do not receive early warning are more vulnerable
Average number of natural hazards in the past 10 years	Average number of natural hazards in the past 10 years.	How many times were you affected by natural hazards in the past 10 years?	(+) More natural disasters increase exposure and vulnerability
Percentage of HH that lost livestock due to floods and droughts	Percentage of HH that lost livestock due to floods and droughts in the past 10 years.	Did your livestock die due to climate change in the past 10 years?	(+) Higher percentage of HH that loss livestock result in higher vulnerability
Percentage of HH with members injured or decease due to floods and droughts	Percentage of HH with members injured or decease due to floods or droughts in the past 10 years.	Did your HH member get injured or die due to floods or droughts in the past 10 years?	(+) Loss or injury of family member increases vulnerability
Percentage of HH who reported a rise in drought incidences	Percentage of HH who reported a rise in drought incidences in the past 10 years.	Did occurrence of droughts increase in the last 10 years?	(+) Increase in drought increases exposure and vulnerability
Mean standard deviation of monthly rainfall	Mean standard deviation of monthly rainfall		(-) Increase in monthly rainfall reduces vulnerability
Mean standard deviation of monthly average maximum temperature	Mean standard deviation of monthly average maximum temperature		(+) Increase in temperature, increases vulnerability
Mean standard deviation of monthly average minimum temperature	Mean standard deviation of monthly average minimum temperature		(+) Increase in temperature, increases vulnerability

Appendix 3. 2: LVI sub-component values, minimum and maximum for Exchange, Insukamini and Ruchanyu

	Unit	Exchange	Insukamini	Ruchanyu	Max	Min
Socio-Demographic profile						
Dependency ratio	Percent	80.2	68.9	80.4	100	0
Female HH	Percent	0.365	0.409	0.297	100	0
HH did not attend school	Percent	0.5	1.2	0.000	100	0
HH with orphans	Percent	0.193	0.364	0.568	100	0
Average age of HH	Years	56.2	52.3	53.1	87	18
Livelihood Strategies						
Percentage of HH with members working outside	Percent	0.661	0.529	0.608	100	0
Percentage HH depending solely on agriculture	Percent	0.922	0.830	0.811	100	0
Average livelihood diversification Index	1/ no livelihoods	0.070	0.080	0.070	0.5	
Food						
Percentage of HH dependent on family farm for food	Percent	0.870	0.727	0.946	100	0
Average number of months without food	Month	0.062	0.118	0.101	7	0
Average crop diversification index	1/ no crops grown	0.37	0.08	0.300	0.5	0.11
Percentage of HH that do not save food	Percent	0.042	0.068	0.081	100	0
Percentage of HH that do not save seed	Percent	0.302	0.136	0.054	100	0
Water						
Water conflicts	Percent	0.265	0.364	0.378	100	0
Average time to water source	Minutes	73.7	74.2	26.4	180	0
Percentage HH do not have constant water supply	Percent	6.8	35.2	8.1	100	0
Households not satisfied with irrigation infrastructure maintenance	Percent	0.196	0.452	0.616	100	0
Household not satisfied with water distribution in scheme	Percent	0.309	0.484	0.487	100	0
Households reporting poor conflict resolution in scheme	Percent	0.377	0.459	0.481	100	0
Household reporting a decline in irrigation water supply	Percent	0.823	0.859	0.687	100	0
Households not participating in water scheduling	Percent	0.698	0.722	0.189	100	0
Households not participating in water related trainings	Percent	0.268	0.853	0.311	100	0
Health						
Hours to health facility	Minutes	60.2	34.3	35.1	180	3
Percentage of HH with members chronically ill	Percent	6.8	6.8	29.7	100	0
Percentage of HH with members who have been sick in the last 2 weeks	Percent	7.8	33.0	29.7	100	0
Social Networks						
Average Receive: Give ratio	Receive/Give	0.954	0.840	0.846	1	0
Average Borrow: Lend money ratio	Borrow/Lend	0.302	0.409	0.405	1	0

Percentage of HH that have not get assistance from government and NGOs	Percent	0.5	38.6	24.3	100	0
Percentage HH with members not in cooperatives	Percent	7.8	83.0	54.1	100	0
Natural Disaster and Climate variability						
Percentage of HH that do not receive warning about pending natural hazard	Percent	19.3	33.0	16.2	100	0
Average number of floods, droughts events in the past 10 years	disasters	3.2	5.5	4.0	10	0
Percentage of HH with members lost or hurt due to floods or drought in the past 10 years	Percent	53.1	61.4	51.4	100	0
Percentage of HH that lost livestock due to floods or drought in the past 10 years	Percent	2.6	3.4	10.8	100	0
Percentage of HH who report a rise in drought incidences	Percent	94.3	95.5	81.1	100	0
Mean, standard deviation of monthly rainfall	mm/month	59.58	59.58	59.58	396.8	0
Mean, standard deviation of monthly average maximum daily temperature	°C	0.536	0.536	0.536	24	2.7
Mean, average of monthly average minimum daily temperature	°C	0.393	0.393	0.393	31.8	19.3

Appendix 3. 3: Contributing factors to LVI-IPCC

IPCC contributing factors to vulnerability	Exchange	Insukamini	Ruchanyu	Test Statistic (p-value)
Exposure	0.419	0.500	0.478	0.106
Adaptive Capacity	0.275	0.330	0.294	0.000
Sensitivity	0.444	0.503	0.442	0.013
LVI-IPCC	0.071	0.087	0.071	0.059